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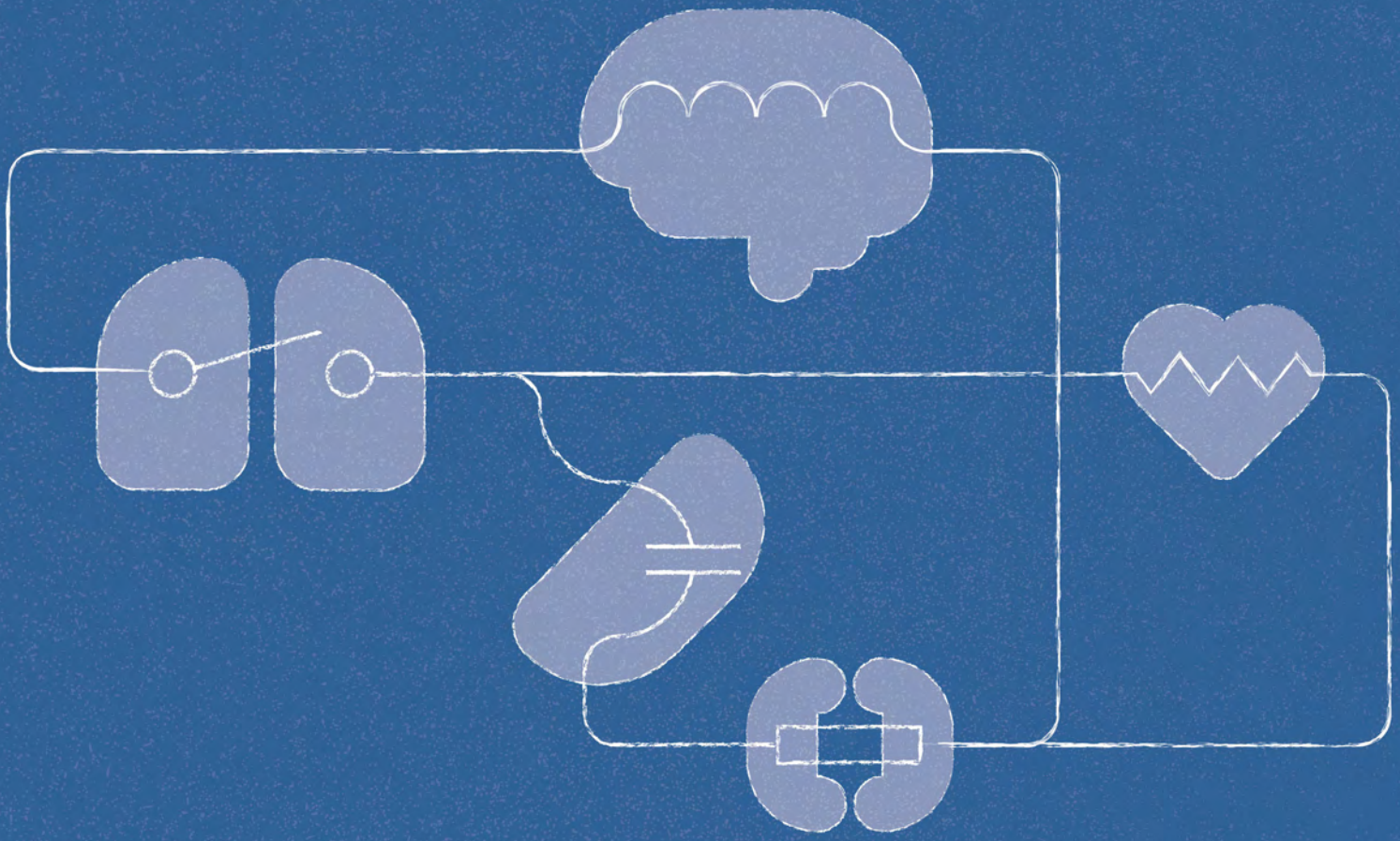

2nd Annual
NIH Investigator Meeting for Interoception Research

November 11, 2023

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Walter Koroshetz, M.D., Director, National Institute of Neurological Disorders and Stroke (NINDS)

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Le Zhang, Ph.D., Yale University. *Neuro-Immune Interactions and Interoception in Prodromal Parkinson's Disease*

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Karl Deisseroth, M.D., Ph.D., Stanford University. *From Microbial Membrane Proteins to the Heart-Brain Connection*

Sahib Khalsa, M.D., Ph.D., Laureate Institute for Brain Research. *Perturbing the Rhythms Within: Cardiorespiratory and Gastrointestinal Insights Into Psychiatric Disorders*

Todd Coleman, Ph.D., Stanford University. *Advancing Methods and Technologies To Monitor and Modulate Couplings Between the Human Brain and Stomach*

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Julie Pilitsis, M.D., Ph.D., M.B.A., Florida Atlantic University Schmidt College of Medicine. *Modulation of Spinal Pathways Involved in Interoception in Patients With Chronic Pain*

John Osborn, Ph.D., University of Minnesota. *Research Evaluating Vagal Excitation and Anatomical Links (REVEAL) in Humans*

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5:00 p.m. | Adjourn

Welcome and Opening Remarks

Helene M. Langevin, M.D., Director, National Center for Complementary and Integrative Health

Dr. Langevin was sworn in as director of the National Center for Complementary and Integrative Health on November 26, 2018. Previously, she was the director of the Osher Center for Integrative Medicine in Boston, jointly based at Brigham and Women's Hospital and Harvard Medical School, and a professor in residence of medicine at Harvard Medical School. She was a professor of neurological sciences at the University of Vermont Larner College of Medicine in Burlington until 2012. Her research has centered around the role of connective tissue in chronic musculoskeletal pain and the mechanisms of acupuncture, manual, and movement-based therapies. Her more recent work has focused on the effects of stretching on inflammation resolution mechanisms within connective tissue. Dr. Langevin received her medical degree from McGill University in Montreal, Canada. She completed a postdoctoral research fellowship in neurochemistry in the Medical Research Council Neurochemical Pharmacology Unit at the University of Cambridge, England, and a residency in internal medicine and postdoctoral fellowship in endocrinology and metabolism at the Johns Hopkins Hospital in Baltimore.

Walter Koroshetz, M.D., Director, National Institute of Neurological Disorders and Stroke

Dr. Koroshetz is the director of the National Institute of Neurological Disorders and Stroke (NINDS). Dr. Koroshetz joined NINDS in 2007 as deputy director, and he served as acting director from October 2014 through June 2015. As NINDS director, Dr. Koroshetz directs program planning and budgeting and oversees the scientific and administrative functions of the Institute. He has held leadership roles in many National Institutes of Health (NIH) and NINDS programs, including NIH's Brain Research through Advancing Innovative Neurotechnologies Initiative, the NIH Blueprint for Neuroscience Research, the Traumatic Brain Injury Center collaborative effort between the NIH intramural program and the Uniformed Services University of the Health Sciences, and the establishment of the NIH Office of Emergency Care Research. Before joining NINDS, Dr. Koroshetz served as vice chair of the neurology service and director of stroke and neurointensive care services at Massachusetts General Hospital (MGH). He was a professor of neurology at Harvard Medical School and led neurology resident training at MGH between 1990 and 2007. Dr. Koroshetz received his medical degree from the University of Chicago.

Program Updates

Wen Chen, M.MSc., Ph.D., National Center for Complementary and Integrative Health

Dr. Chen, branch chief of Basic and Mechanistic Research, Division of Extramural Research, National Center for Complementary and Integrative Health (NCCIH), oversees fundamental science research, translational research, and intervention optimization research, as well as methodology and technology development related to all complementary and integrative health approaches. Dr. Chen received her doctorate in biological chemistry and molecular pharmacology from Harvard University. She also earned a master's degree in medical sciences as part of the Harvard-Markey Medical Scientist training program at Harvard Medical School. Dr. Chen did her postdoctoral training in proteomics at the Massachusetts Institute of Technology. Before joining NCCIH, she worked as a scientific editor at *Neuron,* program coordinator at the National Institute of Mental Health, and program director at the National Institute on Aging overseeing a research portfolio on sensory and motor disorders of aging.

Keynote Presentation

Moderator: Dana Schloesser, Ph.D., Office of Behavior and Social Science Research (OBSSR), National Institutes of Health

Dr. Schloesser is a health scientist administrator at the National Institutes of Health (NIH) Office of Behavioral and Social Sciences Research (OBSSR), with a focus on the neurosciences across the NIH Institutes and Offices, particularly where they intersect with the behavioral and social sciences. She is currently involved in the BRAIN Initiative, BluePrint for Neuroscience Research, Sleep Research Coordinating Committee, Myalgic Encephalomyelitis/ Chronic Fatigue Syndrome Working Group, and Adolescent Brain Cognitive Development Study. Dr. Schloesser came to OBSSR from the National Institute of Neurological Disorders and Stroke (NINDS) in Channels, Synapses, and Neural Circuits, where she was a health scientist. During her time at NINDS, she was involved in programmatic efforts involving chronic fatigue, epilepsy, and the BRAIN Initiative. Prior to NINDS, Dr. Schloesser was an American Association for the Advancement of Science (AAAS) fellow (2014–2015) at OBSSR, with a focus on behavioral neurosciences. Dr. Schloesser has been engaged in various fields of biological research, including behavioral neuroscience and radiation neurobiology. In these fields, she has presented and published research, received awards for presentations, and developed a comprehensive understanding of these areas.

Kay Tye, Ph.D., Salk Institute for Biological Studies

Dr. Tye is a Howard Hughes Medical Institute (HHMI) Investigator and Wylie Vale Professor at the Salk Institute for Biological Studies. She earned her bachelor's degree from the Massachusetts Institute of Technology (MIT) in 2003, majoring in brain and cognitive sciences, and her Ph.D. for thesis work with Patricia Janak at the University of California, San Francisco, focusing on how the amygdala undergoes plasticity for reward learning, for which she was recognized with the Lindsley Prize and the Weintraub Award. Dr. Tye did her postdoctoral training with Karl Deisseroth at Stanford University, where she pioneered the use of projection-specific optogenetic manipulations, a mainstay of circuit neuroscience, and used this approach to dissect anxiety circuits in the amygdala. Dr. Tye started her own lab at MIT in 2012, and she was awarded the New Innovator Award to investigate the neural circuit mechanisms of emotional valence. In 2016, Dr. Tye was the sole recipient of the Society for Neuroscience's Young Investigator Award. In 2017, she won the National Institutes of Health Director's Pioneer Award to study social homeostasis, a conceptual framework she formalized in 2019. Dr. Tye moved her lab to the Salk Institute in 2019 and became Wylie Chair Professor of the Systems Neurobiology Laboratory. She became a Blavatnik Laureate and HHMI Investigator in 2021 and continues to investigate the neural bases of

emotional valence and social homeostasis on the circuit, systems, and computational levels. Dr. Tye is most passionate about improving the health of academic culture in terms of serving as a mentor, advocate, and activist. Dr. Tye has been recognized with mentoring awards at the undergraduate, graduate, and postdoctoral levels. She has placed 13 former trainees into faculty positions leading their own independent research programs within academia, in addition to launching successful careers outside academia (5 of whom are women and 5 of whom are underrepresented minorities). Dr. Tye is committed to outreach and promoting diversity, equity, inclusion, and accessibility by creating and supporting outreach programs, by being active with science communication (TED Talk, *Scientific American,* Nova), and by making systemic and infrastructural changes at the local and global levels.

Neural Mechanisms of Social Homeostasis

How does our brain rapidly determine if something is good or bad? How do we know our place within a social group? How do we know how to behave appropriately in dynamic environments with ever-changing conditions? The Tye lab is interested in understanding how neural circuits important for driving positive and negative motivational valence (seeking pleasure or avoiding punishment) are anatomically, genetically, and functionally arranged. The lab studies the neural mechanisms that underlie a wide range of behaviors ranging from learned to innate, including social, feeding, reward-seeking, and anxiety-related behaviors. Interests also include “social homeostasis”—how our brains establish a preferred set-point for social contact, and how this maintains stability within a social group. How are these circuits interconnected with one another, and how are competing mechanisms orchestrated on the neural population level? Optogenetic, electrophysiological, electrochemical, pharmacologic, and imaging approaches are employed to probe these circuits during behavior.

Session One: Flash Talks by Junior Investigators

Moderator: Emmeline Edwards, Ph.D., Director of the Division of Extramural Research, National Center for Complementary and Integrative Health

Dr. Edwards is director of the Division of Extramural Research of the National Center for Complementary and Integrative Health (NCCIH). In this capacity, she is responsible for development of scientific programs or areas of science that fulfill NCCIH's mission as well as planning, implementation, and policy. Prior to joining NCCIH, Dr. Edwards served as deputy director of the extramural program at the National Institute of Neurological Disorders and Stroke. Before coming to the National Institutes of Health, Dr. Edwards earned her Ph.D. in neurochemistry from Fordham University, did postdoctoral research in behavioral pharmacology and neuroscience at the State University of New York, and was a tenured associate professor in the Department of Pharmacology at the University of Maryland. Her research there focused on the neural mechanisms of complex behaviors and characterization of a genetic model of affective disorders. She also served as chair of the Graduate Studies and Research Committee and as a member of the Dean's Executive Council at the University of Maryland.

Moderator: Olga Tjurmina, Ph.D., National Heart, Lung, and Blood Institute

Dr. Tjurmina serves as a program director for the Heart Failure and Arrhythmias Branch of the National Heart, Lung, and Blood Institute (NHLBI). She is responsible for the solicitation, review, award, management, and analysis of grants and programs. Her interests include neural control of cardiac function, cardiac excitability and contractility, arrhythmias, cardiac resilience and adaptation to stress, and stress-induced remodeling. Prior to joining NHLBI, Dr. Tjurmina was a scientific review officer for the Cardiac Contractility, Hypertrophy, and Failure Study Section of the Center for Scientific Review, where she planned, organized, and conducted standing study section and Special Emphasis Panel review meetings, as well as selected and nominated the standing committee chartered members. Dr. Tjurmina previously was an intramural research fellow at the National Institute of Mental Health, where she studied the relationships between genotypic and neurochemical and homeostatic phenotypic changes in mice with targeted disruptions of genes involved in monoaminergic neurotransmission. As a Fogarty postdoctoral fellow at the National Institute of Neurological Disorders and Stroke, she studied the effects of neuroendocrine factors and stress on central catecholaminergic function and sympathetic activity. She also was a special consultant and a visiting fellow at the Massachusetts Institute of Technology. Dr. Tjurmina earned her Ph.D. in biological

sciences (physiology) from the Russian Cardiology Research Center and Moscow State University. Her research focused on the role of endogenous catecholamines in blood pressure regulation and the contribution of the sympathetic nervous system to stress-evoked cardiovascular effects.

Minel Arinel, B.S.c., Duke University

Minel Arinel, B.S.c., is a fifth-year Ph.D. student in neurobiology at Duke University. Her thesis research centers on understanding how interoceptive signals from the gut are communicated to the brain to drive feeding behaviors. Because of the accessibility of its nervous system, she conducts her research on zebrafish. Arinel received her bachelor's degree in molecular biology, genetics, and bioengineering from Sabanci University in Turkey, along with minors in chemistry and psychology. During her undergraduate education, she conducted research in Dr. Eda Yildirim's laboratory at Duke to investigate the role of nucleoporin 153 in chromatin structure and gene regulation. After her undergraduate education, she began graduate school and became a Boehringer Ingelheim Fellow. Alongside her graduate work, Arinel also investigates the impact of psychedelics on sensory systems and functional connectivity across the brain. Arinel is an advocate for diversity and inclusivity in the scientific community. She serves as the co-president for first-generation/low-income graduate and professional students at Duke, co-leads a summer neuroscience research program for high school students from underserved schools, and offers guidance and support to first-year graduate students as an institutionally appointed peer mentor.

Mapping the Gut-Brain Neural Circuitry

Specialized sensory cells in the gut epithelium termed enteroendocrine cells (EECs) have been shown to send enteric information directly to the brain via synaptic connections with vagal neurons. Yet, the purpose and mechanisms by which gut-brain circuits encode sensory information to impact neural activity across the brain remain elusive. The larval zebrafish is ideal to study this gut-brain communication, as its transparency provides access to the whole system at single-cell resolution. To investigate how different types of nutritional information are processed, first a preference assay was developed to determine how nutrients in the gut affect feeding behavior. By encapsulating different EEC-activating chemical stimuli within tasteless alginate complex particles, gut-mediated salience was tested in freely swimming larval zebrafish. After establishing the valence of specific nutrients, a computer-controlled microgavage system was engineered to inject nanoliter volumes of chemical stimuli directly into the intestinal lumen of larval zebrafish while volumetric two-photon microscopy was performed. Using precisely timed injections of EEC-activating nutrients directly into the gut, lateralized responses in right and left vagal ganglia and a variety of gut-evoked neural response dynamics across hindbrain neurons were shown. Finally, simultaneous functional imaging of these regions during optogenetic photostimulation of EECs along the gut directly implicated these cells in driving specific neural activity patterns and established topographic representations of the gut across the brain. Together, this research systematically determines how interoceptive stimuli are sensed along the gut and communicated to the brain via the vagus nerve, providing a better understanding of the gut-brain neural circuitry.

Khalil Ramadi, Ph.D., New York University

Dr. Ramadi is an assistant professor of bioengineering at New York University, with joint appointments across the New York and Abu Dhabi global campuses. Dr. Ramadi is director of the Laboratory for Advanced Neuroengineering and Translational Medicine. Dr. Ramadi's research centers on enhancing technologies that can solve clinical problems and advance human health. His lab works on various ingestible pills and implantable devices for drug delivery and neural/hormonal modulation. This work has implications for treatment of gastrointestinal, neurologic, and metabolic disorders. Beyond the bench, Dr. Ramadi also leads research on health entrepreneurship and medical innovations. He is a board member and former co-director of MIT Hacking Medicine, a group dedicated to enabling multidisciplinary health entrepreneurship worldwide. Prior to his faculty appointment, Dr. Ramadi was a National Institutes of Health Ruth L. Kirschstein F32 postdoctoral fellow at the Massachusetts Institute of Technology (MIT) and Brigham and Women's Hospital. Dr. Ramadi obtained his Ph.D. in biomedical engineering and medical physics at MIT and Harvard Medical School and has been named a TED Junior Fellow, MIT Technology Review Innovator Under 35 (MENA), CIFAR Azrieli Global Scholar, MIT Sandbox Innovation Fellow, and Koch Convergence Scholar. He has received multiple honors, including the Biomedical Engineering Society Career Development Award, Materials Research Society Graduate Student Award, MIT IDEAS Global Challenge Award, and a NASA Aeronautics Scholarship.

Neuromodulation Devices That You Can Eat

Bidirectional gut-brain pathways can be leveraged for neuromodulation. The gut is unique among organs in offering the ability to target neural afferents with high spatial selectivity in a noninvasive manner. An ingestible electronic device was developed for gastric neural/hormonal modulation through electrical stimulation. The bio-inspired surface design of the capsule enabled effective mucosal engagement and stimulation despite the presence of mucus and gastric juices by wicking fluid away from the electrode-mucosal interface through hydrophilic surface grooves. It was shown how this ingestible electroceutical can modulate systemic levels of neurohormones in a vagal-dependent manner without necessitating wireless power transfer or communication. In large animal models, the effects of mucosal electrical stimulation were directly controlled by varying electrical stimulation parameters. Devices were ingested and safely excreted by large animals without breaking apart and with causing no adverse effects. Similar ingestible electroceutical platforms could be used for noninvasive modulation of other neural circuits within the gastrointestinal tract.

Michael Cardenas, B.S., University of Arizona

Michael Cardenas, B.S., is a fourth-year graduate student in the Gothard laboratory at the University of Arizona. His doctoral project on interoception is informed by his undergraduate training combining physiology and neuroscience. Cardenas is interested in understanding the mechanisms by which internal states arise and how these states lead to shifts in the behavior of an organism. The main goal of his project is to determine how interoceptive signals bias the neural mechanisms of decision making. Outside of his research, Cardenas is involved in developing an educational curriculum designed to teach neurobiology to students ranging from grades 1 to 12 in a collaboration with a Tucson-based nonprofit.

Interoception Biases Decision Making on an Approach-Avoidance Conflict Task

Real-life decision making often relies on the evaluation of multiple conflicting factors. In such cases, choices reflect the tradeoff between the motivation to approach appetitive stimuli and avoid aversive stimuli. Both internal and external variables can alter how an organism weighs costs and benefits. However, the contribution of interoceptive signals to approach-avoidance decision making beyond the communication of homeostatic needs is unknown. It is hypothesized that behavior on an approach-avoidance conflict task would shift toward avoidance when the visceral state is dominated by sympathetic tone. To test this hypothesis, rhesus monkeys performed an approach-avoidance conflict task after being administered glycopyrrolate, a parasympatholytic drug that does not cross the blood-brain barrier. In all three animals tested, glycopyrrolate increased avoidance behavior, indicating that a sympathetic-dominated visceral state, communicated through interoceptive afferents, is sufficient to modify the behavioral agenda of the animals. This finding supports the somatic error hypothesis of anxiety and lays the groundwork for neurophysiological studies that will assess the neural mechanisms by which interoceptive signals can bias decision making.

Senegal Alfred Mabry, B.A., M.P.A., Cornell University

Senegal Alfred Mabry, B.A., M.P.A., is a third-year Ph.D. student in the neuroscience area of the Department of Psychology and Human Development at Cornell University. Mabry is working on better characterizing the heart-brain axis in Parkinson's disease by using magnetic resonance imaging, investigating differences in heart-based interoception in Parkinson's disease, and exploring how mind-body interventions like exercise training improve Parkinson's disease symptoms through engaging the autonomic nervous system. Mabry is an alum of the Summer Program for Neuroscience Excellence and Success at the Marine Biological Laboratory at Woods Hole, an alum of the University of Wisconsin Health Minds Center Summer Well-being Workshop, and a Society for Neuroscience associate. Mabry is the graduate student advisor of the Cornell University chapter of Parkinson's Pals, an organization partnered with the Davis Phinney Foundation to connect people with Parkinson's disease to undergraduates for social interaction and support. He is also the Community Neuroscience Initiative Graduate Research Fellow at Cornell

University, working to democratize neuroscience through education and health programs, and he is an Obama Foundation My Brother's Keeper Alliance Advisory Council Member.

Differences in Functional Connections and Impairments in Heart-Based Interoception in Parkinson's During Stress and Exercise

Parkinson's disease (PD) is the second most common neurodegenerative disease globally and the fastest rising one. While the cardinal symptoms of PD are worsening voluntary motor function and cell death in the dopamine-producing substantia nigra, symptoms begin earlier with invisible autonomic visceromotor changes and widespread denervation of the heart, which can occur years before brain changes but require specialized positron emission tomography (PET) imaging to detect reliably. In this study, 20 people (10 with PD, 10 age-sex matched healthy controls) performed a social evaluative threat task while photoplethysmogram (PPG) data and resting-state functional magnetic resonance imaging (fMRI) scans were collected. Participants reported changes in their perceived stress and ability to feel their heart-based interoceptive signals during the task's baseline, stress, and recovery periods. Then, participants with PD participating in a twice-a-week high-intensity cardiopulmonary exercise intervention to improve their motor-gait symptoms rated their perceived level of exertion and how strongly they could feel their heartbeat before, during, and after each training session. Preliminary data from the stress task show that participants living with PD perceive stress from the task at the same level as their healthy controls; however, they cannot feel their heartbeat during the baseline, stress, and recovery periods despite recorded PPG increases after the stress period. It is hypothesized that differences exist in substantia nigra resting-state fMRI connections to and stress processing regions interest between the healthy and PD groups during the stress task. It is also hypothesized that participants living with PD will not report changes in their interoceptive awareness before, during, and after their twice-weekly high-intensity exercise sessions.

Le Zhang, Ph.D., Yale University

Dr. Zhang is an assistant professor of neurology and neuroscience at Yale University School of Medicine. Dr. Zhang's research focuses on the immune responses of the central nervous system and neuro-immune interactions in neurodegenerative diseases, particularly gut-brain interactions in Parkinson's disease, using cutting-edge single-cell technologies. Dr. Zhang received her bachelor's degree in biological science from Peking University and her Ph.D. degree from the University of Hong Kong in molecular biology and biochemistry. Dr. Zhang did her postdoctoral trainings at the University of Pennsylvania School of Medicine and Harvard Medical School in epigenetics. Prior to joining Yale University, she was a scientist at Pfizer in the Neuroscience and Pain Research Unit, overseeing the Next Generation Sequencing Technology Center.

Neuro-Immune Interactions and Interoception in Prodromal Parkinson's Disease

Rapid eye movement (REM) sleep behavior disorder (RBD) is a preclinical state to Parkinson's disease (PD) or other synucleinopathy. It is hypothesized that progression of RBD and PD pathology is initiated by an autoimmune process involving α-synuclein-specific T cell activation triggered by gut microbiome dysbiosis, followed by neuroimmune interactions through interoception that establish PD pathology in the brain. This hypothesis was addressed by integrating neuroimmunology, single-

cell genomics, and microbiome approaches in patients with RBD and PD. From single-cell analysis of paired blood and cerebrospinal fluid (CSF) cells, over 600,000 immune cells were profiled from healthy controls and patients, and the first human single-cell CSF atlas of RBD and PD was generated. Characterization of 36,000 CSF myeloid cells revealed significant cell type proportion changes with increased CSF-specific monocytes in RBD and PD and enriched tumor necrosis factor (TNF) signaling pathways. CSF changes in RBD were compared to those in multiple sclerosis (MS), and, strikingly, decreases in TNF pathways were found in MS. This suggested a potential use of anti-TNF therapy in preventing PD, given that TNF inhibitors worsen MS and epidemiology data show anti-TNF lowers PD risk in inflammatory bowel disease. To characterize immune cells from the gastrointestinal mucosa and to compare their functional profile to immune cells from other anatomic niches, colonoscopy and gut tissue biopsy from human donors were performed. Comparing blood, CSF, and gut immune populations will reveal underlying mechanisms of immune regulation in the disease and determine the role of the gut-brain axis in regulating immune responses in RBD and PD.

Jose L. Herrero Rubio, Ph.D., Feinstein Institutes for Medical Research

Dr. Herrero, assistant professor in neuroscience and psychology at the Feinstein Institutes for Medical Research in New York, received his Ph.D. in neuroscience and pharmacology from Newcastle University (United Kingdom). As a 2022 RO1 recipient, Dr. Herrero's current research investigates the neural components of interoception with a focus on respiroception—how abnormalities in respiratory-related neural processing can lead to clinical conditions such as dyspnea (persistent breathlessness), anxiety, cardiovascular disease, and hyperexcitability of cortical networks. Dr. Herrero assists in the surgical management of patients with intractable epilepsy in the Laboratory of Human Brain Mapping and Institute of Bioelectronic Medicine. Prior to joining the Feinstein Institutes for Medical Research, Dr. Herrero did his postdoctoral training in macaque electrophysiology at Columbia University.

Persistent Dyspnea: Insights From Invasive Human Recordings of Respiratory Related Brain Oscillations During Respiratory Challenges

In the past 3 years, the world has experienced rapid and unforeseen changes. One important change has been the astonishing increase in the incidence of respiratory diseases, ranging from acute (e.g., COVID-19 acute respiratory distress syndrome) to more chronic syndromes related to higher levels of pollutants/allergens (i.e., asthma, chronic obstructive pulmonary disease) and other factors (i.e., long-term COVID, obesity, opioid-induced respiratory depression). This has shaped the way in which people relate to their own breathing sensations and, consequently, the way the brain processes these ascending respiratory signals. To evaluate this, respiratory-related brain oscillations (RRBOs) were recorded in five epilepsy patients implanted with intracranial electrodes (iEEG) in cortical and subcortical areas during a task that induced dyspnea (breathlessness). The preliminary findings revealed new insights into the brain's response to respiratory challenges. When the airways were partially obstructed by the experimental loads, increased respiratory responses—RRBOs—were observed in the lateral olfactory and posterior cingulate cortices. On the other hand, the sensorimotor cortex exhibited comparable increases during both load and nonload trials. These

observations indicate that the sensorimotor cortex may play a pivotal role in monitoring the current behavioral state (“Am I breathing now?”), while the olfactory and cingulate cortices may encode the current effort (“How hard is it to breathe now?”). These results align with previous noninvasive studies that identified dyspnea-related signals in the motor and cingulate cortices. Moreover, the findings suggest that distinct brain areas are engaged in the motor awareness versus the effort associated with breathing. This nuanced understanding of how different cortical regions process respiratory sensations holds significant implications for comprehending the underlying mechanisms and management of breathlessness.

Session Two: Technology, Translation, and Reverse Translation in Interoception Research

Moderator: Todd Horowitz, Ph.D., National Cancer Institute

Dr. Horowitz is a program director in the Behavioral Research Program's Basic Biobehavioral and Psychological Sciences Branch, located in the Division of Cancer Control and Population Sciences at the National Cancer Institute (NCI). Prior to joining NCI, he was an assistant professor of Ophthalmology at Harvard Medical School and associate director of the Visual Attention Laboratory at Brigham and Women's Hospital. Dr. Horowitz's research interests include attention, perception, medical image interpretation, cancer-related cognitive impairments, sleep, and circadian rhythms. Dr. Horowitz received his doctorate in cognitive psychology at the University of California, Berkley. He has published more than 70 peer-reviewed research papers in vision science and cognitive psychology.

Moderator: Olujimi Ajijola, M.D., Ph.D., University of California, Los Angeles

Dr. Ajijola is the associate director of the Cardiac Arrhythmia Center and Electrophysiology programs at the University of California, Los Angeles (UCLA). He also directs the Neurocardiology Research program at UCLA and co-directs the National Institutes of Health (NIH)-funded UCLA-Caltech Medical Scientist Training program. Dr. Ajijola is interested in novel approaches for cardiac arrhythmias, and he performs invasive cardiac electrophysiological procedures. His research interests revolve around peripheral neural circuits that control cardiac function in health and disease, including neural interventions that alleviate progressive cardiac dysfunction and arrhythmias. Dr. Ajijola completed his undergraduate studies at the University of Virginia and received his medical degree from Duke University. He went on to the Massachusetts General Hospital for residency training in internal medicine and completed clinical fellowships in cardiovascular medicine and cardiac electrophysiology at UCLA. Dr. Ajijola received his doctorate in molecular, cellular, and integrative physiology at UCLA as part of the Specialty Training and Advanced Research (STAR) program. Dr. Ajijola is the recipient of the NIH Director's New Innovator Award, the Jeremiah Stamler Cardiovascular Research Award, an A.P. Giannini Foundation post-doctoral award, and a Young Physician Scientist Award from the American Society for Clinical Investigation. He is a member of the New Voices program of the National Academies of Science, Engineering, and Medicine.

Karl Deisseroth, M.D., Ph.D., Stanford University

Dr. Deisseroth is the D.H. Chen Professor of Bioengineering and of Psychiatry and Behavioral Sciences at Stanford University, an investigator at the Howard Hughes Medical Institute, and a practicing psychiatrist at Stanford with specialization in major depression and autism spectrum disorder, employing medications along with neural stimulation. His laboratory has developed optogenetics, hydrogel-tissue chemistry, and other tools for single-cell control and for the investigation of intact biological systems; and his laboratory is known for discovering the high-resolution structural principles of light-gated ion conduction. Dr. Deisseroth received his undergraduate degree from Harvard University and his doctorate and medical degrees from Stanford University. He also completed postdoctoral training, a medical internship, and adult psychiatry residency at Stanford University. Dr. Deisseroth is board certified by the American Board of Psychiatry and Neurology.

From Microbial Membrane Proteins to the Heart-Brain Connection

ChRmine is the paradigmatic member of the pump-like channelrhodopsin family with properties of monovalent-cation selectivity, unusually large photocurrents, exceptional red-shift, and extreme light-sensitivity. ChRmine has opened up new opportunities in optogenetics, including the control of specific mammalian perceptions at single-cell resolution and the use of noninvasive light delivery to study body-wide cellular communication, revealing a long-hypothesized, body-to-brain axis for eliciting emotions. Resolving the structure of a further-selective member of the pump-like ChR group (the KCR/potassium-selective ChR) required an understanding of its potential as an inhibitory tool for optogenetics while broadly posing the fundamental mystery of how K^+ selectivity can be achieved. The resulting design of a new KCR with increased K^+ selectivity (KALI) has provided key new advantages for in vivo optogenetics research. This talk will summarize emerging insights on the structural resolution of natural proteins in relation to the development and application of brain-wide recording approaches. These insights have led to a deeper understanding of the conserved and ancestral survival drives in animals, including thirst and hunger, which can be perceived even at the fundamental level of single-cell resolution and the highest-level integrative functions of the brain, which can be perceived across both the brain and body. These findings support a heart-to-brain axis of communication that is precisely and causally relevant to setting internal affective/emotional states.

Sahib Khalsa, M.D., Ph.D., Laureate Institute for Brain Research

Dr. Khalsa is the director of clinical operations at the Laureate Institute for Brain Research in Tulsa, Oklahoma, and an associate professor in the Oxley College of Health Sciences at the University of Tulsa. His work as a physician-scientist aims to delineate how interoception influences mental and physical health, using innovative physiological probes to study heart-brain and gut-brain communication. Dr. Khalsa aims to discover modifiable neuroscience-based targets to improve the treatment of psychiatric disorders, like anxiety and eating disorders, as well as medical conditions affecting the gastrointestinal and cardiovascular systems.

Dr. Khalsa received his medical and doctorate degrees in neuroscience from the University of Iowa and completed his residency training in psychiatry at the University of California, Los Angeles (UCLA). He served as the program chief resident and chief resident in the Anxiety Disorders Program at UCLA.

Perturbing the Rhythms Within: Cardiorespiratory and Gastrointestinal Insights Into Psychiatric Disorders

Interoception is crucial for human health. It serves as the afferent limb of the brain-body feedback loop, linking internal sensations with body regulation, minimizing erroneous feedback, and maintaining homeostasis. Emerging data highlight the critical role of disrupted interoception in manifesting symptoms across various psychiatric disorders, opening avenues for targeted therapeutic interventions. This talk will spotlight noteworthy advances in understanding how the nervous system interprets signals from the cardiorespiratory and gastrointestinal systems, using pharmacologic modulation of peripheral adrenergic receptors and nonpharmacologic modulation of gut mechanosensation, respectively. Key intersections with nonhuman animal work will be emphasized, and nonpharmacologic therapeutic findings relevant to interoceptive treatments for anxiety and eating disorders will be delineated. The central proposition is that manipulating peripheral organ signals can illuminate how interoceptive circuits influence symptom perception in psychiatric disorders. In summary, studies on interoceptive perturbation are enriching our grasp of the neural circuits of interoception and laying groundwork that holds promise for tailored approaches to psychiatric treatment.

Todd Coleman, Ph.D., Stanford University

Dr. Coleman is the Yu Family Faculty Scholar in the School of Engineering and an associate professor in the Department of Bioengineering at Stanford University. He previously held faculty positions in electrical and computer engineering and in neuroscience at the University of Illinois, as well as in bioengineering at the University of California, San Diego. Dr. Coleman's research spans from developing fundamental information theory and machine learning techniques to developing technologies to monitor and modulate the physiology of nervous systems in the brain and visceral organs. His multidisciplinary research uses tools from applied probability, physiology, and bioelectronics. Dr. Coleman received his bachelor's degrees in electrical engineering *(summa cum laude)* and computer engineering *(summa cum laude)* from the University of Michigan. He received his master's and doctorate degrees in electrical engineering from the Massachusetts Institute of Technology (MIT) and completed postdoctoral studies in neuroscience at MIT. Dr. Coleman has been selected as a National Academy of Engineering Gilbreth lecturer, a fellow of the Institute of Electrical and Electronics Engineers (IEEE), and a fellow of the American Institute for Medical and Biological Engineering. He is currently the chair of the National Academies Standing Committee on Biotechnology Capabilities and National Security Needs.

Advancing Methods and Technologies To Monitor and Modulate Couplings Between the Human Brain and Stomach

This talk will present novel methodologies and technologies to measure, understand, and modulate the interorgan network comprising the stomach and brain. The dysregulation of this network in

disease will be discussed, and an overview will be provided on the development of stretchable adhesive–integrated devices placed on the human abdomen. This development shows that features of strength and regulation can be uncovered related to the autonomic nervous system during sleep and its regulation of gastric meal responses. In addition, this talk will highlight a novel, inductively powered, gastric pacing technology that can modulate the slow wave patterns of the stomach. Given its anatomical connection with the brain, this technology may have the potential to modulate brain function.

Dana Small, Ph.D., McGill University/Yale School of Medicine

Dr. Small is a psychologist and neuroscientist who, following a faculty role at Yale from 2004 to 2023, is currently transitioning her lab to McGill University to launch and direct a new program in brain and metabolism. In 2023, she was selected as a Canadian Excellence in Research chair, prompting this transition. Dr. Small's research focuses on understanding how sensory, metabolic, and neural signals are integrated to determine food choices and how the dysregulation of these systems contributes to the development of obesity, diabetes, and cognitive impairment. Dr. Small received her degrees from McGill and Yale Universities. She has served as a standing member of the Human Studies of Diabetes and Obesity (formerly the Clinical and Integrative Diabetes and Obesity) study section and on the executive boards of the Association for Chemoreception Sciences (AChemS) as secretary and program chair and the Society for the Study of Ingestive Behavior as program chair and president. Dr. Small has also served two terms as a member of the National Academy of Sciences Board on Behavior, Cognitive, and Sensory Sciences.

Translating Gut-Derived Reinforcement

Rodent work has shown that when lipids bind to receptors in the upper intestine, a reinforcing signal is generated that ascends to the brain via the vagus nerve to release dopamine. This pathway can be blunted by habitual intake of high-fat food, and this is associated with reduced dopamine release and shifting preference away from low-fat foods. Administration of oleoylethanolamide (OEA), a lipid messenger that is depleted by high fat diet, reverses these effects, suggesting a new gut-brain therapeutic target for weight loss. An overview will be provided on the evidence that suggests these effects can translate to benefit humans. First, there is evidence for dopamine signaling of post-oral reinforcement. Second, a short-term high-fat dietary intervention decreases preference for low-fat foods and enhances responses to food cues and prediction error coding, indicative of altered dopamine signaling. Third, OEA administration improves weight loss outcomes on a behavioral weight loss intervention, but only in individuals who are habitual consumers of a high-fat diet. These findings support the translation of a lipid-sensing gut-derived reinforcing pathway from mice to humans.

Sarah Garfinkel, Ph.D., University College London

Dr. Garfinkel is a professor at the Institute of Cognitive Neuroscience, University College London (UCL), where she leads the Clinical and Affective Neuroscience Group. Dr. Garfinkel's research focuses on brain-body interactions underlying emotion and cognition in clinical and neurodevelopmental groups, with a particular focus on the heart. Dr. Garfinkel received her doctorate in experimental psychology at the University of Sussex before undertaking a fellowship in psychiatry and neuroscience at the University of Michigan. At the Brighton and Sussex Medical School, she underwent further training in autonomic neuroscience before establishing her lab at UCL. Dr. Garfinkel was named a "Rising Star" by *Nature* in 2018, and she was awarded the Mid-Career Prize by the British Association for Cognitive Neuroscience in 2021.

Cardiac Interoceptive Training Enhances Insula Connectivity and Reduces Anxiety

Cognitive and emotional processes are shaped by the dynamic integration of brain and body. Interoception can be delineated across different hierarchical levels, including the nature of afferent signals, their neural processing, and the accuracy with which they can be detected. Precision into bodily signals can aid the regulation of emotions, and anxiety has been associated with interoceptive error. Two experiments, including a randomized superiority clinical trial, demonstrated that cardiac interoceptive training can enhance interoceptive accuracy and significantly reduce anxiety in both neurotypical and autistic individuals. Reductions in anxiety were maintained after 1 year. Increases in interoceptive accuracy were associated with enhanced insula connectivity with the agenesis of the corpus callosum (ACC) and the ventromedial prefrontal cortex (vmPFC). Together, these results suggest that trait interoceptive accuracy is malleable, with observable changes in insula connectivity and clinically meaningful reductions in anxiety. Novel therapeutic approaches that target interoceptive mechanisms offer promise for the treatment of mental health conditions.

Session Three: Brain–Multiorgan System Connections

Moderator: Julia Berzhanskaya, Ph.D., National Heart, Lung, and Blood Institute

Dr. Berzhanskaya is a health scientist administrator in the Innovation and Commercialization Office at the National Heart, Lung, and Blood Institute (NHLBI). She is a program officer for the National Institutes of Health (NIH)-wide Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) Phase 0 program (for Research Evaluation and Commercialization Hubs and NIH Centers for Accelerated Innovations) and is the lead innovator support for NHLBI's Office of Translational Alliances and Coordination. Before joining NHLBI, she was a SBIR/STTR program officer at the National Institute on Drug Abuse, program officer for the biomedical facilities program at the NIH Office of the Director, and scientific review officer. Dr. Berzhanskaya has contributed to several NIH-wide initiatives, including the Helping to End Addiction Long-term® Initiative, or NIH HEAL Initiative®; the Brain Research Through Advancing Innovative Neurotechnologies (BRAIN) Initiative; the Stimulating Peripheral Activity to Relieve Conditions (SPARC) program; the Maternal Morbidity and Mortality Web Portal; and the Diversifying the Entrepreneurial Workforce group. Before joining NIH, she conducted research in neuroprosthetics, computational modeling of complex systems, big data, and translational science. She earned her master's degree in neuroscience from the University of Pittsburgh and her doctorate in cognitive and neural systems (neural networks) from Boston University.

Moderator: Mark L. Andermann, Ph.D., Beth Israel Deaconess Medical Center, Harvard Medical School

Dr. Andermann is a professor of medicine in the Division of Endocrinology, Diabetes, and Metabolism for the Beth Israel Deaconess Medical Center at Harvard Medical School. His laboratory seeks to understand how the brain senses the needs of the body and manages competing motivational drives, including the drives to seek food, water, mates, and safety, and how these drives determine the contents of our imagery and our exteroceptive and interoceptive attentional focus. To achieve these goals, his laboratory employs cellular and subcellular imaging methods to track brain cell activity in the brainstem, thalamus, cortex, amygdala, and hypothalamus of mice across weeks as they seek food, water, mates, or safety. Dr. Andermann received his undergraduate training in mathematics and physics at McGill University. His doctoral training at the Massachusetts Institute of Technology and Harvard University focused on functional maps in the barrel cortex and trigeminal ganglion of rats. He conducted his postdoctoral training at the Helsinki University of Technology, where he used noninvasive brain-computer interfaces to study selective auditory attention in humans. He completed a second postdoctoral fellowship at Harvard Medical School,

where he used cellular imaging methods to develop new tools for studying the neural basis of visual perception in behaving mice.

Ardem Patapoutian, Ph.D., Scripps Research and Howard Hughes Medical Institute

Dr. Patapoutian is a molecular biologist and physiologist, the Presidential Endowed Chair in Neurobiology, and a professor in the Department of Neuroscience at Scripps Research. He is also an investigator for the Howard Hughes Medical Institute. His laboratory identified the molecules that sense temperature and pressure and are involved in touch, pain, and regulating blood pressure. Dr. Patapoutian was born in Lebanon in 1967 and immigrated to the United States in 1986. He received his bachelor's degree from the University of California, Los Angeles, in 1990 and received his doctorate from Caltech in 1996. He joined the faculty of Scripps Research in 2000. He is a member of the National Academy of Sciences (2017) and a member of American Academy of Arts and Sciences (2020). He is co-recipient of the 2020 Kavli Prize in Neuroscience, the 2021 BBVA Foundation Frontiers of Knowledge Award, and the 2021 Nobel Prize in Physiology or Medicine (all shared with David Julius).

Role of PIEZO2 in Interoception

Mechanotransduction was perhaps the last major sensory modality not understood at the molecular level. Proteins and ion channels that sense mechanical force are postulated to play critical roles in sensing touch and pain (somatosensation), sound (hearing), and shear stress (cardiovascular function), among others. However, the identity of the ion channels involved in sensing mechanical force remained elusive. The Patapoutian laboratory identified PIEZO1 and PIEZO2, mechanically activated cation channels that are expressed in many mechanosensitive cell types. Genetic studies established that PIEZO2 is the principal mechanical transducer for touch, proprioception, baroreception, and bladder and lung stretch, and that PIEZO1 mediates blood-flow sensing, which impacts vascular development and iron homeostasis. Clinical investigations have confirmed the importance of these channels in human physiology.

Julie G. Pilitsis, M.D., Ph.D., M.B.A., Florida Atlantic University Schmidt College of Medicine

Dr. Pilitsis is the vice president for medical and strategic initiatives at Florida Atlantic University (FAU). Under her stewardship, the FAU Health Network promotes premium academic health care while addressing medical workforce shortages. Dr. Pilitsis' compassionate care for patients permeates to the community, where she continues to tackle complex health challenges and create meaningful change. Previously, she was dean of the Schmidt College of Medicine at FAU, where she was the first woman neurosurgeon to become a dean. During her tenure, Dr. Pilitsis raised $42 million in philanthropy, increased the medical student class size and graduate medical education fellowships and rotations, and launched the first co-branded academic medical center and faculty practice for FAU. Dr. Pilitsis

continues to practice neurosurgery and run her laboratory, which has received three grants from the National Institutes of Health and has 25 learners. She is an international expert in multidisciplinary pain and movement disorders, including Parkinson's disease, and serves as the current president of the North American Neuromodulation Society. She is also president-elect of the American Society for Stereotactic and Functional Neurosurgery. Before joining FAU, Dr. Pilitsis was a division chief of functional neurosurgery, chair, and professor at Albany Medical College.

Modulation of Spinal Pathways Involved in Interoception in Patients With Chronic Pain

The autonomic nervous system is well-known to be involved in interoception. The role of the somatic nervous system, particularly through spinal pathways, is less clear. Alterations that occur in chronic pain disease states compound the understanding of that role. Further, the tridimensional aspects of pain that occur in rodent models and those experienced by humans are likely to differ. This research has demonstrated how modulation of the dorsal root ganglia (DRG) and dorsal columns in a swine model and in humans influenced pain behavior and brain electrophysiology. Specifically, low-intensity, focused ultrasound was used to show modulation of the DRG in a neuropathic swine model. In addition, high-resolution electroencephalography was used to show the effects of spinal cord stimulation on pain processing in humans. Ongoing research will show how spinal cord stimulation and evoked motor potentials elicited in the lower extremities can be used to create a somatotopy of the dorsal thoracic spinal cord. The techniques, advantages, and disadvantages of studying interoception in humans will be discussed.

John Osborn, Ph.D., University of Minnesota

Dr. Osborn is a professor of surgery at the University of Minnesota and director of the Minnesota Consortium for Autonomic Neuromodulation, which is leading the National Institutes of Health–funded Research Evaluating Vagal Excitation and Anatomical Links (REVEAL) study, a seven-center global study on the effects of vagal nerve stimulation on physiological systems in human subjects. His current focus is translational studies on the role of renal interoception in the regulation of body fluid balance and on arterial pressure in health and disease. This focus was motivated by clinical trials that used medical devices to target renal sympathetic ablation in humans. He received his doctorate in physiology from the Medical College of Wisconsin, where he studied hormonal-neural interactions in hypertension. He conducted his postdoctoral fellowship in biomedical engineering at the Johns Hopkins School of Medicine, where he studied the mechanisms of autonomic hyperreflexia in spinal cord injury. Dr. Osborn then joined the faculty of the University of Minnesota, where he has focused on the relationship between the autonomic nervous system and cardiometabolic diseases.

Research Evaluating Vagal Excitation and Anatomical Links (REVEAL) in Humans

The activation or blockade of the vagus nerve produces central and peripheral multiorgan physiological responses. Cervical vagus nerve stimulation (VNS) through an implant is clinically approved for treating epilepsy and depression and for poststroke recovery. Yet, despite more than 100,000 patients receiving treatment with VNS and numerous studies in various animal models, the physiological effects on peripheral organs in humans remains poorly understood. The REVEAL study

aims to conduct groundbreaking research on the effect of VNS on four key systems: autonomic nervous, cardiovascular, immune, and metabolic. The response of these systems to both acute (minutes) and chronic (months) VNS will be studied in 144 participants already being treated for treatment-resistant depression or drug-resistant epilepsy. A subset of participants will receive an implant that will deliver VNS. Functional magnetic resonance imaging (fMRI) of the brain will be conducted before and after implantation and during VNS. Imaging of moment-activation responses to VNS will be used to ascertain whether upstream central nervous system modulation is key to changes observed in the peripheral organ systems. Interleaved fMRI will act as a window to the direct, in-the-moment effects of VNS on brain activity and interoceptive processes. Cutting-edge precision functional mapping will reliably map the multimodal networks involved in interoception and allostasis. Improved understanding of the bidirectional role of vagus nerve mediation of central and peripheral change will ultimately support a new Common Fund initiative that will examine bidirectional body and mind interactions to achieve optimal well-being.

Rui Chang, Ph.D., Yale School of Medicine

Dr. Chang is an assistant professor of neuroscience and cellular and molecular physiology at Yale School of Medicine. His laboratory uses state-of-the-art molecular, genetic, and imaging approaches that reveal the physiologic functions of diverse organ-to-brain circuits to better understand the body-brain interface and to develop novel, neuron-based therapeutic strategies for disease intervention. Dr. Chang received his bachelor's degree in biological sciences and biotechnology from Tsinghua University, China. He studied sensory transduction with Emily Liman and earned his doctorate in neuroscience at the University of Southern California. He completed his postdoctoral training with Stephen Liberles at Harvard Medical School, where he investigated body sensory cues that are monitored by the brain through the vagus nerve. He examined how those internal signals regulate whole-body physiology. In 2018, he joined the departments of neuroscience and cellular and molecular physiology at Yale School of Medicine.

The Coding Logic of Interoception in the Vagus Nerve

Interoception, the ability to timely and precisely sense changes inside the body, is critical for survival. Vagal sensory neurons (VSNs) form an important body-to-brain connection, navigating visceral organs along the body's rostral-caudal axis and diving across the organ's surface-lumen axis into appropriate tissue layers. The brain can discriminate numerous body signals through VSNs, yet the underlying coding strategy remains poorly understood. This research aimed to understand the coding architecture of the vagal interoceptive system. Multiple state-of-the-art technologies were developed, including unique projection barcodes composed of exogenous nucleotide sequences (Projection-seq) and vagal calcium imaging-transformed fluorescence in situ hybridization (vCatFISH), to precisely determine neuronal identity based on innervations and response patterns. The research demonstrated that VSNs code visceral organs, tissue layers, and stimulus modality—key features of interoceptive signaling—in different dimensions. Multiplexed projection barcodes were used to profile large-scale, single VSN cells from seven major organs and revealed a "visceral organ" dimension of differentially expressed gene modules that coded organs along the body's rostral-caudal axis. Another "tissue layer" dimension with gene modules coded

VSN-ending locations along the organ's surface-lumen axis. Calcium imaging was used to guide spatial transcriptomics, which showed that VSNs were organized in functional units that sensed similar stimuli across organs and tissue layers, constituting a third "stimulus modality" dimension. Together, the three independent, feature-coding dimensions specified many parallel VSN pathways that combine to facilitate complex VSN projection in the brainstem. This research highlights a novel multidimensional coding architecture of the mammalian vagal interoceptive system for effective signal communication.

Richard Lang, Ph.D., Cincinnati Children's Hospital Medical Center

Dr. Lang is the Emma and Irving Goldman Scholar Endowed Chair in the Division of Pediatric Ophthalmology, director of the Visual Systems Group, and codirector of the newly established Science of Light Center at the Cincinnati Children's Hospital Medical Center. His scientific interests include early eye development, the role of myeloid cells in development, vascular development, and the role of light responses in mammalian physiology. These programs are supported by funding from the National Institutes of Health and the Emma and Irving Goldman Scholar endowment. Previously, Dr. Lang was an associate professor at the Skirball Institute of New York University Medical Center. He received his bachelor's degree and doctorate from the University of Melbourne and the Ludwig Institute for Cancer Research. In 1989, he moved to the University of California, San Francisco, for postdoctoral training with Nobel laureate Dr. J. Michael Bishop. Over the years of his career, Dr. Lang has received numerous awards, including a Searle scholarship and the Research to Prevent Blindness Lew R. Wasserman Merit Award, and was a Sackler lecturer for the Mortimer and Raymond Sackler Institute of Advanced Studies at Tel Aviv University.

Extraocular Light Sensing Via the Opsin GPCRs OPN3 and OPN5 Regulates Energy Homeostasis

The availability of photons from the sun has created opportunities for evolution to generate adaptive, light-sensing mechanisms. The obvious examples are the visual system, which allows object identification through decoding of radiant photons, and the circadian system, where physiologic rhythmicity can be entrained by light detection in the eyes. The Lang laboratory has been interested in the possibility of extraocular light-sensing pathways in mammals and has been investigating encephalopsin (OPN3) and neuropsin (OPN5). Recent analysis has shown that both opsins mediate extraocular light sensing in mice. OPN5, a violet-sensitive opsin (with a lambda max of 380 nm) is expressed in preoptic area neurons that function as deep-brain photoreceptors. OPN3 is found in white adipocytes that directly respond to violet-blue photons (at about 430 nm). These two light-sensing tissues function in a regulatory circuit that controls many metabolic parameters, including body temperature. Light stimulation of preoptic area OPN5 neurons downregulates sympathetic nervous system output to brown adipose tissues and thus suppresses body temperature. In contrast, blue-light stimulation of white adipocytes promotes an increase in body temperature by enhancing the lipolysis pathway and the production of free fatty acids used as heating fuel. These and other light-sensing pathways mediated by OPN3 and OPN5 are called "sun-coupled" physiology.

Travel Awardees

Osama Harraz, Ph.D., University of Vermont

Dr. Harraz is an assistant professor of pharmacology and a Bloomfield Early Career professor of cardiovascular research. His research focuses on blood flow regulation in health and disease with a particular interest in understanding mechanical interoception in the brain vasculature and the changes associated with vascular and neurodegenerative diseases as well as aging. His previous research involved the discovery of a phospholipid regulator of capillary signaling and brain blood flow control. Dr. Harraz received his bachelor's and master's degrees from Alexandria University in Egypt. He received a doctorate degree from the University of Calgary as a recipient of the prestigious Vanier Canada Graduate Scholarship. His research is supported by the National Heart, Lung, and Blood Institute, the National Institute on Aging, the Bloomfield Endowed Professorship by the Cardiovascular Research Institute of Vermont, and the Totman Medical Research Trust. Dr. Harraz serves on study sections at the National Institutes of Health and the American Heart Association and on the editorial board of *Physiological Reviews* at the American Physiological Society.

Kasey Jackman, Ph.D., Columbia University

Dr. Jackman is an assistant professor at the Columbia University School of Nursing and a nurse scientist at New York-Presbyterian Hospital. Dr. Jackman is also a board-certified psychiatric nurse practitioner with almost two decades of clinical experience in various mental health treatment settings, including inpatient, outpatient, and partial hospital programs. Dr. Jackman's research focuses on the mental health of sexual and gender minority populations with a special interest in identifying mechanisms that contribute to mental health disparities and developing tailored interventions to reduce these disparities. Dr. Jackman conducted previous research on the knowledge, attitudes, and preparedness of health care providers caring for LGBTQI+ patients in alignment with a goal to improve clinical care for this population. Dr. Jackman's research has been published in impactful, peer-reviewed journals, including *Nursing Outlook,* the *Journal of Counseling Psychology,* and *LGBT Health*. Dr. Jackman received a doctorate degree in nursing, a master's degree in psychiatric mental health nursing, and a bachelor's degree in nursing at Columbia University. Dr. Jackman's postdoctoral training focused on reducing health disparities through informatics. Dr. Jackman co-founded and co-leads the research interest group focused on LGBTQI+ health and health disparities at the Eastern Nursing Research Society.

Truong Ly, B.S., M.S., University of California, San Francisco

Mr. Ly is a doctoral student studying neuroscience at the University of California, San Francisco (UCSF). He conducts research on how the caudal brainstem processes ingestive feedback to control feeding behavior in the lab of Dr. Zachary Knight in the Department of Physiology at UCSF. He remains broadly interested in studying the neurobiology of homeostasis. Mr. Ly received his bachelor's and master's degrees in physiological science at the University of California, Los Angeles.

Atharva Sahasrabudhe, B.S., M.S., Massachusetts Institute of Technology

Mr. Sahasrabudhe is a doctoral student studying bioelectronics at the Massachusetts Institute of Technology. His current research focuses on the intersection of materials science, medical devices, and systems neuroscience. Mr. Sahasrabudhe develops soft, stretchable, and multifunctional microsystems in unusual form factors to modulate and monitor functions of the nervous system in the brain, spinal cord, and gastrointestinal tract. He produces these microscale probes, which are wirelessly addressable, through scalable fabrication approaches. Mr. Sahasrabudhe aims to use this technology to decipher neural circuits underlying interoception and help guide clinically relevant autonomic neuromodulation therapies. Mr. Sahasrabudhe received his integrated bachelor's and master's degrees in chemical studies at the Indian Institute of Science Education and Research Kolkata. His undergraduate research focused on functional inorganic materials and spanned the fields of supramolecular polyoxometalate chemistry, colloidal quantum-dot chemistry, and photovoltaics.

Poster Session

Use the QR code to see the poster abstracts.

1. **Anita Autry, Ph.D.,** Albert Einstein College of Medicine. *Hypothalamic Urocortin-3 Expressing Neurons Project to the Pituitary Gland and Signal to the Periphery*
2. **Alexandra Klein, Ph.D.,** University of California, San Francisco. *Control of Anxiety States and Underlying Neural Dynamics by Respiratory Rhythms*
3. **Charles Verdonk,** Post-Doctoral Research Affiliate, Laureate Institute for Brain Research. *Heartbeat-Evoked Neural Response Abnormalities in Generalized Anxiety Disorder During Peripheral Adrenergic Stimulation*
4. **Yujuan Su, Ph.D.,** University of California, San Diego. *An Interoception Neural Circuit for Allergen-Induced Airway Hyperreactivity in Lung*
5. **Heberto Suarez-Roca, M.D., Ph.D.,** Duke University Medical Center. *Baroreceptor Interoception as a Predictor of Postoperative Pain and Inflammation Outcomes*
6. **Aubrey Chan, M.D., Ph.D.,** University of Iowa. *Acid-Sensing Ion Channels Mediate Distinct Neural and Behavioral Responses to Interoceptive Carbon Dioxide*
7. **Caroline McLaughlin,** Ph.D. Student, Brown University. *Multisensory Integration During Heartbeat Feedback in Healthy Participants*
8. **Jose L. Herrero Rubio, Ph.D.,** Feinstein Institutes for Medical Research. *Persistent Dyspnea: Insights From Invasive Human Recordings of Respiratory Related Brain Oscillations During Respiratory Challenges*
9. **Ritchie Chen, Ph.D.,** University of California, San Francisco. *Cardiogenic Control of Affective Behavioral States*
10. **Liang Han, Ph.D.,** Georgia Institute of Technology. *Jugular Sensory Neurons Controlling Airway Constriction*
11. **Anita Barber, Ph.D.,** Feinstein Institutes for Medical Research. *Autonomic Brain Circuitry Related to Cognition in Normal Blood Pressure and Hypertensive Individuals*
12. **Gary Mouradian, Ph.D.,** Medical College of Wisconsin. *Dissecting the Role of Neural Sensory Mechanisms in the Lung in Health and a Preclinical Model of Bronchopulmonary Dysplasia*
13. **Mariana Ruiz Lauar, Ph.D.,** University of Minnesota. *The Kidney-OVLT Interoceptive Pathway Mediates Hypertension and Polydipsia in 2-Kidney, 1-Clip Rats*
14. **Elizabeth Gonye, Ph.D.,** University of Virginia. *Intrinsic pH-Sensitivity of the Proton Sensor GPR4 Is Necessary for Retrotrapezoid Nucleus Modulation by CO_2/H+ and for CO_2-Stimulated Breathing*

15. **Kasey Jackman, Ph.D.,** Columbia University School of Nursing. *Exploration of the Role of Interoception in Suicide Risk Among Transgender and Gender Diverse People*

16. **Karina Mayagoitia, Ph.D.,** Loma Linda University. *The Effect of Chronic In Utero Vagus Denervation on the Cardiopulmonary Transition From Fetus to Newborn and Lung Morphology*

17. **Maria Alejandra Gonzalez-Gonzalez, M.Sc., Ph.D.,** Baylor College of Medicine. *The Autonomic Brain-Multi-Organ Response in Hypertension*

18. **Noam Gannot, B.S.,** Graduate Student, University of Michigan. *A Vagal-Brainstem Interoceptive Circuit for Cough-Like Defensive Behaviors in Mice*

19. **Paul Beach, D.O., Ph.D.,** Beth Israel Deaconess Medical Center/Harvard Medical School and Emory University School of Medicine. *Orthostatic Hypotension Symptoms and Cardiac Interoception: An Interplay of Physiology, Cognition, and Interoceptive Beliefs*

20. **Michael Schappe, Ph.D.,** Harvard Medical School. *Neural-Epithelial Coding of Airway Senses*

21. **Eunsu Park, Ph.D.,** University of Texas Health Science Center at Houston. *Mutant KRAS in Vascular Endothelial Cells Change the Humoral Immunity Driving Inflammation in a Mouse With Brain Arteriovenous Malformation*

22. **Dan Christoffel, Ph.D.,** University of North Carolina at Chapel Hill. *Regulation of Hedonic Feeding by Nucleus Accumbens Medium Spiny Neurons*

23. **John Coetzee, Ph.D.,** Stanford University. *Heart-Brain Coupling Factor Associated With Treatment Outcomes in an RCT of Stanford Neuromodulation Therapy and With Treatment*

24. **Le Wang, Ph.D.,** Child Health Institute of New Jersey, Rutgers-Robert Wood Johnson Medical School. *GLP-1 Signaling in the Hypothalamic-Brain Stem Descending Circuit Regulates Energy Homeostasis*

25. **Zhe Yu, Ph.D.,** George Washington University. *Identification of a Locus Coeruleus-Amygdala Angiotensinergic Circuit: Implications for Stress-Related Cardiovascular Diseases*

26. **Addison Webster,** Ph.D. Candidate, University of Virginia. *RAMPANT Molecularly Identifies Novel Presynaptic Partners to Hunger Neurons*

27. **Osama Harraz, Ph.D.,** University of Vermont. *Vascular Interoception and Cerebral Blood Flow Control*

28. **Yuanzhong Xu, Ph.D.,** University of Texas Health Science Center at Houston. *A Novel MC4R Neurocircuit for Regulating the Balance Between Feeding and Emotional Valence*

29. **Nicholas Neuwald, M.S.,** Penn State University. *An Innovative Approach for Assessing Interoception: Validation of the Tuning Into the Cardiac Tempo for Adults and Children Task (TICTACH)*

30. **Heike Muenzberg, Ph.D.,** Pennington Biomedical Research Center. *Interconnection of Adipose Tissue and the Central Nervous System To Modulate Energy Metabolism*

31. **Amanda Costa Veiga, M.Sc.,** Ph.D. Candidate, University of Minnesota. *Loss of Interoceptive Input From the Kidney Reveals Differential Renal Regulation of Salt Appetite in DOCA-Salt Versus Spontaneously Hypertensive Rats*

32. **Yu Wang,** Ph.D. Student, Scripps Research Institute. *Dissecting the Interoceptive Circuit of the Adipose Tissues*

33. **Senegal Alfred Mabry,** Ph.D. Student, Cornell University. *Interoceptive Awareness Is Disrupted in Parkinson's During a Social Stress fMRI Task and High-Intensity Exercise*

34. **Gargi Mishra, M.Sc.,** Ohio State University. *Uncovering Sensory Nerve Functions in White Adipose Tissue*

35. **Kathryn E. Evans,** Harvard Medical School. *Representations of the Interoceptive Effects of Nicotine in the Insular Cortex*

36. **Sora Shin, Ph.D.,** Virginia Tech. *Lateral Hypothalamic Proenkephalin Neurons Drive Threat-Induced Overeating Associated With a Negative Emotional State*

37. **Sergios Charntikov, Ph.D.,** University of New Hampshire. *Chemogenetic Inhibition of Corticostriatal Projections Attenuates Expression of Appetitive Learning With Nicotine Stimulus*

38. **Marito Hayashi, Ph.D.,** Harvard Medical School. *Enteroendocrine Cell Lineages That Differentially Control Feeding and Gut Motility*

39. **Alisa Zoltowski,** Vanderbilt University. *Insular Connectivity in Autistic and Nonautistic Development*

40. **Chuchu Zhang, Ph.D.,** University of California, Los Angeles. *Neural Mechanisms of Nausea in the Area Postrema*

41. **Shlomit Beker, Ph.D.,** Albert Einstein College of Medicine. *Autism as a Disorder of Synchronization With the Central and Autonomic Nervous Systems*

42. **Yu-Ting Cheng, Ph.D.,** Boston Children's Hospital/Harvard Medical School. *Ascending Neural Circuits That Shape the Perception of Visceral Pain*

43. **Masashi Tabuchi, Ph.D.,** Case Western Reserve University School of Medicine. *Microscale Instability of Neural Dynamics Drives Macroscale Pathological Manifestations*

44. **Laurent Gautron, Ph.D.,** University of Texas Southwestern Medical Center. *Evidence of Extraganglionic Vagal Mechanoreceptors in the Mouse Vagus Nerve*

45. **Aaron Freedman, M.A.,** Osher Center for Integrative Health, University of California, San Francisco. *Similarities and Differences in Interoceptive Bodily Awareness Between U.S.-American and Japanese Cultures*

46. **Wanzhu Hou, C.M.D., M.D. (C.N.),** All Natural Medicine Clinic. *Healing GERD Through Vagus Function*

47. **Joshua Drake, Ph.D.,** Virginia Tech. *Early Development of Peripheral Nerve Dysfunction in a Mouse Model of Alzheimer's Disease May Underlie Altered Exercise Adaptation in Muscle*

48. **Lihua Ye, Ph.D.,** Ohio State University. *Gut Microbiota Targets EEC–Vagal Communication To Change Feeding Behavior and Metabolism*

49. **Xiaolin Tian, Ph.D.,** Louisiana State University Health Sciences Center New Orleans. *A Brain-Gonad Axis Regulates Female Fertility and Lifespan*

50. **Rachel Essner,** Ph.D. Candidate, Beth Israel Deaconess Medical Center/Harvard Medical School. *Representation of Visceral Signals in the Lateral Parabrachial Nucleus During Feeding*

51. **Roberto De Luca, Ph.D.,** Beth Israel Deaconess Medical Center/Harvard Medical School. *Effect of Noradrenaline in the Ventrolateral Preoptic Area*

52. **Matthew Perkins, Ph.D.,** Icahn School of Medicine at Mount Sinai. *Spinal Contributions to Somatosensory Representations of Visceral Organs*

53. **Susanta Behura, Ph.D.,** University of Missouri, Columbia. *A Mouse System To Study Impacts of Leukemia on Brain-Body Connection*

54. **Annie Londregan,** Ph.D. Student, Thomas Jefferson University. *Neuropod Cell GUCY2C Relieves Visceral Pain*

55. **Ann Van de Winckel, Ph.D., M.S.P.T., P.T.,** University of Minnesota. *Interoceptive Awareness Improvements After Body Awareness Training in Adults With Spinal Cord Injury*

56. **Ann Choe, Ph.D.,** Kennedy Krieger Institute; Johns Hopkins University. *Are Most Brain Networks Synchronized With the Stomach?*

57. **Meiyu Shao,** Ph.D. Candidate, Penn State University. *Elucidating Mechanisms Underlying Stress Resilience in Mice With Disinhibited SST+ Neurons*

58. **Xiaokai Wang,** Ph.D. Student, University of Michigan. **Steven Oleson,** Ph.D. Student, University of Michigan. **Jiayue Cao, Ph.D.,** University of Michigan. **Xiaoyin Wu, M.D.,** University of Michigan. **Zhongming Liu, Ph.D.,** University of Michigan. *A Novel Technique for In Vivo Tracing of the Ascending Vagal Projections in Rodents*

59. **Alison Affinati, M.D., Ph.D.,** University of Michigan. *Distinct Neural Circuits Mediate Glycemic Versus Behavioral Stress Responses*

60. **Truong Ly, M.S.,** University of California, San Francisco. *Sequential Appetite Suppression by Oral and Visceral Feedback to the Brainstem*

61. **Hannah Smith,** Ph.D. Candidate, George Washington University. *An Innovative Automated Software for Measuring Internal State-Dependent Conditioned Fear*

62. **Atharva Sahasrabudhe,** Ph.D. Candidate, Massachusetts Institute of Technology. *Multifunctional Microelectronic Fibers Enable Wireless Modulation of Gut-Brain Axis*

63. **Leonor Remedio, Ph.D.,** Columbia University. *Descending Innervation and Control of Splenic Function*

64. **Minel Arinel, B.Sc.**, Duke University. *Mapping Brain-Wide Responses to Gut-Mediated Signals in Larval Zebrafish*

65. **Agostina Casamento Moran, Ph.D.,** Johns Hopkins University. *Fatigue Reflects an Affective Response to Dyshomeostasis and Is Part of an Allostatic Strategy*

66. **Amol Sharma, M.D.,** Medical College of Georgia. *Thoracic Spinal Nerve Neuromodulation Shows Durable Resolution of Symptoms of Diabetic Gastroparesis in a Proof-of-Concept Study*

67. **Karen Lindquist, M.S.,** University of Texas Health Science Center at San Antonio. *Diversity in Mechanically Activated Current Responses for Trigeminal Ganglion Neurons Innervating Masseter Muscle*

68. **Khalil Ramadi, Ph.D.,** New York University. *Ingestible Electroceutical Platforms for Gastric Neuromodulation*

69. **T. Dorina Papageorgiou, Ph.D.,** Baylor College of Medicine. *Individualized Neuromodulation of Interoceptive Functions of Swallow and Tongue Motor and Sensory*

70. **Mahavir Singh, D.V.M., Ph.D.,** University of Louisville School of Medicine. *Understanding and Enhancing Interoception: Implications in Health and Chronic Disease Conditions*

71. **Md Ali, Ph.D.,** University of Maryland Baltimore, School of Dentistry. *Central Projection of Nucleus of Tractus Solitarius Neurons TRAPped by Vagus Nerve Stimulation in Mice*

72. **Hailey Welch,** Ph.D. Student, University of Texas at Dallas. *Exploring Vagal Sensory Lateralization via Transcriptomics*

73. **Wynn Legon, Ph.D.,** Fralin Biomedical Research Institute at Virginia Tech. *Effects of Low-Intensity Focused Ultrasound to Human Insula and Anterior Cingulate Cortex on Autonomic Reactivity, EEG Dynamics, and Perceived Pain*

74. **Hanlin Zhu,** Ph.D. Student, Rice University. *Long-Term, 24/7 Tracking of Same Neuron Populations in Freely Behaving Mice With Ultraflexible Electrode Array for Studying Interoception*

75. **Yu Shin Kim, Ph.D.,** University of Texas Health Science Center at San Antonio. *Functional Vagal Neural Circuits in Interoceptive Modulation of Temporomandibular Joint Pain*

76. **Crystal Pan, M.S.,** Scripps Research Institute. *The Role of Neural Valence Coding on Downward Modulation of Physiological Homeostasis and Adaptive Behaviors Associated With Neurodevelopmental Disorders*

77. **Dana Dharmakaya Colgan, Ph.D.,** Oregon Health & Science University and National University of Natural Medicine. *Amplitude and Habituation of Pain-Related Evoked Potentials Predict Chronic Pain Status and Correlate with Interoceptive Awareness*

78. **Jessica L. Hazelton, Ph.D.,** Latin American Brain Health Institute (BrainLAT), Universidad Adolfo Ibáñez, Santiago, Chile. *Investigating Spatiotemporal Brain Dynamics of Interoception in Neurodegenerative Diseases*

79. **Yang Chen, B.A.,** Vollum Institute, Oregon Health & Science University. *Local Circuits of the Insular Cortex Provide Specialized Integration of Sensory and Cognitive Signals in the Central Interoceptive System*

80. **Alejandra Quintero, B.S.,** Florida Atlantic University. *Analysis of Cortical Lateralization With Spinal Motor Mapping in a Patient With Chronic Pain: A SCS Case Study*

81. **Emily Choquette, Ph.D.,** Laureate Institute for Brain Research. *Longitudinal Impact of an Interoceptive Therapy on Disordered Eating Symptoms in Anorexia Nervosa*

82. **Andrew S. Perley, M.S.,** Stanford University. *A Convex Formulation of Point Process Heartbeat Dynamics for Autonomic Monitoring*

83. **Jiyeon Hwang, Ph.D.,** Albert Einstein College of Medicine, **Woohyun Jo, Ph.D.,** Albert Einstein College of Medicine, **Gary J. Schwartz, Ph.D.,** Albert Einstein College of Medicine, **Young-Hwan Jo, Ph.D.,** Albert Einstein College of Medicine. *Deleting Vagal Sensory Neurons Innervating the Liver Prevents Diet-Induced Obesity and Hepatic Steatosis in Mice.*

84. **Michael Cardenas, B.S.,** University of Arizona. *Interoception Biases Decision Making on an Approach-Avoidance Conflict Task in Non-Human Primates.*

2023 NIH Interoception Investigator Meeting Planning Committee

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