Barrels 36

Baltimore

Thursday, November 9th, 2023

9:00 to 9:10
Welcome

9:10 to 10:10

INVITED TALK (30 minutes)
Randy Bruno, Oxford
Secondary Somatosensory and Visual Thalamus in Behavior

1. Short talk (15 minutes)
Learning induced neuronal identity switch in the superficial layers of the primary somatosensory cortex
J. Dai and Q.Q Sun. Univ. Wyoming

2. Short talk (15 minutes)
Input- and target-specific synaptic plasticity in neocortical layer 1 during sensory learning
Ajit Ray, Joseph C Christian, Alison L Barth, Carnegie Melon University

---

Stretch Break 10 minutes

10:20-11:20

INVITED TALK (30 minutes)
Anurag Pandey, Cardiff
Role of a feedback circuit from S2 to vS1 in learning-induced structural plasticity in vS1 cortex

3. Short talk (15 minutes)
Responses to cortical stimulation reveal thalamocortical state-dependent features in mice and humans
Simone Russo, Leslie Claar, Lydia Marks, Giulia Furregoni, Flavia Maria Zauli, Gabriel Hassan, Michela Solbiati, Simone Sarasso, Mario Rosanova, Ivana Sartori, Andrea Pigorini, Christof Koch, Marcello Massimini, Irene Rembado. Allen Brain Institute

4. Short talk (15 minutes)
Stimulus novelty uncovers coding diversity in visual cortical circuits
Farzaneh Najafi, Marina Garrett, Peter Groblewski, Alex Piet, Doug Ollerenshaw, Iryna Yavorska, Stefan Mihalas, Anton Arkhipov, Christof Koch, Shawn R Olsen. Allen Institute

---

Coffee Break 20 minutes

11:40 to 12:40

INVITED TALK (30 minutes)
Jessica Cardin, Yale
Rhythm and flow in the cortex: flexible perceptual encoding by patterned activity

INVITED TALK (30 minutes)
Soohyun Lee, NIMH
Brainwide synaptic network of behavior-state dependent cortical neurons

---

Lunch break
12:40 to 2:30

2:30 to 3:30

INVITED TALK (30 minutes)
Solange Brown, Johns Hopkins
Neural activity in the claustrum during a cross-modal sensory selection task

5. Short talk (15 minutes)
Microglia-astrocyte crosstalk during synaptic remodeling in the barrel cortex
Travis E. Faust, Yi-Han Lee, Georgia Gunner, Ciara O'Connor, Margaret Boyle, Ana Badimon, Pinar Ayata, Anne Schaefer, Dori Schafer. UMass Chan Medical School and Icahn School of Medicine at Mount Sinai

6. Short talk (15 minutes)
Is paradoxical sleep a paradoxical state of sleep?
Flore BOSCHER and Nadia URBAIN

Coffee Break 15 minutes

3:45 to 5:00

INVITED TALK (30 minutes)
Aleena Garner, Harvard
A Cortical Circuit for Audio-Visual Predictions

7. Short talk (15 minutes)
Organizing principles of cortical interneurons
F. YÁÑEZ, F. MESSORE, G. QI, D. FELDMEYER, B. SAKMANN, M. OBERLAENDER Max Planck Institute for Neurobiology of Behavior

8. Short talk (15 minutes)
Prrxl1 knockout – a non-invasive model of chronic pain
Ezekiel Willerson, Leah Kramer, Eliana Eichler, Jacob Zar, Kayla Wilamowsky, Giuseppe Cataldo, Joshua C. Brumberg, Queens College, CUNY

9. Short talk (15 minutes)
Ultra-Flexible tentacle electrodes for months-long tracking of assemblies of single units simultaneously from many brain areas
Tansel Baran Yasar, Peter Gombkoto, Eminhan Ozil, Alexei Vyssotski, Angeliki Vavladeli, Simon Steffens, Orhun Caner, Eren, Wolfger von der Behrens, Mehmet Fatih Yanik.

Posters and Dinner
5:00 to 9:00

Friday, November 10th, 2023

Day 2
9:00 to 9:10

Announcements

9:10 to 10:10 am

INVITED TALK (30 minutes)
Dan Feldman, UC Berkeley
History-based attentional cueing in the whisker system

11. Short talk (15 minutes)
Simulation tools for studying the vibrissal array
Mitra J Hartmann, Departments of Biomedical and Mechanical Engineering, Northwestern University

12. Short talk (15 minutes)
Cortical contributions to context-dependent sensorimotor transformation
Parviz Ghaderi, Sylvain Crochet and Carl Petersen
Swiss Federal Institute of Technology Lausanne

Stretch Break 10 minutes

10:20 to 11:20

INVITED TALK (30 minutes)
Florent Haiss, Institute Pasteur
Coexistence of state, choice, and sensory integration coding in barrel cortex

13. Short talk (15 minutes)
Connectomic analysis of astrocyte-synapse interactions in mouse barrel cortex
Yagmur Yener, Alessandro Motta, Moritz Helmstaedter
Max-Planck Institute for Brain Research

16. Short talk (15 minutes)
Joint representation of self-motion and touch in the Superior Colliculus
Suma Chinta & Scott R Pluta. Purdue University

Coffee Break (20 minutes)

11:40 to 12:40

INVITED TALK (30 minutes)
Rui Liu, UCSD
Spatiotemporal representation of rhythmicity by thalamocortical inputs during active sensing

INVITED TALK (30 minutes)
Nicholas Bush, U Washington
Brainstem populations that underlie breathing follow rotational, attractor-like dynamics

---

Lunch break
12:40 to 2:30

2:30 to 3:45
INVITED TALK (30 minutes)
Nuo Li, Baylor

A combinatorial code for motor memory

14. Short talk (15 minutes)
In-Vivo Recording of Optogenetically Identified Rapidly-Adapting Whisker Neurons
P. M. Thompson, Jun Takatoh, Seonmi Choi, Andrew Harahill, and Fan Wang. Massachusetts Institute of Technology

15. Short talk (15 minutes)
Jaw muscle spindle afferents as multiplexed channels for sensing and guiding orofacial movement
William Olson, Varun Chokshi, Jeong Jun Kim, Montrell Vass, Noah Cowan, Daniel O'Connor. Johns Hopkins University

16. Short talk (15 minutes)
What does motor cortex tell sensory cortex?
Edward Zagha. University of California Riverside

Coffee Break (15 minutes)

4:00 to 5:15

17. Short talk (15 minutes)
Functional network analysis of cortical dynamics seen with fast wide-field voltage imaging in a right/left cued decision lick task
Dieter Jaeger, Yunmiao Wang. Emory University

18. Short talk (15 minutes)
Motor cortex modulation of nociception and movement through corticobulbar circuits
Nicole Mercer Lindsay, Simon Haziz, Thomas Baer, Mark Schnitzer & Grégory Scherrer. Stanford University, University of North Carolina and New York Stem Cell Foundation

19. Short talk (15 minutes)
Sparse and distributed cortical populations mediate sensorimotor integration
Ravi Pancholi, Andrew Sun-Yan, Maya Laughton, **Simon Peron**. NYU

INVITED TALK (30 minutes)
Daniel O'Connor, Johns Hopkins
Rule-based modulation of a sensorimotor transformation across cortical areas

The End

ABSTRACTS FOR INVITED TALKS (in line with schedule)

Secondary Somatosensory and Visual Thalamus in Behavior
Randy Bruno
Oxford University, UK

Each sensory modality has its own primary and secondary thalamic nuclei. While primary thalamic nuclei are well understood to relay sensory information from the periphery to the cortex, the function of secondary sensory nuclei is elusive. One hypothesis has been that secondary nuclei may support feature-based attention. If this is true, one would expect the activity in different nuclei to reflect the degree to which modalities are or are not behaviorally relevant to a learned task. We trained head-fixed mice to attend to one sensory modality while ignoring a second modality, namely attend to touch and ignore vision (or vice versa). Arrays were used to record simultaneously from secondary somatosensory thalamus (POm) and secondary visual thalamus (LP, the mouse homolog of primate visual pulvinar). In mice trained to respond to tactile stimuli and ignore visual stimuli, POm was robustly activated by whisker touches and largely unresponsive to visual stimuli. The reverse pattern was observed when mice were trained to respond to visual stimuli and ignore touch, with POm now more robustly activated during visual trials. This POm plasticity was not explained by differences in movements (i.e., whisking, licking) resulting from the two tasks (respond to vision vs respond to touch). Post hoc histological reconstruction of array tracks through POm revealed that subregions varied in their degree of plasticity. LP exhibited similar phenomena. We conclude that behavioral training reshapes activity in secondary thalamic nuclei. Secondary nuclei may then serve as “control knobs” on sensory processing and plasticity in their corresponding sensory cortical areas, such as primary somatosensory and primary visual cortex.

Role of a feedback circuit from S2 to vS1 in learning-induced structural plasticity in vS1 cortex
Anurag Pandey, Sungmin Kang, Nicole Pacchiarini, Hanna Wyszynska, Aneesha Grewal, Alex Griffiths, Imogen Healy-Millett, Zena Masseri, Neil Hardingham, Joseph O’Neill, Robert C. Honey and Kevin Fox
Cardiff University

Feedforward and feedback pathways are important for transfer and integration of information between sensory cortical areas. Here we find that two closely connected cortical areas, the primary (S1) and secondary (S2) somatosensory cortices are both required for mice to learn whisker-dependent texture discrimination. Increased inhibition in either area (using excitatory DREADDs expressed in inhibitory neurones) prevents learning. We find that learning the discrimination produces structural plasticity on layer 2/3 pyramidal neurones in vibrissae S1 (vS1), that is restricted to the basal dendrites and leaves dendritic spines on apical dendrites unchanged. As S2 projects to the apical dendrites of vS1 neurones, we tested whether S2 affects LTP-induction in S1. We found that feedback projections from S2 to S1 gates LTP on feedforward pathways within S1. To test whether this feedback circuit might affect structural plasticity in vivo, we inhibited S2 unilaterally during texture discrimination learning. We found plasticity to be strongly attenuated in vS1 ipsilateral to the site of S2 inhibition, suggesting that feedback from S2 to S1 controls plasticity during texture discrimination learning. Funding- BBSRC UK

Rhythm and flow in the cortex: flexible perceptual encoding by patterned activity.
Jessica A. Cardin
Department of Neuroscience, Kavli Institute for Neuroscience, Wu Tsai Institute, Yale University School of Medicine, New Haven, CT, USA.

Cognitive processes underlying behavior are linked to specific spatiotemporal patterns of neural activity in the neocortex. These patterns arise from synchronous synaptic activity and are often detected as prominent peaks in particular frequency bands in the cortical field potential. Activity in a wide range of frequencies (5-100Hz) generally occurs in correlation with cognitive behaviors such as navigation, attention, perception, and memory. However, cortical activity is highly variable on multiple timescales

(milliseconds to hundreds of seconds), obscuring the fine temporal relationship between bouts of patterned activity and behavior. Identifying discrete neural events underlying patterned activity within highly dynamic cortical network fluctuations thus remains a critical challenge. We developed a novel analytical method to track individual network events underlying state-dependent activity with single-cycle precision. We find in mouse primary visual cortex (V1) that γ- (30-80Hz), but not β- (15-30Hz), range events are associated with feedforward thalamocortical drive and can be selectively evoked by thalamocortical stimulation in a biologically realistic pattern, but not by Poisson or regular stimulation. g, but not b, events are associated with enhanced visual encoding by V1 neurons despite their neighboring frequency bands. event rate increases steadily prior to visually-cued behavior, accurately predicting trial-by-trial visual detection performance. This relationship between cortical γ events and behavior is sensory modality-specific and rapidly modulated by changes in task objectives, but unaffected by behavioral state. events thus selectively support flexible cortical encoding according to behavioral context, suggesting a distinct role for transient patterns of cortical activity.

Brainwide synaptic network of behavior-state dependent cortical neurons
Ana R. Inácio, Ka Chun Lam, Yuan Zhao, Francisco Pereira, Charles R. Gerfen, and ***Soohyun Lee***
National Institute of Mental Health, National Institutes of Health, Bethesda, MD, USA

Neuronal connections provide the scaffolding for neuronal function. Revealing the connectivity of functionally identified individual neurons is necessary to understand how activity patterns emerge and support behavior. Yet, the brain-wide presynaptic wiring rules that lay the foundation for the functional selectivity of individual neurons remain largely unexplored. Cortical neurons, even in primary sensory cortex, are heterogeneous in their selectivity, not only to sensory stimuli but also to multiple aspects of behavior. Here, to investigate presynaptic connectivity rules underlying the selectivity of pyramidal neurons to behavioral state in primary somatosensory cortex (S1), we used two-photon calcium imaging, neuropharmacology, single-cell based monosynaptic input tracing, and optogenetics. We show that behavioral state-dependent neuronal activity patterns are stable over time. These are not determined by neuromodulatory inputs but are instead driven by glutamatergic inputs. Analysis of brain-wide presynaptic networks of individual neurons with distinct behavioral state-dependent activity profiles revealed characteristic patterns of anatomical input. While both behavioral state-related and unrelated neurons had a similar pattern of local inputs within S1, their long-range glutamatergic inputs differed. Our results revealed distinct long-range glutamatergic inputs as a substrate for preconfigured network dynamics associated with behavioral state. Funding: NIH IPR ZIAMH00295

Neural activity in the claustrum during a cross-modal sensory selection task
Solange Brown,
Johns Hopkins

Although the functions of the claustrum, a thin, elongated subcortical nucleus located between the neocortex and striatum that forms extensive reciprocal connections with the neocortex, remain unclear, it has recently been implicated in sensory selection. It has been proposed that claustrocortical activity evoked by sensory input modulates the neocortex's context-dependent responses to sensory stimuli. We tested this hypothesis by recording from claustrum neurons in vivo while mice performed a crossmodal sensory-selection task. We found that claustrum neurons, including putative claustrocortical neurons projecting to primary somatosensory cortex, rarely responded solely to tactile or visual stimuli. We found instead that neurons in anterior claustrum exhibited direction-tuned motor responses and encoded upcoming lick direction during intertrial intervals. Anterograde and retrograde tracing studies confirmed that the claustrum is interconnected with cortical motor areas such as ALM. Chemogenetic inhibition of claustrocortical neurons significantly decreased lick responses to inappropriate sensory stimuli while leaving the response rates to appropriate sensory stimuli unaffected. Together, these data suggest that the claustrum is integrated into higher-order premotor circuits recently implicated in decision-making.

A Cortical Circuit for Audio-Visual Predictions

Aleena R. Garner[1,3] and Georg B. Keller[1,2]
[1]Friedrich Miescher Institute for Biomedical Research, Basel, Switzerland; [2]Faculty of Natural Sciences, University of Basel, Basel, Switzerland; [3]Harvard Medical School Department of Neurobiology, Boston, Massachusetts

Learned associations between stimuli in different sensory modalities can shape the way we perceive these stimuli (Mcgurk and Macdonald, 1976). During audio-visual associative learning, auditory cortex has been shown to underlie multi-modal plasticity in visual cortex (McIntosh et al., 1998; Zangenehpour and Zatorre, 2010). However, how processing in visual cortex is altered when an auditory stimulus signals a visual event and what the neural mechanisms are that mediate such experience-dependent audio-visual associations is not well understood. Here we describe a neural mechanism that contributes to shaping visual representations of behaviorally relevant stimuli through direct interactions between auditory and visual cortices. We show that auditory association with a visual stimulus leads to an experience-dependent suppression of visual responses in visual cortex. This suppression of the predictable visual stimulus response is driven in part by input from auditory cortex. By recording from auditory cortex axons in visual cortex, we find that these axons carry a mixture of auditory and retinotopically matched visual input. Moreover, optogenetic stimulation of auditory cortex axons in visual cortex selectively suppresses the neurons responsive to the associated visual stimulus after, but not before, learning. Our results are consistent with the interpretation that cross-modal associations can be stored in long-range cortical connections and that with learning these cross-modal connections function to suppress the responses to predictable input.

History-based attention in the whisker system

DL Ramamurthy, L Rodriguez, ***DE Feldman***

Attention flexibly selects specific sensory stimuli for prioritized processing, but the neurobiological mechanisms remain poorly understood. We studied a common form of attention in which the history of stimulus-reward association causes animals, including humans, to automatically attend to previously rewarded stimuli. In a simple whisker detection task, mice rapidly shifted attention between specific whiskers, based on the recent history of stimulus-reward association. A prior rewarded hit trial on a given whisker elevated behavioral detectability (d-prime) for that whisker. This effect was somatotopically specific, lasted ~10 sec, and was flexibly shifted between whiskers. Whisker stimulation alone, without reward, did not trigger this effect. Reward delivery also generally elevated lickiness (i.e., reduces criterion), which occurred in addition to this whisker-specific attentional effect. We tested for neurobiological correlates of attention in S1, using 2p imaging from L2/3 pyramidal (PYR) cells during behavior. Whisker-evoked DF/F for a given whisker was strongly increased when the prior trial was a rewarded hit on that same whisker. This response amplification fell off with cortical distance in S1 from the rewarded whisker's column, and thus was somatotopically organized. Prior reward also caused a smaller, spatially non-specific ramping of PYR activity that may reflect general expectation. In ongoing Neuropixels recordings, we confirmed that attention increases the gain of whisker-evoked spiking responses by regular-spiking (presumed PYR) units. Thus, attention powerfully modulates the whisker sensory code in S1. Funding: Supported by R01 NS092367 to DEF, and F32NS114327 and K99NS129753 to DLR

Coexistence of state, choice, and sensory integration coding in barrel cortex

Pierre-Marie Gardères[1,2,] Sébastien Le Gal[1], Charly Rousseau[1], Alexandre Mamane [1], Dan Alin Ganea[2,3], ***Florent Haiss[1]***.
1: Institut Pasteur, Université Paris Cité, Unit of Neural Circuits Dynamics and Decision Making, 75015 Paris, France
2: IZKF Aachen, Medical School, RWTH Aachen University, 52074 Aachen, Germany
3: University of Basel, Department of Biomedicine, 4001 Basel, Switzerland

During perceptually guided decisions, correlates of choice are found as upstream as in the primary sensory areas. However, how well these choice signals align with early sensory representations, a prerequisite for their interpretation as feedforward substrates of perception, remains an open question. We designed a two alternative forced choice task (2AFC) in which mice compared stimulation frequencies applied to two adjacent vibrissae. The optogenetic silencing of individual columns in the primary somatosensory cortex (wS1) resulted in predicted shifts of psychometric functions, demonstrating that perception depends on focal, early sensory representations. Functional imaging of layer II/III single neurons revealed sensory, choice and engagement coding. From trial to trial, these three varied substantially, but independently from one another. Thus, coding of sensory and non-sensory variables co-exist in orthogonal subspace of the population activity, suggesting that perceptual variability does not originate from wS1 but rather from state or choice fluctuations in downstream areas.

Spatiotemporal representation of rhythmicity by thalamocortical inputs during active sensing
Rui Liu[1], Karin Dekel[2], Pan-tong Yao[3], Abhi Aggarwal[4], Kaspar Podgorski[4], Daniel H. O'Connor[5], David Golomb[2,6,7] and David Kleinfeld[1,8]
[1]Department of Physics, University of California, San Diego, La Jolla, California, USA
[2]Department of Physiology and Cell Biology, Ben Gurion University, Beer-Sheva, Israel
[3]Neurosciences Graduate Program, University of California San Diego, La Jolla, California, USA
[4]Allen Institute for Neural Dynamics, Seattle, Washington, USA
[5]The Zanvyl Krieger Mind/Brain Institute, Johns Hopkins University, Baltimore MD, USA
[6]Department of Physics, Ben Gurion University, Beer-Sheva, Israel
[7]Zlotowski Center for Neuroscience, Ben Gurion University, Beer-Sheva, Israel
[8]Department of Neurobiology, University of California, San Diego, La Jolla, California, USA

In tactile active sensing, the swift shift from exploratory whisking to the state of "minimal impingement" plays a crucial role in achieving optimal sensation when unexpectedly encountering objects. This rapid switching necessitates prompt location-based perception. We consider the possibility that sensation is derived from the mechanics of a sensorimotor plant and directly encoded by thalamocortical afferents, with limited neuronal processing. Our study utilizes the rhythmically active rodent vibrissa system in combination with high-resolution imaging of glutamate activities on thalamocortical inputs in mouse layer 4 barrel cortex. We employ adaptive optical two-photon microscopy to survey the activity of a substantial population of thalamocortical boutons throughout one entire barrel while performing whisking dynamic pole contact task. Our findings reveal, firstly, that in moving contacts, the torque upon touch, the azimuthal angle of contact and the phase of contact onset are proportional to each other for small deflections. Next, the spiking at a preferred phase in the free whisking cycle is a reliable and spatially-ordered metric to label thalamocortical afferents. Thalamocortical boutons with similar phase preferences are spatially clustered. Further, the strength of phase representation depends on the rhythmic regularity and setpoint of vibrissa movement. Finally, the response probability to the contact location indicated by phase is in line with the preferred phase of free whisking across a large number of thalamocortical boutons. This work is supported by NIH U19 NS107466 and U24 EB028942.

Brainstem populations that underlie breathing follow rotational, attractor-like dynamics
Nicholas Bush
Seattle Children's Research Institute; Jan-Marino Ramirez, University of Washington, Seattle Children's Research Institute

Breathing is a vital, rhythmic motor behavior that persists throughout the life of an animal. Despite its simplicity, the neural circuits that generate, pattern, and maintain breathing are embedded in a large population of anatomically distributed and molecularly diverse neurons in the medulla called the Ventral Respiratory Column (VRC). The populations in the VRC must not only generate rhythmic activity, but also modulate breathing to maintain blood gas concentrations, and monitor mechanosensory signals that represent lung state. We leverage Neuropixels probes to record simultaneously from a large spatial

extent of the VRC in anesthetized mice with intact neuro-respiratory systems while they breathe at physiological rates. We record from over 15,000 units to characterize their respiratory related activity and perform opto-tagging and histological analyses to map the cell-type and anatomical location of these units. Through population-level analyses we uncover continuous rotational trajectories along a low-dimensional neural manifold that target the offset of inspiration. Lastly, we disrupt the respiratory system with opioids and hypoxic challenge. Opioids cause respiratory depression that results in diverse changes in single unit activity, but the rotational population dynamics are preserved. In contrast, hypoxic challenge induces gasping which eliminates the rotational dynamics and results in punctuated, one-phase inspiratory efforts. Funding: NIH F32HL159904.

A combinatorial code for motor memory

Nuo Li
Baylor College of Medicine

In our lifetime we stably retain a repertoire of motor skills. How are learned actions stored in motor memory? Moreover, how are motor memories maintained as we continuously acquire new motor skills? To explore these questions, we used automated home-cage training to establish a continual learning paradigm in mice. Mice learned to perform directional licking in multiple tasks. We combined this paradigm with chronic two-photon imaging of anterior lateral motor cortex (ALM) to track the neural representation of directional licking for up to 6 months and across continual learning. Within the same task, activity driving directional licking was stably retained with little representational drift. When learning new tasks, new preparatory activity emerged to drive the same licking actions. This created parallel new motor memories while retaining the previous memories. Re-learning to make the same actions in the previous task re-activated the previous preparatory activity, even 3 months later. Across multiple tasks, distinct preparatory activities encoded the same action in a context-dependent manner. Our results show that preparatory activity reflects motor memories that stably encode learned actions in combination with their context, which we call a combinatorial code. Context-specific modular memories could reduce interference of new learning on existing representations, enabling stable retention of motor repertoire in the face of continual learning.

Rule-based modulation of a sensorimotor transformation across cortical areas

Yi-Ting Chang, Eric A. Finkel, Duo Xu, ***Daniel H. O'Connor***
Johns Hopkins

Flexible responses to sensory stimuli based on changing rules are critical for adapting to a dynamic environment. However, it remains unclear how the brain encodes rule information and uses this information to guide behavioral responses to sensory stimuli. Here, we made single-unit recordings while head-fixed mice performed a cross-modal sensory selection task in which they switched between two rules in different blocks of trials: licking in response to tactile stimuli applied to a whisker while rejecting visual stimuli, or licking to visual stimuli while rejecting the tactile stimuli. Along a cortical sensorimotor processing stream including the primary (S1) and secondary (S2) somatosensory areas, and the medial (MM) and anterolateral (ALM) motor areas, the single-trial activity of individual neurons distinguished between the two rules both prior to and in response to the tactile stimulus. Variable rule-dependent responses to identical stimuli could in principle occur via appropriate configuration of pre-stimulus preparatory states of a neural population, which would shape the subsequent response. We hypothesized that neural populations in S1, S2, MM and ALM would show preparatory activity states that were set in a rule-dependent manner to cause processing of sensory information according to the current rule. This hypothesis was supported for the motor cortical areas by findings that (1) the current task rule could be decoded from pre-stimulus population activity in ALM and MM; (2) neural subspaces containing the population activity differed between the two rules both prior to the stimulus and during the stimulus-evoked response; and (3) optogenetic disruption of pre-stimulus states within ALM and MM impaired task performance. Our findings indicate that flexible selection of an appropriate action in response to a sensory input can occur via configuration of preparatory states in the motor cortex.

ABSTRACTS FOR SHORT TALKS AND POSTERS (Alphabetically)

1. Short talk
Is paradoxical sleep a paradoxical state of sleep?
Flore BOSCHER and Nadia URBAIN

Paradoxical sleep (PS), coined as such by Jouvet in 1959 for the striking resemblance of its electroencephalogram (EEG) to the one observed during the fundamentally different cognitive state of wakefulness, is characterized by muscular atonia and the occurrence of rapid eye movements (REM). In addition to REM, in mice, we observed rapid whisker movements. The whisker system therefore offers the unique opportunity to study cortical and thalamic dynamics associated with whisker movements in both wakefulness and REM sleep. We performed extra- and intracellular recordings of thalamic cells in head-fixed mice, combined with local field potential (LFP) recordings in the primary somatosensory (S1) and motor (M1) cortices, while simultaneously monitoring the EEG, the electromyogram and the whisker movements with a high-speed camera. Our results show that self-generated movements are associated with an increase in thalamic neuronal firing and a cortical activation in REM sleep, as in wakefulness. Unexpectedly, our data further reveal a substate of REM, outside phasic events, which bears clear NREM characteristics, opening a new insight into the function of REM sleep.

2. Short talk
Joint representation of self-motion and touch in the Superior Colliculus
Suma Chinta & Scott R Pluta, Department of Biology, Purdue University, West Lafayette, IN

In the absence of body movement, tactile localization is performed by mapping stimuli directly to receptors on the body surface. However, in real life, tactile localization is active, whereby the position of the body is constantly changing. Therefore, tactile localization requires the brain to combine its somatotopic map of the body surface with an egocentric model of its position. Where in the brain does this joint representation of somatotopic and egocentric space arise? We discovered neural activity in the midbrain superior colliculus (SC) that is linearly related to volitional whisker position. A time-shifted encoding model revealed that neural activity either accurately predicted or was predicted by specific kinematic variables, ultimately revealing the proportion of sensory and motor information in individual SC neurons. Active touch modulated the neural representation of self-motion by increasing the proportion of sensory information in these neurons. A select group of neurons reliably fired action potentials milliseconds before the start of whisker protraction, with greater spike rates preceding larger movements. In these neurons (and others), tuning to whisker phase, amplitude and midpoint were combined to generate an accurate representation of whisker position at high temporal resolution. Therefore, SC neurons contain the full spectrum of afferent and efferent information needed to perform active tactile localization. Funding:Whitehall Foundation grant

3. Short talk
Learning induced neuronal identity switch in the superficial layers of the primary somatosensory cortex
J. Dai and Q.Q Sun, Univ. Wyoming, Wyoming Sensory Biology Center.

We studied the sensory cortical neuronal coding of trace eyeblink conditioning (TEC) learning in head-fixed, freely running mice, where whisker deflection was used as a conditioned stimulus (CS) and an air puff to the cornea delivered after an interval was used as unconditioned stimulus (US). GCaMP6 signals were monitored by a two-photon microscope under a cranial window. The local blockade of S1 activities with muscimol abolished the behavior learning suggesting that S1 is required for the TEC. In naive animals, based on the response properties to the CS and US, identities of 20% of responsive primary neurons (PNs) were divided into two subtypes: CR and UR neurons. After animals learned the task, identity of CR and UR neurons changed: while the CR neurons are less responsive to CS, UR neurons

gain responsiveness to CS, a new phenomenon we defined as 'learning induced neuronal identity switch (LINIS)'. To explore the potential mechanisms underlying LINIS, we found that systemic and local (i.e. in S1) administration of the nicotinic receptor antagonist during TEC training blocked the LINIS, and concomitantly disrupted the behavior learning. Additionally, we monitored responses of two types of cortical interneurons (INs) and observed that SST, but not PV contribute to the LINIS. Thus, we conclude that L2/3 PNs in S1 encode perceptual learning by LINIS like mechanisms, and cholinergic pathways and cortical SST interneurons are involved in the formation of LINIS. Funding: NIH.

4. Short talk

Microglia-astrocyte crosstalk during synaptic remodeling in the barrel cortex

Travis E. Faust1, Yi-Han Lee1, Georgia Gunner1, Ciara O'Connor1, Margaret Boyle1, Ana Badimon2, Pinar Ayata2, Anne Schaefer2, Dori Schafer1 1-Department of Neurobiology, Brudnick Neuropsychiatric Research Institute, UMass Chan Medical School, Worcester, MA 2-Fishberg Department of Neuroscience, Department of Psychiatry, Friedman Brain Institute, Icahn School of Medicine at Mount Sinai, New York, NY

Synapses remodel in response to changes in sensory experience and neural activity. Microglia and astrocytes both contribute to activity-dependent synapse remodeling by engulfing and removing synapses from less active neurons. Yet, how these two cell types communicate to remodel synapses, while sparing others, remains an open question. Previously, we showed that microglia engulf and remove synapses in neonate mouse barrel cortex following whisker lesioning and whisker trimming-induced reductions of neural activity. This whisker lesioning-induced synapse removal was dependent on signaling between neuronal fractalkine (CX3CL1) and its cognate microglial fractalkine receptor (CX3CR1). Using this whisker lesioning paradigm, we are now exploring how astrocytes and microglia coordinate to regulate synapse remodeling. Using cell type specific translating ribosome affinity purification followed by RNAseq (TRAPseq), we are exploring transcriptional changes in microglia and astrocytes following whisker lesioning. In the process, we have identified putative receptor-ligand signaling between these two cell types. We are also now using expansion microscopy to assess how astrocytes modify their interactions with synapses in a microglial CX3CR1 signaling-dependent manner. Together, our results provide a novel mechanism by which microglia signal to astrocytes to facilitate synapse engulfment and remodeling of cortical synapses in response to changes in neural activity.

5. Short talk

Cortical contributions to context-dependent sensorimotor transformation

Parviz Ghaderi, Sylvain Crochet and Carl Petersen . Swiss Federal Institute of Technology Lausanne

Flexible integration of sensory stimuli in a context-dependent manner is a key cognitive process required to generate appropriate behavior. An intriguing question, then, is how the same sensory stimulus can be interpreted differently according to context in order to generate different behavioral responses. We designed a task in which mice were trained to lick for reward in response to a single whisker stimulus if it was preceded 1 s earlier by a brief Go-Tone, but not if it was preceded by a NoGo-Tone.Optogenetic inactivation of primary auditory cortex (A1), primary whisker somatosensory cortex (wS1), secondary whisker somatosensory cortex (wS2), secondary whisker motor cortex (wM2), and anterior lateral motor cortex (ALM) revealed prominent temporally-specific deficits in task performance for each area, whereas inactivation of primary forepaw somatosensory cortex had no impact.We investigated neuronal correlates of context-dependent sensorimotor transformation using high-density extracellular Neuropixels recordings combined with high-speed video filming of facial movements. Neuronal activity in A1, wS1, wS2, wM2, and ALM differed comparing Go-context hit trials to NoGo-context correct rejection trials.

6. Short talk

Simulation tools for studying the vibrissal array

Mitra J Hartmann, Departments of Biomedical and Mechanical Engineering, Northwestern University, Evanston IL 60208

The rodent vibrissal array offers a tantalizing promise to neuroscientists: the ability to correlate whisking behavior with neural activity throughout the trigeminal system. Yet once enticed, researchers often find themselves daunted by limitations of this promise, alternately marveling at and cursing the whiskers' small size and rapid motions. The core problem lies in our inability to directly measure tactile input signals from a whisker without disrupting the signals themselves. Even if we could measure signals from a single whisker, it would be challenging to measure the signals from all ~50 whiskers. And even if we could measure the signals from all whiskers in the anesthetized animal, it would be challenging to measure all signals during active whisking behavior in a complex environment. In this presentation, I describe our laboratory's efforts to develop simulation tools to help tackle these problems. We aim to enable researchers to estimate the tactile-input signals generated when stimulating the whiskers of an anesthetized animal, as well as the tactile-input signals during active whisking. I will show one example in which we simulate tactile inputs for all whiskers in the array during a ~2 second trial of active whisking of a freely-moving rat. I will also describe an initial model of the facial musculature that controls whisker movements, and discuss the next steps required to close the loop between simulations of tactile input and muscle output.

7. Short talk
Functional network analysis of cortical dynamics seen with fast wide-field voltage imaging in a right/left cued decision lick task
Dieter Jaeger, Yunmiao Wang

Population imaging of cortex-wide activities can shed light on the cortical dynamics and functional networks of motor control. We employed the fast genetically expressed voltage sensor JEDI-1P with wide-field imaging. JEDI-1P was expressed cortex-wide in the cell bodies of excitatory neurons via a soma–targeting Cre-dependent JEDI-1P AAV vector injection into the ventricles of neonatal EMX-1 Cre mice. Imaging was performed through a cleared intact skull in adult head-fixed mice at a frame rate of 200 Hz. We trained mice expressing JEDI-1P in a left/right lick decision making task with a delay to follow fast voltage dynamics throughout this behavioral task. We find that the contralateral S1 and M1 cortex show clear lick related activity. Using Independent Component Analysis (ICA), a number of different task-related functional networks with distinct voltage dynamics could be identified. These networks each follow a distinct temporal dynamic during the task and reveal multiplexed task responses in different cortical networks related to sensory processing, motor preparation, and motor execution. Additionally, a coherence analysis in different frequencies showed that these networks in some cases are coupled through oscillatory activity.Funding: NIH BRAIN Initiative 1R01NS111470

8. Short talk
Motor cortex modulation of nociception and movement through corticobulbar circuits
Mercer Lindsay, Nicole1-3,5-7; Haziza, Simon1-3; Baer, Thomas3,4*; Schnitzer, Mark1-3,8*; & Grégory Scherrer5-7,9* 1Department of Biology, 2CNC program, 3Department of Applied Physics, 4Stanford Photonics Research Center, Stanford University, 5Department of Cell Biology and Physiology, 6UNC Neuroscience Center, 7Department of Pharmacology, The University of North Carolina at Chapel Hill, 8Howard Hughes Medical Institute, 9New York Stem Cell Foundation--Robertson Investigator, *Co-corresponding authors

Motor cortex stimulation (MCS) reduces pain experience in humans suffering from chronic pain; however, how motor cortex activity drives antinociception is poorly understood. This direct influence of motor circuitry on sensory experience provides an ideal system to dissect feedforward motor circuits' impact on sensory afferent signaling. Using mice as a model system, we sought to dissect the underlying mechanisms of MCS by detailing response properties of key neurons in the stimulation site (i.e., motor cortex) and in a downstream circuit responsible for modulating orofacial nociception during and following MCS. Using a mouse-sized transcranial magnetic stimulation (TMS) device we built, we performed TMS of the vibrissa motor cortex in mice with an infraorbital nerve constriction, a model of trigeminal

neuropathic pain. We observed a dose-dependent decline in pain behaviors for one week. We then used voltage imaging, chemogenetics, pharmacology, and Neuropixels electrophysiological probes to reveal that MCS activates layer 5 pyramidal neurons, which recruit a downstream opioidergic circuit in the medulla to induce antinociception through direct projections to the spinal trigeminal nucleus caudalis. Altogether, our data show that motor cortex feedforward circuits tune nociceptive sensory signaling, RVM neurons drive these sensory modifications, and RVM endogenous opioid signaling regulates both MCS-induced antinociception and movement. Funding: K99DE031802 - 01A1, R01NS106301

9. Short talk
Stimulus novelty uncovers coding diversity in visual cortical circuits
Farzaneh Najafi, Marina Garrett, Peter Groblewski, Alex Piet, Doug Ollerenshaw, Iryna Yavorska, Stefan Mihalas, Anton Arkhipov, Christof Koch, Shawn R Olsen; Affiliations: Allen Institute
The detection of novel stimuli is critical to learn and survive in a dynamic environment. Though novel stimuli powerfully affect brain activity, their impact on specific cell types and circuits is not well understood. Disinhibition is one candidate mechanism for novelty-induced enhancements in activity. Here we characterize the impact of stimulus novelty on disinhibitory circuit components using longitudinal 2-photon calcium imaging of Vip, Sst, and excitatory populations in the mouse visual cortex. Mice learn a behavioral task with stimuli that become highly familiar, then are tested on both familiar and novel stimuli. Mice consistently perform the task with novel stimuli, yet responses to stimulus presentations and stimulus omissions are dramatically altered. Further, we find that novelty modifies coding of visual as well as behavioral and task information. At the population level, the direction of these changes is consistent with engagement of the Vip-Sst disinhibitory circuit. At the single cell level, we identify separate clusters of Vip, Sst, and excitatory cells with unique patterns of novelty-induced coding changes. This study and the accompanying open-access dataset reveals the impact of novelty on sensory and behavioral representations in visual cortical circuits and establishes novelty as a key driver of cellular functional diversity.

10. Short talk
Jaw muscle spindle afferents as multiplexed channels for sensing and guiding orofacial movement
William Olson, Varun Chokshi, Jeong Jun Kim, Montrell Vass, Noah Cowan, Daniel O'Connor; Johns Hopkins University Kavli Neuroscience Discovery Institute, Johns Hopkins University

Muscle spindle afferents (MSAs) are muscle stretch sensors that provide real-time feedback to the nervous system about body position and movement. While classic models proposed that MSAs are 'kinematic encoder' sensory neurons, more recent models highlight the dynamic tuning of these neurons and propose they instead serve task-specific motor control functions. Here, we record from MSAs innervating the jaw musculature (located in the mesencephalic trigeminal nucleus, MEV) in behaving mice to test these competing hypotheses. In our task, head fixed mice lick a moving 'port' through an arc of seven locations surrounding the mouse's face to receive a water reward. MSA ensemble activity is complex, evolving over single lick cycles as well as over entire licking sequences. While a large component of MSA ensemble activity is correlated with jaw kinematics, major components of the activity show clear decoupling from the kinematics. We find that (1) encoding of kinematics varies across the MSA ensemble, with a small fraction of single MSAs showing strong encoding in a manner consistent with classic models, (2) MSAs innervating jaw synergist muscles show distinct activity based on muscle of innervation, with MSAs from one muscle (temporalis) showing the strongest kinematic encoding, and (3) comparison of activity during active licking vs. passive movement under anesthesia reveals that MSA kinematic tuning is actively set by the awake animal. Funding: NIH F32MH120873, Kavli Foundation

11. Short talk
Sparse and distributed cortical populations mediate sensorimotor integration
Pancholi, Ravi; Sun-Yan, Andrew; Laughton, Maya; Peron, Simon

Touch information is central to sensorimotor integration, yet little is known about how cortical touch and movement representations interact. Touch- and movement-related activity is present in both somatosensory and motor cortices, making both candidate sites for touch-motor interactions. We studied touch-motor interactions in layer 2/3 of the primary vibrissal somatosensory and motor cortices of behaving mice. Volumetric two-photon calcium imaging revealed robust responses to whisker touch, whisking, and licking in both areas. Touch activity was dominated by a sparse population of broadly tuned neurons responsive to multiple whiskers that exhibited longitudinal stability and disproportionately influenced interareal communication. Movement representations were similarly dominated by sparse, stable, reciprocally projecting populations. In both areas, many broadly tuned touch cells also produced robust licking and/or whisking responses. These touch-licking and touch-whisking neurons showed distinct dynamics suggestive of specific roles in shaping movement. Cortical touch-motor interactions are thus mediated by specialized populations of highly responsive, broadly tuned neurons.

12. Short talk
Input- and target-specific synaptic plasticity in neocortical layer 1 during sensory learning
Ajit Ray, Joseph C Christian, Alison L Barth

Changes in higher-order thalamic inputs to cortical neurons are implicated in learning. These inputs densely innervate layer 1 (L1), where excitatory synaptic changes in pyramidal neurons (Pyr) have been demonstrated by anatomical and electrophysiological methods. However, L1 also houses dendrites from several inhibitory populations including VIP interneurons, which are a critical circuit node controlling computation across the cortical column. Here, we tested whether VIP dendrites in L1 also show input-specific synaptic changes during learning. Using a high-throughput genetically-encoded fluorescence-based synapse analysis pipeline that we previously used to show thalamocortical synaptic changes on L5 Pyr in a whisker-dependent learning task, we examined structural changes in thalamic (POm) synapses on VIP interneurons in barrel cortex. Sensory association drove a rapid increase in the overall number and size of excitatory synapses on VIP dendrites in L1, but not in their L2 dendrites. POm-specific synapses showed a similar increase in size as non-thalamic synapses. Thus, learning triggers broad synaptic changes across multiple long-range inputs to VIP neurons and are not restricted to thalamic inputs. In contrast, we observed POm-specific plasticity in L1 dendrites of L2/3 Pyr in the same task. This suggests that VIP neuron activity in the sensory cortex may sharply increase during early learning due to stronger feedback from other cortical areas and higher-order thalamus.

13. Short talk
Responses to cortical stimulation reveal thalamocortical state-dependent features in mice and humans
Simone Russo, Leslie Claar, Lydia Marks, Giulia Furregoni, Flavia Maria Zauli, Gabriel Hassan, Michela Solbiati, Simone Sarasso, Mario Rosanova, Ivana Sartori, Andrea Pigorini, Christof Koch, Marcello Massimini, Irene Rembado

Stimulating neocortex using a brief pulse is used in several experimental and clinical preparations. The extent to which cortico-thalamo-cortical or cortico-cortical feedback circuits contribute to the late responses is unclear. Stimulating secondary motor cortices with a single pulse while recording from head-fixed mice using EEG and Neuropixels probes leads to a stereotyped tri-phasic EEG response that is modulated by the state of the animal, such that movement leads to a smaller late response compared to resting. We demonstrate that when optogenetically inhibiting the thalamus at different points in time, the late EEG signal component likewise shifts in time, correlated to the degree of bursting and synchronicity of thalamic neurons. Both factors can be modulated by movement, causing the observed modulation of the EEG response. Intracranial stereo-encephalographic recordings of electrically evoked responses in epileptic patients and EEG responses to transcranial magnetic stimulation in healthy subjects revealed a similar modulation of the late responses with movement, here of the hand. These results identify a state-dependent engagement of the cortico-thalamo-cortical loop at the origin of EEG responses to cortical stimulation which is preserved across species and stimulation modalities.

14. Short talk

In-Vivo Recording of Optogenetically Identified Rapidly-Adapting Whisker Neurons

P. M. Thompson, Jun Takatoh, Seonmi Choi, Andrew Harahill, and Fan Wang. McGovern Institute for Brain Research. Massachusetts Institute of Technology

The sensation of touch is constructed from multiple types of unique sensory receptors acting in parallel. The functions of morphologically distinct mechanoreceptors in the whiskers during active touch remain poorly understood with the exception of Merkel ending neurons. We describe how the genes NetrinG1 and Chondrolectin are selectively expressed in two specific types of touch receptors in the mouse whisker follicle: club-like and lanceolate endings, respectively. We optogenetically-identified primary trigeminal afferents with these endings in vivo and recorded their activities during behavior. We found that both ending types were rapidly adapting to touch. While small number of neurons displayed an increased spiking probability with the force of contact, most of these neurons only fired transiently at the onset of contact during periods of relatively low whisker forces. These neurons were not refractory, however, because the same units could be driven to fire at high rates in response to high-frequency stimulation. Our results suggest that these neurons are ideally suited to detect the precise timing of contact, and that the rapid adaptation in these neurons may be the result of receptive fields for high-frequency components of mechanical stimuli, rather than being due to intrinsic neuronal accommodation.Funding: NS 077986

15. Short talk

Prrxl1 knockout – a non-invasive model of chronic pain

Ezekiel Willerson(4,2), Leah Kramer(1,2), Eliana Eichler(2), Jacob Zar(1,2), Kayla Wilamowsky(2), Giuseppe Cataldo(1,2), Joshua C. Brumberg(1,2,3,4) 1. Neuroscience Major, Queens College, CUNY 2. Department of Psychology, Queens College, CUNY 3. Neuroscience Subprogram, Biology PhD Program in Biology, The Graduate Center, CUNY 4. Behavioral and Cognitive Neuroscience Training Area, PhD Program in Psychology, The Graduate Center, CUNY

Prrxl1, a paired homeodomain transcription factor, is indispensable for development of patterning in the trigeminal lemniscal pathway. In Prrxl1 knockout (KO) animals, somatotopic patterning is intact in the spinal trigeminal nucleus (SpV) yet absent along the entire trigeminal lemniscal pathway from principal sensory nucleus (PrV) to cortex. The PrV has been implicated in a variety of active sensing behaviors, while the SpV is associated with transmission of noxious input. Prrxl1 KO animals were previously known to be hypo-algesic to the body, yet here we show they are hyper-algesic in the orofacial region, as seen by facial withdrawal (von Frey) and excessive facial grooming. Grooming was confirmed as pain behavior by injecting histamine (which produces itch) and capsaicin (pain) into the whisker pad of wildtype mice. Only capsaicin resulted in the stereotyped wiping seen in Prrxl1 KOs. Mice treated with capsaicin also scored higher on the facial grimace scale. Next, we analyzed anatomical correlates of these behaviors. Perineuronal nets (PNNs), extracellular matrix structures integral for synapse stability, are reportedly degraded in chronic pain. When stained, we found that the PrV of Prrxl1s exhibit reduced PNNs. Microglia activation has also been implicated in chronic pain. Upon staining and reconstruction, we found Prrxl1 PrV microglial took on an “activated” phenotype. In sum, knockout of Prrxl1 results in a chronic model of orofacial pain.Funding source: NS126987

16. Short talk

Organizing principles of cortical interneurons

F. Yáñez[1], F. Messore[2], G. Qi [3], D. Feldmeyer[3], B. Sakmann[4], M. Oberlaender[1].
1. MPI for Neurobiol. of Behav., Bonn, Germany
2. Univ. of Oxford, Oxford, UK
3. Res. Ctr. Juelich, Juelich, Germany
4. MPI for Biol. Intelligence, Martinsried, Germany

Cortical inhibitory neurons (INs) are diverse, including attributes such as morphology and intrinsic physiology. Here we systematically assess the degree and character of the variability of these properties across the entire cortical depth of rat S1. We analyzed 306 morphological reconstructions and current injection responses, which were representative of the distribution of INs per depth. Each IN was comprehensively characterized by morphoelectric features. We assigned INs into 13 e-, 20 m-, and 25 me-types using unsupervised multimodal clustering. These classes are consistent with previous reports in mouse V1. Soma depth is the primary determinant for defining me-types. The spatial extent of both axons and dendrites increases as a function of cortical depth, regardless of me-type. The spike-frequency also increases with cortical depth, whereas the spike-frequency adaptation remains unaffected by it. A simple depth-independent relationship, where the spike-frequency exceeds the spike-frequency adaptation, delineates a class of INs resembling the distribution of Pvalb-INs, including small to large basket, chandelier, and translaminar cells. The assignment based on depth-independent relationships shows a strong correspondence with the distributions of Pvalb-, Sst-, and Vip-expressing INs in both rat S1 and mouse V1. Thus, simple organizing principles may largely account for the diversity of INs through the adjustment of their morphoelectric properties in cortex. Funding: DFG

17. Short talk
Ultra-Flexible tentacle electrodes for months-long tracking of assemblies of single units simultaneously from many brain areas.
Tansel Baran Yasar, Peter Gombkoto, Eminhan Ozil, Alexei Vyssotski, Angeliki Vavladeli, Simon Steffens, Orhun Caner, Eren, Wolfger von der Behrens, Mehmet Fatih Yanik

While the number of channels in the state-of-the-art in vivo electrophysiology systems is rapidly increasing, these technologies do not cover simultaneously more than a few brain areas equally well and the mismatch between these probes and the brain causes significant tissue damage, limiting the longevity and quality of recordings. To address these challenges, we developed ultra-flexible intracortical microelectrode arrays - Ultra-Flexible Tentacle Electrodes (UFTE). Unlike existing flexible electrode technologies, we can rapidly adapt the spatial distribution of UFTE electrodes and deliver them simultaneously into several brain areas at arbitrary locations with no depth limitations. Each channel is mechanically independent in these arrays, ensuring optimal compatibility with brain tissue. Immunostaining of the brain slices revealed no detectable long-term reaction/damage in the brain tissue surrounding the UFTEs. Our UFTE recordings achieve 2-3x higher signal-to-noise ratio (SNR) with respect to the state of the art. Our design allows packing hundreds of channels into each brain area with a compact footprint. We were able to perform stable recordings of hundreds of single-units from each area and track neuronal assemblies for many months simultaneously from the medial prefrontal cortex (mPFC), retrosplenial cortex (RSC), dorsal hippocampus (dHPC), intermediate hippocampus (iHPC), and orbitofrontal cortex (OFC) in freely moving rats using UFTEs. We also developed a second gen

18. Short talk
Connectomic analysis of astrocyte-synapse interactions in mouse barrel cortex
Yagmur Yener, Alessandro Motta, Moritz Helmstaedter
*Max-Planck Institute for Brain Research

Astrocytes express sensors for neurotransmitters released by synapses and are thought to release chemicals associated with neuromodulation. Because of their complex morphology, each astrocyte can contact thousands of synapses in its cellular territory. A systematic mapping of the glia-connectome interaction in cortex is still lacking. Here, we developed classifiers for voxel-wise classification of astrocytes using convolutional neural networks. This enabled us to quantify the nature of the contact between synaptic elements and the peri-synaptic glial processes that partially wrap around synapses. Using a previously published 3D EM dataset from mouse barrel cortex (Motta et al., 2019; n=200,507 synapses), we systematically analyzed the spatial relation between astrocytes and synapses. We observed that there is a strong dependence of the fraction of astrocyte processes at the periphery of dendritic spine synapses on synapse size. Importantly, this effect is absent in other synapse types and

does not occur for random non-synaptic interfaces. We furthermore found glial coverage to depend on connectomic types, such as thalamocortical axons, smooth dendrites, inhibitory synapses, and investigated its properties as a possible indicator of recent synaptic activity and synaptic plasticity. Together, our data indicate the relevance of astrocytic coverage for synapse stability, and demonstrate a surprising level of specificity for particular synaptic types.

19. Short talk
What does motor cortex tell sensory cortex?
Edward Zagha, Department of Psychology, University of California Riverside

Whisker motor cortex sends robust mono-synaptic and poly-synaptic projections to whisker sensory cortex. These pathways have long been considered important in the context of active sensing and corollary discharge. In this talk, I will develop the argument that these motor cortex to sensory cortex pathways are well positioned to contribute to non-motor, cognitive processes. To support this argument, I will present data from a recent study in our lab demonstrating a specific role for these pathways for sensory discrimination in a passive sensing task: suppressing the propagation of non-target stimuli into target-aligned response fields. By modulating sensory cortex excitability and receptive field properties, motor cortex can modulate top-down context for motor and non-motor processes.Supported by: NIH/NINDS R01NS107599

20. Short talk (Sponsor talk)
FemtoFiber ultra Lasers for Neuroscience
Joseph Mastron, TOPTICA Photonics, Inc.

TOPTICA is excited to introduce our FemtoFiber ultra lasers, tailored for applications in Neuroscience. Our stable, low-maintenance laser systems at 780 nm, 920 nm, and 1050 nm offer exceptional pulse quality comparable to Ti:Sapph lasers while maintaining the advantages of a fiber laser. With our innovative design, these laser systems can be optically synchronized for multi-color experiments. In this talk, I will discuss the underlying technologies that enable these capabilities, and briefly highlight some applications.

POSTERS

Coding of sensorimotor variables in dysgranular vibrissal somatosensory cortices
Alisha Ahmed; Andy Garcia; Maya Laughton; Andrew Sun-Yan; Simon Peron

In the mouse whisker system, somatosensory thalamus outputs to primary and secondary vibrissal somatosensory cortices (vS1 and vS2), as well as the dysgranular zone (Killackey et al. 1983), a strip of cortex near the vibrissal and forepaw representations. Despite extensive studies of vS1 and vS2, the dysgranular zone's response to whisker touch remains poorly understood. Vibrissal S1 sends outputs to three areas within the dysgranular zone: the anteromedial (AM), centromedial (CM), and posteromedial (PM) areas (Yamashita et al. 2018). These areas may thus contribute to processing whisker touch. We recorded activity in vS1, vS2, AM, CM, and PM using volumetric two-photon calcium imaging in transgenic mice expressing GCaMP6s in cortical excitatory neurons. We trained mice trimmed to two or three whiskers to actively palpate a pole with their whiskers, reporting touch of the pole with licks to one of two lickports and no touch with licks to the other. We compared touch, whisking, and licking activity across all areas. AM, CM, and vS2 had a larger fraction of touch neurons that were responsive to multiple whiskers than vS1. We also found a higher fraction of lick responsive neurons in CM and a lower fraction of whisking neurons in AM and CM than in vS1. These findings suggest that dysgranular areas may be crucial for integrating touch information across multiple whiskers, likely combining touch information with specific forms of motor information, such as licking and whisking.

Investigating the role of interneuron populations in whisking behavior through chemogenetics
Julien Guy, Jochen F. Staiger
UMG Institute for Neuroanatomy

Because of the precisely defined somatotopic map, the barrel cortex (wS1) is a favorable model for the study of microcircuits and investigation of the roles of neuronal subtypes in the processing of sensory information. Physiological mechanisms of wS1 of whisking behavior have mostly been investigated on head-fixed animals to gain better control of stimuli and precise measurement. However, there is a limited number of studies investigating whisker-based perceptual detection during natural behavioral conditions. Also, the behavioral relevance of parvalbumin (PV) and vasoactive intestinal polypeptide (VIP) expressing GABAergic neurons remains unclear. We aimed to define the contributions of PV and VIP expressing populations within the wS1 towards texture discrimination on freely moving mice using chemogenetic manipulation. To this extent, we have established a textured T-maze task, which is an operant conditioning protocol for whisker-based tactile discrimination and to measure the perceptual detection threshold of freely moving mice. In this protocol, food-restricted animals were trained for a 2-choice reward task in a T-maze. Textured T-maze come out as a reliable measure for the discriminiation capacity of mice. Furthermore, it can be safely combined with chemogenetic manipulation since neither intracranial surgery nor IP injection of C21 impaired mice's performance.

Cortical circuits for goal-directed cross-modal transfer learning
Maëlle Guyoton, Giulio Matteucci, Charlie G. Foucher, & Sami El-Boustani
University of Geneva

In an environment full of complex multisensory stimuli, flexible and effective behaviors rely on our ability to transfer learned associations across sensory modalities. Here we explored the intertwined cortical representations of visual and whisker tactile sensations in mice and their role in cross-modal transfer learning. Mice trained to discriminate stimulations of two different whiskers seamlessly switched to the discrimination of two visual cues only when reward contingencies were spatially congruent across modalities. Using multi-scale calcium imaging over the dorsal cortex, we identified two distinct associative domains within the ventral and dorsal streams displaying visuo-tactile integration. We observed multimodal spatial congruency in visuo-tactile areas, both functionally and anatomically, for feedforward and feedback projections with primary sensory regions. Single-cell responses in these domains were tuned to congruent visuo-tactile stimuli. Suppressing synaptic transmission specifically in the dorsal

stream impaired transfer learning. Our results delineate the pivotal cortical pathway necessary for visuo-tactile multisensory integration and goal-directed cross-modal transfer learning.

Modeling sensory perception with neurobiologically detailed artificial neural networks
Matthew Keaton; Rieke Fruengel; Marcel Oberlaender
Max Planck Institute for Neurobiology of Behavior

Unraveling cellular and circuit mechanisms that underlie perception is extremely challenging, because even the simplest sensory stimulus activates hundreds of thousands of neurons distributed throughout the entire brain. Yet, the brain is able to classify this noisy input across the hierarchy of cortical processing stages, triggering flexible and nuanced behaviors - a hallmark of higher cognition. How the brain accomplishes such robust perception is unclear. Here we introduce a novel computational modeling approach that allows translating cellular and circuit mechanisms that represent neural substrates of perception into design principles for artificial neural networks (ANNs). For this purpose, we motivate the network architecture of ANNs with empirical anatomical data from both dense and sparse reconstructions of local and long-range connectivity in the thalamocortical whisker system of the rat. Moreover, we inform the activation functions of nodes in the ANNs with empirical physiological data to capture both the perisomatic and nonlinear dendritic physiology of cortical pyramidal neurons. We provide first evidence that our approach leads to an improved performance and ability of such ANNs to generalize across tasks, and less reliance on large training datasets. These results indicate that neurobiologically detailed ANNs could facilitate dissecting the neural basis of perception, and showcase how higher brain functions emerge from their neurobiological implementations.

A combinatorial code for learned motor actions
Jae-Hyun Kim, Nuo Li
Department of Neuroscience, Baylor College of Medicine, Houston, TX

Motor cortex neurons exhibit preparatory activity that instructs specific future movements. It remains unclear whether activity producing the same movement is stably maintained oveer time and across different sensorimotor contexts. To explore these questions, we used automated home-cage training and in-cage optogenetics to establish a cortex-dependent continual learning paradigm. Mice learned to perform directional licking in different tasks for up to 10 months. We combined this paradigm with chronic 2-photon imaging of anterior lateral motor cortex (ALM) to track the representation of learned actions across extended time and over continual learning. Within the same task context, the pattern of activity around movement was stably retained for 2 months with little representational drift. As mice learned to make the same licking actions under new task contexts, new preparatory states emerged, while activity related to sensory stimulus and movement execution remained surprisingly stable. Yet, the old preparatory states are not lost, re-learning to make the same actions under the previous context re-activated the previous preparatory states, even 3 months later. These data show that learned motor actions are stored in multiple representations in conjunction with its sensorimotor context, which we call a combinatorial code. These results suggest motor cortex exhibit high-capacity storage for context-specific motor memories. Funding: R01NS131229, R01NS112312

Alterations in homeostatic plasticity in Fmr1 KO mice following unilateral whisker deprivation
Lakhani, A & Wenner, P.
Emory University

Fragile X Syndrome (FXS) is the most common form of inherited intellectual disability. It is caused by a loss-of-function of the FMR1 gene on the X chromosome, resulting in the absence of FMRP. Altered cortical activity is an underlying pathology of FXS that is associated with sensory hypersensitivity and epileptic vulnerability. Previous work suggests that homeostatic mechanisms are impaired in FXS models. Unilateral whisker deprivation has been shown to trigger homeostatic responses in the barrel cortex. This has been expressed as an increase in whisker-evoked responses in L4 and L2/3 regular spiking (RS)

excitatory neurons. In order to determine if and how homeostatic plasticity was altered in the Fmr1 KO mouse model of FXS, we trimmed whiskers every other day from postnatal day 14-21 (PD 14-21). Whiskers were deflected using a 3x3 array of piezoelectric actuators to stimulate the principal/most responsive whisker and surrounding whiskers at multiple velocities. Spiking activity was recorded using a 64-channel probe in the somatosensory cortex of lightly anesthetized mice. Preliminary results suggested that spiking in L5/6 RS neurons in control mice was reduced in the KO compared to WT littermates. In addition, following 7 days of whisker deprivation, the sensitivity to whisker stimulation was very different in the whisker-deprived KO compared to whisker-deprived WT littermates.

Behavioral role of individual mouse vibrissal somatosensory cortex barrels in discriminating between touch by distinct whiskers

Laughton Maya, Sun-Yan Andrew, Ryan Lauren, Peron Simon
NYU

As nocturnal mammals, mice use tactile sensation from facial whiskers to probe their surroundings. The mouse primary vibrissal somatosensory cortex is partitioned into a topographic map of well-defined columns ('barrels') receiving input from a single primary whisker. Prior loss-of-function studies established columnar scale lesions of the barrel of interest, in a single whisker behavior task, degrade tactile discrimination but not object detection. In two whisker behavior tasks, mice discriminate between stimuli at distinct locations of the sensory epithelium. It is unclear if this is more like a detection task with distinct sites or a discrimination task. In mice with cranial windows, doing a two whisker behavior task, we lesioned barrels using a femtosecond laser. Dual barrel lesions transiently impacted performance of mice using adjacent whiskers, without disrupting vibrissal kinematics. Single barrel lesions also transiently impacted performance of mice using adjacent whiskers. We analyzed if performance decline was whisker specific or the same across both whiskers. To ensure effects were not a result of degrading neighboring tissue, we performed single barrel lesions in mice using more distal whiskers to solve the task. Post-lesion, the resulting decline in this behavior was smaller and mice tended to recover within the same session rather than across multiple sessions. Thus, tactile information is being integrated across distinct locations of the sensory epithelium.

Poster

Astrocytes modulate a critical window of microglia-mediated synapse remodeling in the barrel cortex

Yi-Han Lee#, Travis Faust#, Ciara O'Connor, Margaret Boyle, Dorothy Schafer
Department of Neurobiology, UMass Chan Medical School, Worcester, MA, USA

Neuroplasticity is required for learning and adaptation to the ever-changing environment. During early development, changes in neuronal activity lead to removal of less active synapses. Microglia and astrocytes participate in the activity-dependent synapse remodeling by engulfing the synapse from less active neurons. However, the clearance of synapses is less robust after specific "critical windows" of development. How these two glial cells precisely clear up specific synapses and regulate the closure of the critical window remains an open question. In mice, the activity-dependent synaptic remodeling can be studied by whisker manipulation. Decreased sensory input from the whiskers results in pruning of thalamocortical presynaptic terminals in the whisker barrel region of the somatosensory cortex. Previously in our study, we demonstrate that microglia are responsible for the removal of thalamocortical synapses in somatosensory cortex upon whisker lesioning. Yet astrocytes do not engulf the synapses but decrease their contact with the synapses in advance of synaptic pruning when whiskers are lesioned at early postnatal stage. Interestingly, when whisker lesioning occurs at later developmental stage, astrocytes no longer retract their processes and synaptic pruning is dramatically reduced. We hypothesize that astrocyte-synapse contacts might be a key modulator that determines the closure of developmental critical window for activity-dependent synaptic pruning. 2R01MH113743

Diverse, state-dependent coupling between cortical activity patterns and the activity of hippocampal and thalamic neuron

Chris Lewis[1], Adrian Hoffmann[1,2], Stewart Berry[1,2], Linus Meienberg[1,2], T. Baran Yasar[2,3], M. Fatih Yanik[2,3], Fritjof Helmchen[1,2]
1)Brain Research Institute, University of Zurich
2)Neuroscience Center Zurich, University of Zurich and ETH Zurich
3)Institute for Neuroinformatics, University of Zurich and ETH Zurich

Adaptive behavior is enabled by the dynamic coordination of diverse signals across spatial and temporal scales. We combined extracellular recording of subcortical activity using flexible multi-electrode arrays with wide-field or 2-photon calcium imaging of cortex to reveal aspects of large-scale dynamics invisible to standard, single-modality approaches. We investigated the relationship between fast dynamics recorded with chronically implanted multi-electrode arrays with simultaneously acquired cortical activity patterns monitored via the expression of GCaMP6f in transgenic animals. We find diverse state-dependent patterns of coupling between concurrently acquired hippocampal and thalamic spiking activity and calcium dynamics across dorsal cortex. The repertoire of activity patterns in single hippocampal and thalamic neurons is stable across days. However, within a recording session the activity of subcortical neurons exhibits distinct patterns of brain-wide coupling dependent on changes in behavioral state, as well as ongoing, intrinsic variations in brain state. The topographical patterns of coupling between the activity of subcortical neurons and cortex activation are anatomically specific and fluctuate over long time scales (10s of seconds to minutes) in a frequency-dependent manner. We believe that these diverse, dynamic activity patterns reflect shifts in functional connectivity that underlie distinct modes of brain-wide coordination and communication.

Connectomic traces of Hebbian plasticity in mouse and human cortex

S. LOOMBA1, A. KHALIFA1, A. MOTTA1, J. GEMPT2, H.-S. MEYER2, M. HELMSTAEDTER1; 1Max Planck Inst. For Brain Res., Frankfurt Am Main, Germany; 2Universitätsklinikums Hamburg-Eppendorf, Hamburg, Germany

Synaptic plasticity plays a crucial role in the organization of neuronal circuits and refinement of their connectivity during learning and development. Our current knowledge of the mechanisms that underlie synaptic plasticity is primarily based on laboratory animal models, in particular rodents. Recent advancements in the accessibility of human tissue have made it feasible to perform physiological studies on human tissue slices, enabling the investigation of synaptic plasticity in human. However, how the principles of synaptic plasticity apply to the human brain remains poorly understood. In this study, we employed 3-dimensional electron microscopy of human, non-human primate and mouse supragranular cortical samples to identify the structural effects of Hebbian plasticity in connectomic data. We quantified the rate of excitatory spines undergoing synaptic weight adaptation consistent with Hebbian learning. The human cortex shows abundance of spines with large synaptic weights, a feature absent in both the mouse and non-human primate cortex. Additionally, the synaptic weights consistent with Hebbian plasticity show stronger correlations in human cortex compared to the mouse and non-human primate cortex. These results suggest that the Hebbian plasticity may be quantitatively different in the human cortex from other species. Together this opens new avenues for future exploration into the functional significance and influence of these distinct plasticity characteristics.

Modeling sensory perception with neurobiologically detailed artificial neural networks

Matthew Keaton; Rieke Fruengel; Marcel Oberlaender

Unraveling cellular and circuit mechanisms that underlie perception is extremely challenging, because even the simplest sensory stimulus activates hundreds of thousands of neurons distributed throughout the entire brain. Yet, the brain is able to classify this noisy input across the hierarchy of cortical processing stages, triggering flexible and nuanced behaviors - a hallmark of higher cognition. How the

brain accomplishes such robust perception is unclear. Here we introduce a novel computational modeling approach that allows translating cellular and circuit mechanisms that represent neural substrates of perception into design principles for artificial neural networks (ANNs). For this purpose, we motivate the network architecture of ANNs with empirical anatomical data from both dense and sparse reconstructions of local and long-range connectivity in the thalamocortical whisker system of the rat. Moreover, we inform the activation functions of nodes in the ANNs with empirical physiological data to capture both the perisomatic and nonlinear dendritic physiology of cortical pyramidal neurons. We provide first evidence that our approach leads to an improved performance and ability of such ANNs to generalize across tasks, and less reliance on large training datasets. These results indicate that neurobiologically detailed ANNs could facilitate dissecting the neural basis of perception, and showcase how higher brain functions emerge from their neurobiological implementations.

Alterations in homeostatic plasticity in Fmr1 KO mice following unilateral whisker deprivation
Lakhani, A & Wenner, P.

Fragile X Syndrome (FXS) is the most common form of inherited intellectual disability. It is caused by a loss-of-function of the FMR1 gene on the X chromosome, resulting in the absence of FMRP. Altered cortical activity is an underlying pathology of FXS that is associated with sensory hypersensitivity and epileptic vulnerability. Previous work suggests that homeostatic mechanisms are impaired in FXS models. Unilateral whisker deprivation has been shown to trigger homeostatic responses in the barrel cortex. This has been expressed as an increase in whisker-evoked responses in L4 and L2/3 regular spiking (RS) excitatory neurons. In order to determine if and how homeostatic plasticity was altered in the Fmr1 KO mouse model of FXS, we trimmed whiskers every other day from postnatal day 14-21 (PD 14-21). Whiskers were deflected using a 3x3 array of piezoelectric actuators to stimulate the principal/most responsive whisker and surrounding whiskers at multiple velocities. Spiking activity was recorded using a 64-channel probe in the somatosensory cortex of lightly anesthetized mice. Preliminary results suggested that spiking in L5/6 RS neurons in control mice was reduced in the KO compared to WT littermates. In addition, following 7 days of whisker deprivation, the sensitivity to whisker stimulation was very different in the whisker-deprived KO compared to whisker-deprived WT littermates.

Behavioral role of individual mouse vibrissal somatosensory cortex barrels in discriminating between touch by distinct whiskers
Laughton Maya, Sun-Yan Andrew, Ryan Lauren, Peron Simon

As nocturnal mammals, mice use tactile sensation from facial whiskers to probe their surroundings. The mouse primary vibrissal somatosensory cortex is partitioned into a topographic map of well-defined columns (‘barrels’) receiving input from a single primary whisker. Prior loss-of-function studies established columnar scale lesions of the barrel of interest, in a single whisker behavior task, degrade tactile discrimination but not object detection. In two whisker behavior tasks, mice discriminate between stimuli at distinct locations of the sensory epithelium. It is unclear if this is more like a detection task with distinct sites or a discrimination task. In mice with cranial windows, doing a two whisker behavior task, we lesioned barrels using a femtosecond laser. Dual barrel lesions transiently impacted performance of mice using adjacent whiskers, without disrupting vibrissal kinematics. Single barrel lesions also transiently impacted performance of mice using adjacent whiskers. We analyzed if performance decline was whisker specific or the same across both whiskers. To ensure effects were not a result of degrading neighboring tissue, we performed single barrel lesions in mice using more distal whiskers to solve the task. Post-lesion, the resulting decline in this behavior was smaller and mice tended to recover within the same session rather than across multiple sessions. Thus, tactile information is being integrated across distinct locations of the sensory epithelium.

New definition of motor areas in the cerebral cortex
**A. MAHARJAN*[1], J. M. GUEST[2], J.-A. RATHELOT[3], P. L. STRICK[4], M. OBERLAENDER[1]
1. Max Planck Inst. for Neurobio. of Behavior – caesar, Bonn, Germany;

2. In Silico Brain Sci., Ctr. of Advanced European Studies and Res., Bonn, Germany;
3. Inst. des Neurosciences de la TImone (UMR 7289), Aix-Marseille Univ., Marseille, France;
4. Systems Neurosci. Inst., Univ. Pittsburgh Sch. Med., Pittsburgh, PA

A primary function of the cerebral cortex is to control voluntary movement. How cortical circuits orchestrate movement remains however poorly understood. Dissecting the circuits for motor control is challenging because neurons in the cortex generally do not form direct monosynaptic connections with motoneurons (MNs) in the spinal cord or brainstem. Instead, pyramidal tract neurons in cortical layer 5 (L5PTs) connect to highly diverse sets of premotor neurons, which then connect to highly diverse sets of MNs, which then innervate several different muscles. Identifying the L5PTs throughout the cerebral cortex that have disynaptic access to the MNs of a single muscle remains hence a major challenge. Here we address this challenge by utilizing wildtype rabies virus, which we inject into the facial muscle that moves a single whisker on the snout of the rat. We complement these experiments with injections into a single muscle that moves digits on the rats' forepaw. We find that disynaptic connections from L5PTs to both muscles extend far beyond the primary motor cortex to the primary sensory cortices, higher-order motor and sensory cortices, and even to association areas, such as the insular cortex. Notably, the distributions of L5PTs within and across these cortical areas is highly specific for each muscle. Our findings set the stage to quantitatively dissect the organization of the circuits by which the cerebral cortex orchestrates movement.

FemtoFiber ultra Lasers for Neuroscience
Joseph Mastron, TOPTICA Photonics, Inc.

TOPTICA is excited to introduce our FemtoFiber ultra lasers, tailored for applications in Neuroscience. Our stable, low-maintenance laser systems at 780 nm, 920 nm, and 1050 nm offer exceptional pulse quality comparable to Ti:Sapph lasers while maintaining the advantages of a fiber laser. With our innovative design, these laser systems can be optically synchronized for multi-color experiments. In this talk, I will discuss the underlying technologies that enable these capabilities, and briefly highlight some applications.

The biophysical mechanisms underlying cellular computation of L5 pyramidal tract neurons in the barrel cortex
Bjorge Meulemeester, Arco Bast, Marcel Oberlaender
Max Planck Institute for neurobiology of Behavior
Morphology and the distribution of ion channels on the dendrite are major determinants of cellular computation. How the interplay of spatially distributed ion channels affects somatic responses remains poorly understood. In general, similar cellular dynamics can be achieved with vastly different ionic currents, while minor variations in ionic currents can yield vastly different cellular dynamics. Here, we generate millions of biophysically detailed models of layer 5 pyramidal tract (L5PT) neurons, which map out the spectrum of possibilities of how channels can be distributed to achieve the characteristic dendritic and somatic electrophysiology of this celltype. We show how to utilise Explainable Artificial Intelligence (XAI) to reveal nonlinear multidimensional relationships between the distribution of channels and somatic output that can be empirically tested. Our approach thereby is an important step towards linking electrophysiological responses to their mechanistic origin.

Brainstem control of larynx and Vocal-respiratory coordination
Jaehong Park, Seonmi Choi, Jun Takatoh, Shengli Zhao, Andrew Harrahill, Bao-Xia Han, Fan Wang
MIT

Vocalization and respiration are closely related behaviors, and their neural circuits are also heavily intermingled in the brainstem. Therefore, it was difficult to dissect precise neural mechanisms of vocal production and vocal-respiratory coordination. The Retroambiguus Nucleus (RAm) in the brainstem regulates vocal pattern generations and their coordination with breathing, but the details are still unclear.

Here, we identified a vocalization-specific laryngeal premotor population in the RAm using an activity-dependent labeling approach in adult mice. Strong Fos activity was found in neurons in the RAm after vocalization (RAm^{VOC} here after), and therefore we tagged those neurons with a Fos-based tagging technique. Monosynaptic tracing of laryngeal motoneurons and molecular identification of the RAm^{VOC} neurons confirmed that RAm^{VOC} neurons are excitatory laryngeal premotor neurons. Inhibition of the RAm^{VOC} neurons by expressing tetanus light chains abolished vocalization in mice, including ultrasonic vocalizations (USVs) and audible stress-response squeaks. Optogenetic stimulation of the RAm^{VOC} neurons induced vocal cord closure and sufficiently evoked USVs without any behavioral contexts. Interestingly, the opto-induced USVs were coordinated with on-going respirations: 1) the duration of USV syllables and post-inspiratory phases were highly correlated, and 2) the opto-induced post- inspiratory phases and vocal cord closures were overridden by inspiration needs during prolonged opto- stimulation. RAm^{VOC}-neurons receive inhibitory inputs from the preBötzinger complex. Ablating inhibitory synapses in RAm^{VOC}-neurons compromised this inspiration overriding of laryngeal adduction, resulting in de-coupling of vocalization and respiration. Our study revealed the hitherto unknown circuits for vocal pattern generation and vocal-respiratory coupling.

'Hidden' HCN channels permit pathway-specific synaptic amplification in L2/3 pyramidal neurons

Viktor János Oláh[1], Jing Wu[2], Leonard K. Kaczmarek[2,3] & Matthew JM Rowan[1,4*]

[1]Department of Cell Biology, Emory University School of Medicine, Atlanta, GA, 30322, USA

[2]Department of Pharmacology, Yale University School of Medicine, New Haven, Connecticut 06520

[3]Department of Cellular and Molecular Physiology, Yale University School of Medicine

[4]Center for Neurodegenerative Disease, Emory University School of Medicine

Neocortical layer 2/3 pyramidal cells are a major component of the canonical cortical circuit, yet little is known about their subcellular excitability. Although these cells comprise the largest population of cortical pyramidal cell type, due to the restricted access to their fine dendritic protrusions by direct patch clamp electrophysiology, not much is known about the somato-dendritic conductances governing the activity of these cells. Of particular interest, hyperpolarization-activated nonselective cation (HCN) channels are known to be expressed in more extensively studied (e.g., L5, CA1) pyramidal cell types, however layer 2/3 pyramidal cells have been widely regarded to lack it, due to the absence of the characteristic "sag" potential in current clamp recordings. These channels are essential for regulating resting membrane potential, the temporal normalization of synaptic events arriving at spatially mismatched locations and establishing oscillation frequency-selectivity. Here we report that layer 2/3 pyramidal cells express functionally relevant HCN channels throughout the cortex. These channels induce steady-state membrane response rectification, constrain neuronal excitability by altering resting membrane potential and input resistance and their currents (Ih) are kinetically and pharmacologically similar to previous reports in other pyramidal cell types. Importantly, we found that HCN channel activation constrains the time-course of synaptic events arriving onto specific parts of the somato-dendritic membrane, in a manner contradictory to previous reports in other principal cells. HCN channels have previously been found to be enriched within the distal apical tufts of cortical L5, and hippocampal CA1 pyramidal cells, resulting in a distance dependent temporal normalization of distal synaptic events. In contrast, we found that in layer 2/3 pyramidal cells only proximal synaptic events are altered by pharmacological blockade of HCN channels. The revealed distance dependent EPSP kinetics were contradictory to passive propagation theory. Combined pharmacological experiments and computational simulations proved that proximally located NMDA receptors are actively modulating a subset of excitatory synaptic events. In functional terms, this unique NMDA receptor and HCN channel distribution yields an effect biased towards information arriving from bottom-up synaptic pathways as opposed to top-down information. We found that Ih expression is developmentally regulated, and the adult brain can capitalize on its modulation through serotonergic receptor ($5\text{-}HT_7R$) activation. Finally, we have confirmed that these channels have a behaviorally relevant function in the adult brain in maintaining

accurate visual processing. Our results demonstrate that layer 2/3 pyramidal cells not only express dendritic HCN channels but also employ these conductances in a previously unobserved manner.

Active sound-seeking in freely moving mice before and after hearing loss
Jessica Mai, Valentina Esho, Rowan Gargiullo, Eliana Pollay, Megan Zheng, Cedric Bowe, Abigail McElroy, Lucas Williamson, Osama Hussein, Carrissa Morgan, Nia Walker, Kaitlyn A. Brooks, and ***Chris Rodgers*** Emory University

In natural behavior, we actively move our heads, eyes, hands, and bodies to collect sensory information. For instance, people are better able to localize sounds when they move their head while listening. This active strategy is especially important for people with cochlear implants or single-sided hearing loss. However, our understanding of the neural circuitry that enables active sound-seeking is limited, because in most auditory studies the head is held still. Therefore we have developed a new behavioral model of active sound-seeking in mice and assessed the corresponding computations in auditory cortex with large-scale wireless recording. Neuron in auditory cortex encoded sound and movement. Surgical induction of conductive hearing loss impaired sound-seeking. Mice robustly recovered from unilateral but not bilateral hearing loss, suggesting a role for plasticity in central auditory pathways. We also developed new hearing loss assessments based on the acoustic startle response using machine learning and videography, and the auditory brainstem response (ABR) using modern digital hardware. In ongoing work, we plan to identify the motor strategies freely moving mice use to localize sound, how this is directed by a network of interacting brain regions, and how this enables recovery from hearing loss.

Visual and tactile integration of object locations in the mouse posterior cortex
Adrian Roggenbach[1,2], Fritjof Helmchen[1,2,3]
1. Brain Research Institute, University of Zurich, Zurich, Switzerland
2. Neuroscience Center Zurich, Zurich, Switzerland
3. University Research Priority Program (URPP), Adaptive Brain Circuits in Development and Learning, University of Zurich, Zurich, Switzerland

Multisensory integration requires transformations between coordinate systems. Somatotopic representations in the barrel cortex (wS1) and retinotopic representations in the visual cortex (V1) could be combined in the rostro-lateral (RL) area of the posterior parietal cortex into a common coordinate system. However, how converging multisensory inputs of nearby objects are processed in these cortical areas remains unclear.To address this question, here we investigate how neurons in mouse wS1, V1, and RL integrate visuotactile information about the location of a pole in reach of the whiskers. Using two-photon calcium imaging, we record neurons across the posterior cortex in L2/3 of head-fixed mice (n=11 mice). A pole is presented either in darkness or under illuminated conditions while we track whisker-pole interactions with a high-speed camera. We find that subsets of neurons in wS1, V1 and RL show selectivity for specific locations in the near space. This location coding in RL is driven by both visual and tactile signals and depends less on whisker kinematics compared to wS1. By fitting a shared-weight artificial neural network trained on all neurons, we are in the process of separating tactile and visual contributions to single-cell activities in the multisensory condition. Together, this suggests that object locations in the posterior parietal cortex are represented based on visual and tactile information, potentially in a shared reference frame.

Characterization of an Enhancer-AAV Specifically Targeting L2/3 Pyramidal Cells
Matthew JM Rowan, Viktor Janos Olah
Emory University

The mammalian brain contains the most diverse array of cell types of any organ, including dozens of neuronal subtypes with distinct anatomical and functional characteristics. The brain leverages these neuron-type-specializations to perform diverse circuit operations and thus execute different behaviors

properly. Through the use of Cre lines, access to specific neuron types has steadily improved over past decades. Despite their extraordinary utility, development and cross-breeding of Cre lines is time-consuming and expensive, presenting a significant barrier to entry for many investigators. Furthermore, cell-based therapeutics developed in Cre mice are not clinically translatable. Recently, several AAV vectors utilizing neuron-type-specific regulatory transcriptional sequences (enhancer-AAVs) were developed which overcome these limitations. Using publicly available single-cell ATAC-Seq datasets of different excitatory cortical neurons, here we identified an enhancer-AAV with impressively high specificity for L2/3 pyramidal neurons in wild-type mice. L2/3-specific targeting with this AAV was observed in barrel cortex, M1, and V1 cortical regions alike. Evaluations are ongoing in other species currently, including macaque. This tool should be of broad applicability, including for genetic and activity manipulation of L2/3 cells, without directly perturbing other distinct neighboring neuronal subtypes.

Bilateral integration in somatosensory cortex is controlled by behavioral context
Hayagreev Keri, Hyein Park, Chengyu Bi, Chaeyoung Yoo, and ***Scott Pluta***
Purdue University

Many natural behaviors require the coordinated integration of tactile features on both sides of the body. Current models suggest that this bilateral integration only occurs at higher cortical areas. However, active tactile sensation requires high temporal resolution, implicating a critical role for primary somatosensory cortex (S1). To test this hypothesis, we performed bilateral electrophysiology in mice solving a task that requires interhemispheric cooperation using whisker-mediated active touch. Mice bilaterally coordinated their whisker movements in accordance with task goals and trial outcome. Temporally coordinated spiking and strong spike-field coupling between the somatosensory cortices emerged for the reward-associated stimuli. In S1 neurons, tactile information from the ipsilateral whiskers primarily facilitated the contralateral response. This ipsilateral facilitation was controlled by behavioral context in task-performing mice, while ipsilateral suppression was dominant in naïve untrained mice. Neural encoding of the bilateral stimulus was inaccurate on trials where mice responded incorrectly. Thus, the flow of tactile information between the somatosensory cortices is controlled by goal-directed processing.

Broad receptive fields are the basis for efficient and robust population coding in cortex
Maria Royo[1], Arco Bast[1], Rieke Fruengel[1], Christiaan P. J. de Kock[2], Marcel Oberlaender[1]
[1] In Silico Brain Sciences Group, Max Planck Institute for Neurobiology of Behavior, Bonn, Germany
[2] Department of Integrative Neurophysiology, Amsterdam Neuroscience, Center for Neurogenomics and Cognitive Research (CNCR), Vrije Universiteit Amsterdam, Amsterdam, The Netherlands

The ability to combine sensory signals with internal information streams is a hallmark feature of the cerebral cortex, forming the basis for perception and behavior. It is thought that the pyramidal tract neurons in cortical layer 5 (L5PTs) are key for such combination processes. Along their extensive dendrites, these major cortical output cells combine information arriving at all layers, and then broadcast the results of this combination to several subcortical regions. It is yet unclear how populations of L5PTs encode information about stimulus features in their sensory-evoked responses. Here we show that sampling the fast responses simultaneously from any population of ~150 L5PTs anywhere within the barrel cortex is sufficient to decode any whisker stimulus. We demonstrate that this robust and redundant encoding of stimuli relies on three properties of L5PTs: fast responses that precede those in layer 4, receptive fields that are much broader than those of their thalamocortical and cortical input neurons, and the shapes of the broad receptive fields vary substantially between L5PTs. Thus, while broad receptive fields lead to a loss of information at single cell level, we found that they are the basis for a highly efficient population code in L5PTs that differs from the one provided by their input neurons in thalamus and cortex – i.e., narrow receptive fields. Our findings set the stage to dissect how cortical output encodes sensory and internal information streams.

Cortical circuitry mediating inter-areal touch signal amplification
Lauren Ryan, Andrew Sun-Yan, Maya Laughton, Simon Peron

NYU Center for Neural Science

Sensory cortical areas are often organized into topographic maps representing the sensory epithelium. Individual areas are richly interconnected, and, in many cases, they are coupled via reciprocal projections that respect the topography of the underlying map. Because topographically matched cortical patches process the same stimulus, their interaction is likely to be central to many neural computations. Here, we ask how topographically matched subregions of primary and secondary vibrissal somatosensory cortices (vS1 and vS2) interact during whisker touch. In the mouse, whisker touch-responsive neurons are topographically organized in both vS1 and vS2. We focus on subregions of vS1 and vS2 that respond to touch from whiskers C2 and C3, ensuring topographically matched areas of both cortical regions. We first employ volumetric two-photon calcium imaging of these matched subregions to characterize touch neuron populations in both areas while a mouse is actively palpating an object with two whiskers. Next, we use retrograde labeling to determine which populations of touch neurons relay touch information to topographically matched targets across both areas. Finally, we selectively lesion patches of either vS1 or vS2 responsive to touch by whiskers C2 and C3 to assess how topographically matched sites mutually influence one another. We find a sparse and superficial population of broadly tuned touch neurons that recurrently amplifies touch responses across vS1 and vS2.

Cortical Encoding of Full-Body Posture and Movement in Freely Behaving Mice
Kyle S. Severson[1]; Helen Jiang2; Jinghao Lu[1]; Wenxi Xiao[1,3]; Seonmi Choi[1]; Timothy W. Dunn[4,5]; Fan Wang[1,2]
1. McGovern Institute, MIT
2. Department of Brain and Cognitive Sciences, MIT
3. Department of Neurobiology, Duke University
4. Department of Neurosurgery, Duke University
5. Department of Biochemical Engineering, Duke University

The brain maintains an internal representation of the body's spatial configuration called the "body schema". While the body schema is critical for body awareness and sensorimotor integration, its sensory origins remain poorly understood. Here, we investigated the sensory origins of body schema by combining large-scale electrophysiology recordings in cortex with full-body 3D tracking in freely-behaving mice. We used DANNCE and geometric models to extract 44 3D keypoint positions and Euler angles for 16 major joints. These joint angles parameterize full-body posture, allowing detailed analysis into how neurons encode various postural, temporal, and spatial features. We recorded single unit activity in S1 dysgranular zone (S1dz), S1-M1 transition zone (S1tz), secondary somatosensory cortex (S2), or posterior parietal cortex (PPC). Joint angle tuning was strongest in PPC and S1tz, weaker in S1dz, and weakest in S2. Joint velocity tuning at fast timescales was weak, while tuning to non-specific movement was relatively strong. Finally, a joint-centered reference frame in early somatosensory regions may be transformed into a body-centered spatial reference frame in PPC. Thus, complex posture and movement representations in somatosensory areas may contribute to the body schema. Funding: BRAIN F32MH122995.

Connectomic analysis of sensory deprivation-induced circuit plasticity in mouse barrel columns
Kun Song, Meike Sievers, Alessandro Motta, Martin Schmidt, Moritz Helmstaedter
Max-Planck Inst. For Brain Res., Frankfurt Am Main, Germany

How experience shapes neural circuits at the connectomic scale is still elusive. The development of large-scale high throughput 3D-EM methods has made it practically feasible to reconstruct neural circuits in cortical samples at about 1 mm3 volume. Here, we studied experience-dependent circuit plasticity in the mouse whisker-touch sensory system, in which the clear whisker-to-barrel column anatomical relationship enables the unique identification of cortical columns. Moreover, the size of the barrel columns (~300 micrometers in diameter) makes it feasible to reconstruct the entire columnal circuit by state-of-the-art analysis methods. Finally, the substantial effects of sensory deprivation induced by whisker trimming

facilitate experimental operation and circuit analysis. We applied whisker trimming in a chessboard pattern in adult mice for one month, then prepared 3D-EM samples comprising at least one sensory-deprived barrel column and one neighboring non-deprived barrel column. Our sampling method achieved micro-meter precision with the use of micro-CT. Afterward, we cut the sample into continuous ultrathin section series by ATUM, with a section thickness of 35 nm and section size of about 1.5*1.5 mm2, for more than 10,000 sections. The sections were then imaged by a multi-beam SEM (Zeiss) with a pixel size of 4 nm, resulting in a final dataset of about 1.5 PB. We are now analyzing the circuits for connectomic consequences of adult sensory deprivation.

Feed-forward inhibition of ventral CA1 by endopiriform nucleus contributes to social discrimination

N. Yamawaki[1], H. Login [1], S. Ø. Feld-Jakobsen[1], B. M. Molnar[1], M. S. Kirkegaard[1], M. Moltesen[1], J. M. Radulovic [2,1], ***A.Tanimura[1]***
1. Biomedicine, Aarhus Univ., Aarhus, Denmark.
2. Albert Einstein Col. of Med., Albert Einstein Col. of Med., the Bronx, NY

The ventral hippocampus, in particular its CA1 subfield (vCA1), is implicated in social discrimination. In many mammals, this memory-guided behavior relies on social odor. The social odor information is thought to be integrated by vCA1 via a circuit encompassing the lateral entorhinal cortex and dorsal CA2. However, there is some evidence indicating that vCA1 receives axons from the endopiriform nucleus (EN), which anatomically sits at the intersection between vCA1 and the olfactory system thus, may contribute to social/odor discrimination processing in vCA1. Nevertheless, we know very little about its circuit organization and function. We found axons from the EN project to, and preferentially connect to interneurons in vCA1 in a layer-specific manner. Photostimulation of EN axons evoked little excitatory postsynaptic current but the robust inhibitory postsynaptic current on vCA1 pyramidal neurons, suggesting EN axons primarily inhibit pyramidal neurons by recruiting local interneurons in vCA1. Monosynaptic rabies tracing revealed that the vCA1-projecting neuron in EN mainly receives input from the piriform cortex processing odor information. Chemogenetic inhibition of vCA1-projecting neurons in EN impaired social discrimination but not sociability. These findings suggest that the EN to vCA1 circuit contributes to social discrimination processing via feed-forward inhibition of vCA1 pyramidal neurons.
Funding: LF grant R310-2018-3611

Early L5 to L2/3 connections drive spontaneous columnar activity in the barrel cortex

J. Vargas-Ortiz [1], V. Martinez [1], R.-J. Liu [1], R. Babij [3], Z. S. Duan [3], S. Wacks [3], S. Khan [1], A. Wang [1], J. Soto-Vargas [1,2], N. Demarco Garcia [3], *A. Che[4,1]
[1] Dept. of Psychiatry.
[2] Interdepartmental Neurosci. Program, Yale Univ. Sch. of Med., New Haven, CT;
[3] Ctr. for Neurogenetics, Brain and Mind Res. Inst.,Weill Cornell Med., New York, NY;
[4] Yale university, New Haven, CT

Synchronous electrical activity is a hallmark of the developing CNS, playing critical roles in neuronal maturation and circuit refinement. In the mouse somatosensory cortex (S1), spontaneous neuronal activity (SNA) during the early postnatal stage is organized in columns and is required for sensory map formation. While thalamic inputs are thought to coordinate layer (L) 4 activity, the source of the robust L2/3 activity at this early stage is unknown. In addition, there is still considerable debate on whether the columnar activation reflects smaller cortical columns consisting of neurons originated from the same radial glia lineage, or whether it is organized in barrel columns as early as the 1st postnatal week (PNW). Using a novel microprism preparation and in vivo 2-photon imaging in neonatal mice, we showed that SNA in S1 was synchronized translaminarly from deep to superficial layers and corresponded to functional barrel columns. To identify the source of L2/3 activation, we performed slice electrophysiology throughout the first three PNWs. We found that L2/3 pyramidal neurons received large L5 inputs but relatively weak L4 inputs during the 1st PNW. L4 to L2/3 inputs drastically increased in strengths from the 1st to the 3rd PNW, while L5 to L2/3 input strengths remained stable. Results from rabies transsynaptic

tracing experiments support that L2/3 pyramidal neurons receive large number of presynaptic inputs from L5 during the 1st PNW, before the number of L4 presynaptic inputs increases as the canonical thalamocortical circuit matures. Preliminary data suggest silencing L5 synaptic outputs chemogenetically or by selectively expressing tetanus toxin light chain (TeLC) resulted in a reduction in L2/3 SNA in the 1st PNW, as well as abnormalL4-L2/3 connectivity and whisker-evoked activation in the 3rd PNW. Our results demonstrate that early SNA in S1 is organized in barrel columns and driven by L5 pyramidal neurons, and that strong, transient L5 to L2/3 inputs play a pivotal role in providing the activity required for the maturation ofL2/3 pyramidal neurons and L4-L2/3 connection, thus supporting the formation of the columnar organization in the barrel cortex. Funding: NIH Grant R00NS114166 Brain & Behavior Research Foundation Young Investigator Award GR114536 NIH Grant R01MH110553

The recruitment of layer six corticothalamic neurons in sensory behavior

E. Dimwamwa, ***C. Waiblinger**, N. Chang, G. B. Stanley
Georgia Inst. of Technol., Atlanta, GA

Amid the traditionally studied feedforward neuronal pathways that enable perception through our senses are numerous feedback processes. Corticothalamic feedback from layer 6 of cortex (L6CT) is one such process that provides extensive input to the thalamus, in addition to direct intracortical inputs. L6CT neurons are well-positioned to play a key role in thalamocortical sensory signaling for perception. To investigate how L6CT neurons are recruited during sensory perception, we conducted extracellular recordings in NTSR1-cre mice selectively expressing ChR2 in L6CT neurons. Recordings were performed in mice that were either engaged or disengaged (reward removed) in a whisker-based detection task. Initial measurements of spiking properties of opto-tagged identified L6CT neurons reveal non-sparse spontaneous and sensory evoked activity. With regard to behavior, L6CT neurons show higher spontaneous firing rates in the disengaged compared to the engaged condition. Similarly, L6CT neurons show higher spontaneous firing rates in error trials (misses) compared to successfully detected trials (hits). These data suggest that L6CT neurons are important for sensory-guided behavior. Their activity is modulated by the behavioral state of the animal, thus enabling L6CT neurons to then modulate ongoing thalamocortical activity in accordance with behavioral needs.NIH BRAIN RF1NS128896 & R01NS104928.Howard Hughes Medical Institute Gilliam Fellowship for Advanced Study.NSF GRF

Characterizing in vivo dynamics of the GPCR activation based acetylcholine sensor GRAB-gACh4h

***Chao Wang*[1]**, Yulong Li[2], Samuel Andrew Hires[1]
[1]Dept of Biological Sciences, Neurobiology, University of Southern California, Los Angeles, CA, USA.
[2]School of Life Sciences, Peking University, Beijing, China

The novel suite of GPCR activation based (GRAB) sensors allows direct imaging of many molecules in the central nervous system, including a group of neuromodulators. The in vivo dynamics of these newly-developed sensors are essential for data interpretation but remain under characterized.Here, we measured the acetylcholine level in the mouse somatosensory cortex (S1) using the high-affinity green acetylcholine sensor (GRAB-gACh4h) in different brain states, coupled with optogenetic activation of local cholinergic axon terminals. We found GRAB-gACh4h signal drastically decreased from awake state to anesthetized state. Acetylcholine release was optogenetically evoked in a light pulse number-dependent and frequency-dependent manner, with distinct temporal dynamics in awake and anesthetized states. Furthermore, the variance in the signal amplitude was correlated with expression of the sensor.

Investigating Brainstem Encoding of Object Location within Peri-head Space

***Wenxi Xiao*[2,3]**, Kyle S. Severson[2], Vincent Prevosto[2], Seonmi Choi[2], Yi Lu[2], Helen Jiang[1,2], and Fan Wang[1,2]
[1]Department of Brain and Cognitive Sciences.
[2]McGovern Institute for Brain Research, Massachusetts Institute of Technology, Cambridge, MA, USA.
[3]Department of Neurobiology, Duke University, Durham, NC, USA.

We use mouse whisker system as a model to study peri-head space. Neurons in the barrel cortex (S1B) show tuning to specific object distances within the space detected by the whiskers. It is unclear if such tuning already exists at subcortical levels. The brainstem principal trigeminal nucleus (PrV) is the first processing stage where inputs from different types of mechanoreceptive afferents within a whisker follicle and across multiple whiskers are integrated and transmitted to S1B. We thus hypothesized that head-centered distance tuning emerges in PrV. We performed in vivo electrophysiological recordings of PrV neuronal responses to a wall stimulus that passes with varying distances from the face, in awake behaving mice. Mice showed active whisker retraction in response to the passing wall in a distance dependent manner, suggesting the degree of whisker retraction depends on the sensation of peri-head distance. Importantly, we discovered a subset of PrV neurons that are tuned to specific wall distances. Reducing inhibition in PrV or removing input from smaller whiskers changed PrV neurons' sensitivity to wall distance. The activity of PrV neurons is modulated by whisker angles, which could help compute peri-head distances from the whisker-centered to head-centered reference frame. Together, these results highlight hitherto under-appreciated role of brainstem PrV circuits in integrating and transforming sensory inputs into meaningful representations to help guide behavior.

Multisensory contribution to texture discrimination in head-fixed mice

Ilaria Zanchi[1,2,3], Alejandro Sempere[1,2], Marco Celotto[4,5], Lorenzo Tausani[1,2], Dania Vecchia1,2, Angelo Forli[1,2], Jacopo Bonato[4,5], Stefano Panzeri[2,4,5], Tommaso Fellin[1,2].
1. Optical Approaches to Brain Function Laboratory, Istituto Italiano di Tecnologia, 16163 Genova, Italy
2. Neural Coding Laboratory, Istituto Italiano di Tecnologia, 16163 Genova, Italy
3. University of Genova, 16126 Genova, Italy
4. Neural Computation Laboratory, Istituto Italiano di Tecnologia, 38068 Rovereto, Italy;
5. Department of Neural Information Processing, Center for Molecular Neurobiology (ZMNH), University Medical Center Hamburg-Eppendorf (UKE), Falkenried 94, D-20251 Hamburg, Germany.

Texture discrimination tasks are extensively used to study the cellular and circuit mechanisms underlying whisker-based decision-making in rodents. However, to explore the environment mice can combine touch with other sensory modalities. Here, we determined whether sensory modalities other than whisker somatosensation contribute to the mouse behaviour in a head-fixed Go/No-Go texture discrimination task. In expert animals, we found that whisker trimming did not affect the proportion of correct choices and that reaction times tended to be longer upon trimming. Moreover, perturbations of olfactory inputs significantly decreased the capability of mice to correctly discriminate between textures, both with and without whiskers. Using two-photon calcium imaging in the superficial layers of the primary somatosensory cortex (S1) and information theoretic analysis, we investigated the coding properties of S1 neurons under the experimental conditions described above. We found that task-related information in S1 neurons depended on the presence of olfactory inputs rather than whiskers touch on textures. Altogether, these results show that olfaction can be sufficient to behaviourally discriminate textures and suggest that S1 neurons may be a site for the integration of multiple (i.e., olfactory and somatosensory) sensory modalities. Funding: Horizon 2020 ICT, https://cordis.europa.eu/project/id/101016787, DEEPER; NIH Brain Initiative, https://braininitiative.nih.gov/, U19 NS107464.

Trigeminal innervation and tactile responses in mouse tongue

Linghua Zhang[1], Maximilian Nagel[2], William P Olson[1], Alexander T. Chesler[2], Daniel H. O'Connor[1].
1. Solomon H. Snyder Dept of Neuroscience, Krieger Mind/Brain Institute, Kavli Neuroscience Discovery Institute, The Johns Hopkins University School of Medicine, Baltimore, MD, USA.
2. Sensory Cells and Circuits Section, National Center for Complementary and Integrative Health, Bethesda, MD, USA.

The mammalian tongue is richly innervated with somatosensory, gustatory and motor fibers. These form the basis of many ethologically important functions such as eating, speaking and social grooming. Despite its high tactile acuity and sensitivity, the neural basis of tongue mechanosensation remains

largely mysterious. Here we explored the organization of mechanosensory afferents in the tongue and found that each lingual papilla is innervated by Piezo2+ trigeminal neurons. Myelinated lingual afferents in the mouse lingual papillae did not form corpuscular sensory end organs but rather had only free nerve endings. In vivo single-unit recordings from the trigeminal ganglion revealed two types of lingual low-threshold mechanoreceptors with conduction velocities in the Aδ range or above and distinct response properties: intermediately adapting (IA) units and rapidly adapting (RA) units. IA units were sensitive to static indentation and stroking, while RA units had a preference for tangential forces applied by stroking. Genetic labeling of lingual afferents in the tongue revealed at least two types of nerve terminal patterns, involving dense innervation of individual fungiform papillae by multiple putatively distinct afferents, and relatively sparse innervation of filiform papillae. Together, our results indicate that fungiform papillae are mechanosensory structures, while suggesting a simple model that links the functional and anatomical properties of lingual tactile neurons.