BIOGRAPHICAL SKETCH

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NAME: Moore, Christopher I.

eRA COMMONS USER NAME (credential, e.g., agency login): cimoore4

POSITION TITLE: Associate Director, Carney Institute for Brain Science; Professor of Neuroscience

EDUCATION/TRAINING *(Begin with baccalaureate or other initial professional education, such as nursing, include postdoctoral training and residency training if applicable. Add/delete rows as necessary.)*

INSTITUTION AND LOCATION	DEGREE (if applicable)	END DATE MM/YYYY	FIELD OF STUDY
Oberlin College, Oberlin, OH	BA	1990	Neuroscience & Philosophy
MIT, Cambridge, MA	PHD	1998	Brain & Cognitive Science
Martinos Center/Harvard Medical School, Charlestown, MA	Postdoctoral Fellow	2002	Systems Neuroscience
Keck Center/UCSF, San Francisco, CA	Other training	2002	Systems Neuroscience

A. Personal Statement

I study mechanisms underlying brain dynamics and their meaning for behavior. We take a systems approach, seeking to understand how multiple cell types and brain areas interact to optimize behavior (e.g., Moore et al., 2010). 'Dynamics' refer to millisecond-to-second time scale changes in activity that impact behavior in real time. Examples include the role of gamma oscillations (e.g., Cardin et al., 2009; Shin and Moore, 2019) and rapid dopaminergic 'waves' moving across the dorsal striatum (e.g., Hamid, Frank and Moore, 2021).

Dynamics in non-neural systems are a major focus: Most notably, we proposed a framework for vascular contributions to information processing (The Hemo-Neural Hypothesis; Moore and Cao, 2008).

We develop techniques for studying these dynamics, and are deeply committed to translating these into real-world impact, primarily through Open Science. Examples include the widely-adopted 'Open Ephys' system developed by students in my lab (J. Voigts and J. Siegle, www.open-ephys.org) and the Discovery Engine for predicting scientific impact (www.theDiscoveryEngine.org). A further innovation was co-development of opto-fMRI for tracking brain-wide hemodynamics after selective neural drive (e.g., Kahn et al., 2011) and tools for selectively regulating vascular motion and the BBB (Moore and Tyler, US 9,687,672; US 10,149,986).

With a multi-level team, we create tools for controlling circuits and image activity using BioLuminescence with OptoGenetics ('BL-OG': Gomez-Ramirez et al., 2019; Moore and Berglund, 2020: www.bioluminescencehub.org). Innovations include Interluminescence, a novel methods for transmission of optical signals between synapses in the brain (Prakash et al., 2022).

I am highly committed to training, and *very* fortunate to mentor great students, over twenty now in tenure-track positions or equivalent (www.themoorelab.org/alumni). I am a deep believer in the teaching value of intensive short courses, that create a new intellectual community and demystify the 'get off the ground' phase of research for students. **This Ben Gurion-Brown course is an ideal example of this highly exciting approach.**

B. Positions, Scientific Appointments and Honors

Positions and Scientific Appointments

2020 - 2025 Max Planck/Ernst Strüngmann Institute for Neuroscience, Scientific Advisory Board
2017 - Associate Director, Carney Institute for Brain Science, Brown University, Providence, RI
2016 - Professor of Neuroscience, Brown University, Providence, RI
2015 - Inventor/Co-Director, The DiscoveryEngine, (www.thediscoveryengine.org)
2013 - 2021 Founding Board Member, Open-Ephys, (www.open-ephys.org)
2011 - 2016 Associate Professor of Neuroscience, Brown University, Providence, RI 2003 -
2011 Assistant-Associate Professor, MIT, Cambridge, MA

Honors

2015 - 2020 NIDA Board of Scientific Counselors (BSC)
2014 - MIT Press: *ad hoc* Reviewer
2014 - Brain Research Foundation Fellow
2014 - NIH BRAIN Initiative reviewer
2005 - *ad hoc* Reviewer, NIH Sensory-Motor Integration Study Section
2014 - 2018 IACUC Committee, Brown University
2005 - 2008 Mitsui Career Development Chair, MIT
1999 - 2002 Postdoctoral Fellowships, Individual NIH NRSA and McDonnell-Pew Foundation
2019 Association for Migraine Disorders: Migraine Innovation Award
2013 NIH Bioengineering of Neuroscience, Vision, and Low Vision Technologies Study Section
2013 NIH Special Emphasis Panel R01 Review Study Section,
2013 NSF/ONR/NIH Workshop on Glia in Learning and Cognition, Invited Participant/Speaker
2012 NSF CRCNS Review Panel
2008 COSYNE Program Committee
2008 Group Leader, NIH Panel on Neuroprosthetics
2005 School of Science Prize for Excellence in Undergraduate Teaching, MIT
2000 Participant, NIH Workshop on Opportunities in Cognitive Neuroscience
1998 Fellow, Kira Institute on Science and Values, Amherst College
1997 Fellow, McDonnel-Pew Institute for Cognitive Neuroscience, Dartmouth College
1995 Angus N. MacDonald Excellence in Teaching Award, MIT
1990 High Honors in Neuroscience, Oberlin College

C. Contribution to Science

1. **The Mechanisms and Meaning of 5-25 Hz Thalamocortical Dynamics for Perception**

The broad hypothesis driving my research is that the fundamental goal of neocortical computation is to provide dynamic flexibility based on learned information to make processing optimal on millisecond-to-second time scales. An important early contribution was the demonstration that despite the canonical view of barrel cortex as a 'labeled line,' and therefore potentially unavailable to rapid neocortical dynamics, SI barrel neocortex actually shows substantial rapid dynamics, facilitated by integration through large subthreshold receptive fields (Moore and Nelson, 1998; Moore et al., 1999). A key feature of a framework hypothesis we proposed (Moore et al., 1999; Moore, 2004) was that sustained lemniscal thalamic input > 525 Hz should diminish perceived tactile intensity. This hypothesis has been directly and specifically supported by work in independent laboratories (e.g., Ollerenshaw et al., 2014). The potential parallels between these sensory driven thalamocortical dynamics and internally generated Alpha and Beta Events led us to study these rhythms. We and others have found an inverse relationship between tactile detection probability—and by extension perceived tactile intensity—and Alpha and Beta Events, and their active allocation to putatively modulate throughput in non-attended representations in humans and rodents (e.g., Jones et al., 2010; Shin et al., 2017). We have worked in close collaboration with Dr. Stephanie Jones to understand the mechanistic drivers of these events (Jones…Moore, 2007; Sherman et al., 2015; Shin et al., 2017).

a. Halassa MM, Siegle JH, Ritt JT, Ting JT, Feng G, Moore CI. Selective optical drive of thalamic reticular nucleus generates thalamic bursts and cortical spindles. Nat Neurosci. 2011 Jul 24;14(9):1118-20. PubMed Central PMCID: PMC4169194.

b. Jones SR, Kerr CE, Wan Q, Pritchett DL, Hämäläinen M, Moore CI. Cued spatial attention drives functionally relevant modulation of the mu rhythm in primary somatosensory cortex. J Neurosci. 2010 Oct 13;30(41):13760-5. PubMed Central PMCID: PMC2970512.

c. Moore CI, Nelson SB, Sur M. Dynamics of neuronal processing in rat somatosensory cortex. Trends Neurosci. 1999 Nov;22(11):513-20. PubMed PMID: 10529819.

d. Shin H, Law R, Tsutsui S, Moore CI, Jones SR. The rate of transient beta frequency events predicts behavior across tasks and species. Elife. 2017 Nov 6;6 PubMed Central PMCID: PMC5683757.

2. **The Mechanisms and Meaning of Neocortical Gamma Oscillations**

A much-debated topic in the study of neocortical function is whether gamma oscillations (30-80 Hz) directly contribute to sensory processing (e.g., enhancement of perceived tactile intensity), or whether they are epiphenomenal ("exhaust fumes of computation"). In an initial study, we employed optogenetic methods to selectively drive fast-spiking (FS) interneurons in neocortex, building on prior computational and correlative studies to show conclusively that naturalistic gamma can be produced by FS synchronization (Cardin et al., 2009). Subsequent modeling, co-mentored with Dr. Jones, captured these dynamics (Vierling-Claassen, Cardin, Moore and Jones, 2010) and led to proposal of a variety of mechanisms underlying transformations in local sensory representations driven by gamma (Knoblich et al., 2010). We subsequently found (Siegle, Pritchett and Moore, 2014; Shin and Moore, in preparation; Shin, PhD Thesis) that optogenetic induction of FS-gamma drives enhanced probability of sensory detection of difficult-to-perceive stimuli.

We recently discovered (Shin and Moore, 2019) that a distinct class of FS fires highly rhythmically at a gamma-band interval (30-55 Hz) and is not perturbed by sensory input. These neurons predict success in information processing (hit versus miss trials) with increased gamma band firing and increased firing regularity, suggesting they may play a role in the organization of optimal timing in relay.

a. Cardin JA, Carlén M, Meletis K, Knoblich U, Zhang F, Deisseroth K, Tsai LH, Moore CI. Driving fastspiking cells induces gamma rhythm and controls sensory responses. Nature. 2009 Jun 4;459(7247):663-7. PubMed Central PMCID: PMC3655711.

b. Shin H, Moore CI. Persistent Gamma Spiking in SI Nonsensory Fast Spiking Cells Predicts Perceptual Success. Neuron. 2019 Sep 25;103(6):1150-1163.e5. PubMed Central PMCID: PMC6763387.

c. Siegle JH, Pritchett DL, Moore CI. Gamma-range synchronization of fast-spiking interneurons can enhance detection of tactile stimuli. Nat Neurosci. 2014 Oct;17(10):1371-9. PubMed Central PMCID: PMC4229565.

3. **Discovery of New Maps in Sensory Neocortex: Basic Advances in Understanding Vibrissal Sensing**

Crucial to using the vibrissa sensory system as a model for Neocortical dynamics was determining specific basic properties of its organization and functionality. We therefore have devoted significant effort to advancing our knowledge of the spatial organization of SI maps and the natural sensory statistics experienced during vibrissal sensing. A motif of high-resolution visual neocortical areas is the presence of multiple, overlying maps, demonstrating intercalated columnar organization for distinct features. The vibrissa barrel neocortex (SI) of rats and mice is a sensory neocortex that similarly processes high-resolution sensory information, but had not previously been found to possess multiple maps, begging the question of whether such maps are a feature of high-resolution systems or are a specific property of the organization of visual information. We discovered 2 new maps that overlie the well-described somatotopic 'barrel column' map in vibrissal SI: A direction 'micro-columnar' map, in which a pinwheel-like organization exists for the direction of vibrissal motion (Andermann and Moore, 2006) and a frequency 'macro-columnar' map, in which sets of barrel columns were found to preferentially represent different frequencies of vibrissal motion, including in the awake and freely behaving animal (Neimark et al., 2003; Andermann et al., 2004; Ritt et al., 2009). These findings not only advanced the understanding of the basic architecture of this well studied model system, but

also provide direct evidence that columnar organization may be a key feature of high-performance sensory systems (vibrissal sensing in mice and vision in visual mammals). These studies were also among the first to record the high-frequency signals transmitted by the vibrissae that are now widely regarded as crucial to sensing in this system. These studies were the first to provide real numbers as to the size (e.g., velocity) of micromotions in free natural sensing using high-speed videography (Ritt et al., 2008; see also studies by Feldman and colleagues and Hartmann and colleagues).

a. Andermann ML, Moore CI. A somatotopic map of vibrissa motion direction within a barrel column. Nat Neurosci. 2006 Apr;9(4):543-51. PubMed PMID: 16547511.
b. Andermann ML, Ritt J, Neimark MA, Moore CI. Neural correlates of vibrissa resonance; band-pass and somatotopic representation of high-frequency stimuli. Neuron. 2004 May 13;42(3):451-63. PubMed PMID: 15134641.
c. Neimark MA, Andermann ML, Hopfield JJ, Moore CI. Vibrissa resonance as a transduction mechanism for tactile encoding. J Neurosci. 2003 Jul 23;23(16):6499-509. PubMed Central PMCID: PMC6740638.
d. Ritt JT, Andermann ML, Moore CI. Embodied information processing: vibrissa mechanics and texture features shape micromotions in actively sensing rats. Neuron. 2008 Feb 28;57(4):599-613. PubMed Central PMCID: PMC4391974.

4. **The Hemo-Neural Hypothesis**

We have proposed that vascular dynamics may play an active role in information processing (Moore and Cao, 2008). Specifically, we predict that rapid and localized changes in vasculature (e.g., dilations that drive the fMRI signal) may directly impact neurons, altering their processing state. We have developed a suite of new optogenetic tools for selective vascular regulation and integrated them with 2-photon microscopy of calcium dynamics to directly test this prediction. We have found that selectively-induced local vasodilation drives unique and consistent responses in a significant sub-population of neocortical neurons, and that these dynamics evoked by optogenetic vascular manipulations predict the variance relative to endogenous (e.g., sensory-evoked) vascular events, in support of key predictions of our prior hypothesis.

a. Moore CI, Cao R. The Hemo-Neural hypothesis: on the role of blood flow in information processing. J Neurophysiol. 2008 99(5):2035-47. PubMed Central PMCID: PMC3655718.

5. **Novel Methods for Systems Neuroscience Research**

We have developed or refined new methods for systems neuroscience. Electrophysiology contributions include *Open Ephys* (www.open-ephys.org), developed by two graduate students in the lab (Voigts and Siegle), an open access low cost electrophysiology system currently in use in several hundred labs. Jakob Voigts and others also developed the miniaturized *flexDrive*, optimized for use in mice (low weight, < 2g, high channel count: Voigts et al., 2013). We have also developed optogenetic approaches, including coinvention of *opto-fMRI* (e.g., Kahn et al., 2011) and novel approaches for controlling blood vessels with light. Our control tools use *BioLuminnescent OptoGenetics* (BLOG), placing light-producing enzymes (luciferases) in molecular proximity to an optogenetic receiver, often tethered to one another (*Luminopsins*). With an *'Intraluminescent'* strategy in which both components are expressed in the same cell, a single molecule can be used for chemo- or optogenetic control in the same animal, and activity-dependent light production can provide real-time and molecule-specific feedback control. We have also developed *Interluminescent* BL-OG, in which an activity-dependent luciferase is placed presynaptically and an opsin postsynaptically. In this *'optical synapse,'* regulation of the post-synaptic cell is only realized when the presynaptic cell fires an action potential, enhancing or suppressing endogenous communication only between a selected pair of cell types.

a. Voigts J, Siegle JH, Pritchett DL, Moore CI. The flexDrive: an ultra-light implant for optical control and highly parallel chronic recording of neuronal ensembles in freely moving mice. Front Syst Neurosci. 2013 13;7:8. doi: 10.3389/fnsys.2013.00008. PMID: 23717267.
b. Kahn I, Desai M, Knoblich U, Bernstein J, Henninger M, Graybiel AM, Boyden ES, Buckner RL, Moore CI. Characterization of the functional MRI response temporal linearity via optical control of neocortical

pyramidal neurons. J Neurosci. 2011 31(42):15086-91. doi: 10.1523/JNEUROSCI.0007 11.2011 PMID: 22016542

c. Gomez-Ramirez M, More AI, Friedman NG, Hochgeschwender U, Moore CI. The BioLuminescent OptoGenetic in vivo response to coelenterazine is proportional, sensitive, and specific in neocortex. J Neurosci Res. 2020 98(3):471-480. doi: 10.1002/jnr.24498. PMID: 31544973

Patents

Moore, CI, Brown, T Optogenetic Control of Endothelial Cells US 9,687,672

Moore, CI, Brown, T Optogenetic Control of Endothelial Cells US 10,149,986

Moore, CI, Hochgeschwender, U, Lipscombe, D Minimally-Invasive and Activity-Dependent Control of Excitable Cells US 11,242,374