

Editorials

A new annual Aperture Neuro special issue: The State of the Brain

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Aperture Neuro has started a new tradition: the annual publishing of “The State of the Brain” special issue, comprising perspectives from the leaders, award winners, and keynote speakers from the annual Organization for Human Brain Mapping (OHBM) meeting. The papers range from reflections on challenges and opportunities in brain imaging research, the meeting itself, the brain imaging community, notable achievements, to emerging methods, findings, and theoretical advances. This special issue, now in its second year, provides a unique set of papers that will certainly inform and inspire the community, and perhaps help shape the field in years to come.

INTRODUCTION

Following the Organization for Human Brain Mapping 2024 meeting, Aperture Neuro sought to foster and promote further reflection on the Annual Meeting, the society, and the field of brain mapping in general by initiating an annual special issue called the “State of the Brain.” This exercise of annual reflection by leaders in our community on the state of the field of brain imaging research is now in its second iteration and has become an established tradition for Aperture Neuro, supporting its mission to foster bi-directional contributions as a community journal. It is a healthy exercise in any context to step back and reflect - to gain a bearing on where we are and where we are going. For these special issues, we are inviting OHBM leaders, annual award winners, and invited speakers to share their thoughts on whatever they deem most worthy to write about. Our instructions were to write on whatever impressed them as most interesting and important, either from the meeting itself, the scientific community, their own research, or of the field of brain imaging in general. Effectively, we gave them a blank slate in the hope that they would return something exciting and thought-provoking, and we believe the inaugural 2024 edition was a success. The second iteration of this reflection, “State of the Brain: 2025”, is now underway. Below we summarize our published first iteration, “State of the Brain: 2024,” in which eight perspective-building articles were published. We then give a brief synopsis of our own take on the field through the lens of these papers. We hope you enjoy and continue to benefit from these ex-

tremely high-quality reflections on the “State of the Brain” for each year.

STATE OF THE BRAIN: 2024

For our first manifestation of this initiative, “State of the Brain: 2024”, we sent out nineteen invites that included all the award winners, invited speakers, and the Chairs of Council, Program Committee, and Education Committee. From these, we received [eight outstanding contributions](#) - editorials, commentaries, and short communications - covering a breadth of topics that included summaries of a lifetime pursuit to extract ever more information from the BOLD signal, insights into the need to make connections across modalities and scales in functional brain imaging, descriptions of the latest technology in transcranial magnetic stimulation (TMS) and magnetoencephalography (MEG), as well as calls for better mechanisms of transparency and reproducibility. Specifically, the papers were the following:

Seong-Gi Kim (Keynote) contributed: “The Road to Mapping Neural Circuits with fMRI: Challenges and Advances,”¹ which highlighted his lifelong pursuit to extract ever more detailed, quantitative, and meaningful information from the functional magnetic resonance imaging (fMRI) signal. His work has been aimed at moving fMRI from mapping simple correlations towards understanding causality in neural circuits. His foundation is the use of animal models, ultra-high field, hemodynamically specific acquisition, and complementary measures. He emphasizes the importance of neuromodulation approaches coupled

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with ultra-high temporal and spatial resolution fMRI and complementary independent measures. He also offers evidence that specific aspects of neuronal activity and neuronal state, such as excitation-inhibition balance as well as inhibitory activity, influence the fMRI signal and therefore may be derived from it.

Alex Fornito (Mentor Award) contributed: “Some reflections on OHBM 2024”.² This is his perspective of the major themes and trends from the 2024 OHBM meeting. A central theme of his article identified a shift towards an integrative approach that emphasized combining magnetic resonance imaging (MRI) with computational models, multi-modal data, and multi-species data. This shift is inevitable and will continue to grow as we grapple with the limits inherent to MRI and fMRI. Similar to Dr. Kim’s view, the primary way forward is the use and integration of complementary measures and more sophisticated mechanistic models that explain and predict the fMRI responses.

Dr. Fornito also discussed ongoing trends in the field, including connectomics, machine learning, open science, and individual precision brain mapping. He also reminded us of ongoing still-unresolved controversies and conventions such as the validity of fMRI global signal regression.

Vince Calhoun (Glass Brain Award) contributed: “Data-guided neuroimaging and visualization: From functional decomposition to dynamic fusion.”³ Here he addresses, head on, the challenge of how to begin to handle the overwhelming amount of data without missing anything. He argues for a principled approach, grounded in “data fidelity”, advocating for the preservation of rich, high-dimensional representations and to resist early, low-dimensional summaries. Reducing dimensionality is often necessary, but it also runs the risk of removing meaningful information.

Dr. Calhoun introduces here a Functional Decomposition Framework for classifying methods based on their Source (anatomic, functional, molecular, multimodal, etc.), Mode (categorical or dimensional), and Fit (modeled, data-driven or hybrid). He discussed his NeuroMark Pipeline, which is a hybrid approach that uses spatial priors yet does not lose individual variability information. He also introduces the idea of Expressive Visualization as a means to reveal novel relationship structures in the data. He also advocates for independent component analysis (ICA), which he has pioneered for fMRI over the past two decades.

Giulia Baracchini, Eli Muller, and Mac (James) Shine (Keynote) contributed: “Bridging the epistemological divide in neuroscience to improve ontological clarity.”⁴ This is a beautiful perspective piece that highlights a primary challenge in brain imaging as well as all of neuroscience. We face epistemological divides as we all use different methods and tools that address different sets of questions, across different scales, on different systems. The field suffers from many silos, with researchers not communicating with each other optimally, thus slowing meaningful advancement and leading to ontological clashes based on differences in fundamental understanding of brain function across sub-disciplines. We all have our models of the brain,

deeply tied to the spatial and temporal scale and the specific measurements that we make. We need to build bridges.

The authors present several solutions including interdisciplinary training and exposure, objective benchmarks for our methods, and finally a unifying Map of Neuroscience. We, at Aperture Neuro, deeply resonate with this message, so much so that the message of interdisciplinary training, communication, sharing, and benchmarking methods and models could be our mission statement. Interdisciplinary training could be fostered through collaboration incentives, online resources, and more multi-disciplinary conferences where a single question is addressed by experts across domains. Objective Benchmarks of methods may be established by leveraging open data repositories and computational toolboxes to create a centralized repository of measures. The Map of Neuroscience is more than just a map of all the components of the brain. It is a map that outlines how different subfields relate and intersect. This map would reveal a scaffolding of potential opportunities as well as a “concept space” across neuroscience and would likely reveal rich opportunities for future investigation. It would quickly become a valuable resource for both seasoned neuroscientists and beginners, helping them identify opportunities and gaps in current understanding.

This paper is fundamentally important, as it clearly reveals the next necessary direction for all neuroscience towards a true “understanding” of the brain and, arguably, provides key roadmaps towards this goal.

Zhengyi Yang, Na Luo, Lingzhong Fan, and Tianzi Jiang (Council Chair) contributed: “Neuromodulation robot for precision TMS.”⁵ Here, the authors shared the progress and vision of the development and future of robotic systems for accurate and flexible TMS. TMS has been limited by a lack of efficacy, in part, because positioning has been imprecise, not accounting for differences in brain and skull structure across individuals. The future TMS systems being developed will be far more effective because they will be more fully automated and precise - aided by closed loop, feedback-driven adaptive neuromodulation.

Ariel Rokem (Education in Neuroimaging Award) contributed: “Human brain mapping at the Singularity.”⁶ In this provocative article, Dr. Rokem discusses the progress of data-driven research in human brain mapping using the framework of “Frictionless Reproducibility” (FR) where other scientists can rerun, test, and extend work with minimal effort. It is built on three pillars: sharable data, re-executable code, and transparent, objective benchmarking or evaluation.

In Dr. Rokem’s paper, he praises the progress of open data (FR1) but suggests that, because so many processing steps are involved in creating and analyzing data, it is not directly actionable. He highlights the need to reward the creation of new data. Regarding code sharing and re-execution (FR2), he notes that open-source software is growing and platforms are more easily used as a scaffolding for creating, sharing and testing new software. In the context of brain imaging (FR3), the biggest challenge is the absence of common frameworks that allow for testing and comparing the effectiveness of experimental designs. The field of brain

mapping typically progresses by the performance of novel experiments and processing to address different questions. In general, Dr. Rokem suggests that those in the field learn programming as a lever to manifest and test new ideas. He also suggests that there should be good friction - that of thinking, discussing, debating, and understanding which methods, models, and interpretations are best over time.

Bratislav Mistic (Early Career Investigator Award) contributed: “The splendour of unthresholded brain maps.”⁷ This position paper suggests that the field step back from its reliance on statistical thresholding, as sub-threshold activity is indeed meaningful and reveals brain activity in a coherent, continuous space. This approach shows how brain activity is overlapping and integrated. It also allows more seamless integration with other modalities that produce measurements on different spatial and temporal scales. Dr. Mistic uses this “no-threshold” stance to argue for a stronger connection between brain activation and underlying neuroanatomy.

It is important to note that Dr. Mistic does not advocate replacing thresholded maps with unthresholded ones but rather using them as complementary tools to understand the brain as the natural continuous whole that it is. There is information outside of the punctate regions that pass statistical threshold and we should not neglect it.

Odile Feys (Karl Zilles Award in Integrative Neuroscience) contributed: “Are we in the science fiction era of brain imaging? A point of view on advances and challenges in brain investigation.”⁸ This article focuses on optically pumped magnetometers (OPMs) for on-scalp MEG. This approach was developed in 2018 and has moved the field toward what was previously viewed as science fiction. OPMs are sensitive to interictal seizure activity and can more easily be adopted to difficult clinical populations with better resolution. Dr. Feys discusses future directions that include integration with electroencephalography (EEG) and application to fetal MEG, spinal cord and peripheral nerve MEG, as well as utility in screening for epilepsy and Alzheimer’s disease.

STATE OF THE BRAIN: 2025

Shortly after OHBM 2025, we again invited the leaders, award winners, and keynote speakers to share their insights on the field, the Annual Meeting, and/or their own research. At the time of this writing, we have over 10 invitees working on formulating their unique perspectives and insights into the exciting developments, opportunities, and challenges to the field. Six outstanding papers have been submitted so far.

CONCLUSION

We have found deep inspiration and many new ideas from reading through the published papers of 2024. We are certain that the articles contributed to this second annual issue will provide yet more new insights and perspectives, and perhaps inspire new ideas in the community as we continue our research towards understanding the brain.

From PAB’s perspective:

1. The field of brain imaging needs to continue to create an infrastructure to integrate and link data and findings from different modalities and results across temporal and spatial scales. At the moment, labs tied to specific questions at specific temporal and spatial scales are mostly, with a few exceptions, islands of research each grappling with their own questions and making their own models but essentially talking past researchers focused on other modalities. We need more integrative models that can begin to address mechanisms and principles that more deeply explain results provided by methods focused on human imaging.
2. We need to continue to find better ways to capture the breadth, depth, and nuance of explosively growing amounts of data. We need to be more engaged in creating and applying models to derive meaning, while remaining vigilant not to overlook significant unmodeled data that might be mistakenly attributed to noise or artifact. We should not be too closely attached to tools that, while offering precision, limit the breadth of questions that can be posed.
3. We need to continue to develop platforms and standards that allow seamless (“frictionless”) sharing of analysis methods and data.
4. We need to continue to innovate on acquisition and neural modulation technology. OPM technology and focused ultrasound, highlighted in two of the papers in the special issue, are examples of nascent technology that may open up entire landscapes of questions and new understanding.
5. The theme of understanding similarities and differences in individuals, tied to measures of behavior, is growing rapidly and will continue to shed light on the significance of specific temporal and spatial signatures in the data.
6. Lastly, as suggested by the inspiring work of Seong-Gi Kim, who recently won the International Society for Magnetic Resonance in Medicine (ISMRM) Gold Medal for some of the work he outlined in his paper, the BOLD signal (and perhaps the signal in any acquisition modality) very likely contains untapped information about neuronal activity and cerebral physiology. There is more information to be uncovered.

From MMC’s perspective:

1. Multi-modal and multi-species is critical. The field of brain mapping has evolved considerably since its inception. While most of the literature in our community describes studies in human participants, there are several contributions from the “State of the Brain: 2024” that skillfully demonstrate the need for multi-scale and multi-species neuroimaging. This is likely a key way forward for translating findings (and maybe even therapeutics) from preliminary stages toward a deeper understanding of the human condition.
2. Our field has long been held up as an exemplar for multi-disciplinary training. Engineers, computer sci-

entists, and physicists need to learn about how the brain is constructed and how it operates. Neuroscientists, clinicians, and psychologists must become technical experts. This has led to rich conversations in our community and has allowed for the development of very progressive learning environments. I was inspired by the submissions that either discussed this interdisciplinarity directly or indirectly. However, it brings to mind a pressing modern challenge: how will the use of artificial intelligence, and large language models, in particular, change these contexts? How do we keep the conversation going while leveraging the clear benefits that these enormous technological advances may provide?

3. “Frictionless reproducibility” is critical. As datasets become larger and the number of experimental design decisions grow, groups will be reporting smaller and more salient effects or conceptual descriptions embedded in multivariate analyses. As a field, we must be ready to reproduce the results and allow others to do so as well. Cooperation and collaboration to this end will be key.
4. Long-term detailed neuroscientific investigation is increasingly important in the “big data” age. As demonstrated by Seong-Gi Kim, MRI-based measures in rodents can be used to better understand findings

in humans. However, it is clear that brain mapping techniques with limited specificity but high sensitivity need these detailed experiments to contextualize and interpret their observations.

“State of the Brain: 2024” papers are a treasure and demonstrate that the state of our field and our community is strong, creative, and open to a changing landscape. “State of the Brain: 2025” promises to continue to deepen, broaden, and add further nuance to our perspectives! There is no doubt that the State of the Brain is healthy and thriving.

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CONFLICTS OF INTEREST

PAB and MMC are Editors-in-Chief of Aperture Neuro.

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