Abstracts for Oral Presentations

Alphabetical

I – PLENARY SESSIONS | Location: Great Hall

Plenary 8 | Friday, July 31 **|** 09:00 – 09:45
Baldwin, Maude, Max Planck Institute for Biological Intelligence, Germany

Evolution of the taste system in vertebrates
Short bio: Maude Baldwin studies the evolution of diverse sensory and physiological innovations across the vertebrate phylogeny. After obtaining an undergraduate degree from NYU studying English and History, she took science courses through New York's CUNY system, and received her PhD in 2015 from Harvard University in the Department of Organismic and Evolutionary Biology. She is now a director at the Max Planck Institute for Biological Intelligence in Munich.

Plenary 1: Huber Lecture | Monday, July 27 **|** 14:00 – 14:45
Dulac, Catherine, Harvard University, USA

Neurobiology of social and sickness behavior
Short bio: Catherine Dulac's work combines cutting edge genetics, transcriptomics, physiology, and imaging approaches to uncover the neural basis of instinctive social behaviors, a set of brain functions typically impaired in mental illness. She is a member of the US and French Academy of Sciences, and the American Philosophical Society. She is a recipient of multiple awards including the Karl Spencer Lashley Award, the Ralph W. Gerard Prize and the Breakthrough Prize in Life Sciences. She is the Samuel W. Morris University Professor at Harvard University and a Howard Hughes Medical Institute Investigator.

Plenary 4 | Wednesday, July 29 **|** 09:00 – 09:45
Fenk, Lisa, MPI for Biological Intelligence, Germany

Mechanisms of active vision in insects
Short Bio: Lisa Fenk is interested in the interaction of sensory processing with active sensor movements. Her lab focuses on retinal movements in Drosophila as a relatively simple model for active vision and combines these efforts with comparative experiments in other species. She studied physics and French before switching to neurobiology for her PhD at the University of Vienna. She conducted postdoctoral work at the Research Institute for Molecular Pathology (IMP) in Austria and the Rockefeller University in NY. In 2021, she became a Lise Meitner Research Group Leader at the MPI for Biological Intelligence.

Plenary 5: Helingenburg Lecture | Wednesday, July 29 **|** 14:00 – 14:45
Ijspeert, Auke, EPFL, Switzerland

Investigating feedforward and feedback control in animal locomotion using robots and neuromechanical simulations
Short bio: Auke Ijspeert's research interests are at the intersection between robotics and computational neuroscience. He is interested in using numerical simulations and robots to gain a better understanding of animal locomotion and movement control, and in using

inspiration from biology to design novel types of robots and locomotion controllers. He is also interested in assisting persons with limited mobility using exoskeletons and assistive furniture. With his colleagues, he has received numerous paper awards. He is a IEEE Fellow, head of the Biorobotics Laboratory and has a B.Sc./M.Sc. in physics from the EPFL), and a PhD in artificial intelligence from the University of Edinburgh.

Plenary 9 | Friday, July 31 **|** 14:00 – 14:45
Long, Michael, NYU Grossman School of Medicine, USA

Neural circuits for interactive communication
Short Bio: Michael Long focuses his attention on the neural circuits underlying skilled movements, often in the service of vocal interactions. To accomplish this, the Long lab has taken a comparative approach, examining relevant mechanisms in the songbird, the parrot, a singing neotropical rodent, and humans. He is the Thomas and Susanne Murphy Professor of Neuroscience and Vice Chair for Education at the NYU Grossman School of Medicine. He completed his graduate studies with Barry Connors at Brown University and his postdoctoral work with Michale Fee at MIT.

Plenary 3 | Tuesday, July 28 **|** 14:00 – 14:45
Narendra, Ajay, Macquarie University, Australia

Tiny brains, true bearings: finding the way home in a big world
Short bio: Ajay Narendra specializes in invertebrate neuroethology. His research focuses on how ants, bees, and spiders navigate, learn, and remember spatial information within various temporal and ecological niches. His group investigates the behavioral, sensory, and neural adaptations that enable movement at the limits of size and light availability. Currently, he serves as the Co-Director of the Pollinator Futures Research Centre and holds the position of Vice-President of the Australasian Society for the Study of Animal Behavior.

Plenary 2 | Tuesday, July 28 **|** 09:00 – 09:45
Parker, Joseph, California Institute of Technology, USA

The evolution of symbiotic entrenchment
Short Bio: Joseph Parker is an evolutionary biologist who has pioneered the study of rove beetles to investigate the evolution of symbiosis and species interactions. Originally from Swansea, Wales, he received a BSc from Imperial College London and a PhD from the University of Cambridge/MRC Laboratory of Molecular Biology. And was a postdoctoral fellow at Columbia University. Currently, he is a Professor of Biology and Biological Engineering at the California Institute of Technology, where he is the director of Caltech's Center for Evolutionary Science. He is also a research associate in the Division of Invertebrate Zoology at the American Museum of Natural History.

Plenary 6 | Thursday, July 30 **|** 09:00 – 09:45
Quintana, Laura, Instituto de Investigaciones Biológicas Clemente Estable, Uruguay

Neurosteroids regulating year-round aggression: insights from electric fish
Short Bio: Laura Quintana investigates the hormonal regulation of social behavior, with a focus on seasonal mechanisms underlying aggression. She studies *Gymnotus omarorum*, a

wild weakly electric fish that exhibits territorial aggression both during and outside the breeding season. Her research integrates fieldwork with behavioral pharmacology and molecular approaches to reveal how seasonal plasticity in neuroendocrine mechanisms - particularly brain-derived estrogens in the social brain network- regulates this year-round aggression. She leads the Neural Basis of Behavior Lab at the Instituto Clemente Estable.

Plenary 7 | Thursday, July 30 **|** 14:00 – 14:45

Standen, Emily, University of Ottawa, Canada

Elongate swimming helps explain relationships between neurocontrol, body mechanics and the external environment

Short bio: Emily Standen's recent research focuses on how one neural control system can drive effective locomotion in both water and on land. To define this, she uses comparative and evolutionary biomechanics to explore the flexibility of animal systems to locomote across vastly different environments. She collaborates widely to bring robotics and computational modeling to her questions and has delivered keynotes at global conferences on topics from evolutionary plasticity to embodied intelligence.

II – HIGHLITED TALKS

| Thursday, July 30 **|** 10:00 – 10:15

Chatterjee, Payel, Princeton Neuroscience Institute, USA
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Functional organization of haltere projections and neck muscles in *Drosophila* flight

Across animal taxa, gaze stabilization and redirection are fundamental reflexes for ensuring efficient stability and maneuverability during locomotion. Flying insects primarily rely on head motion to stabilize gaze as they have limited ability to move their eyes relative to their heads. In flies, these reflexes are mediated by vision and mechanosensory input from the halteres, multifunctional mechanosensory organs that in part function as gyroscopic sensors. Although it is well-established that the neck motor system receives inputs from the halteres, it is not known how their activity is modulated during flight. To address this, we used 2-photon calcium imaging in tethered flying *Drosophila melanogaster* to investigate the functional organization of haltere activity in the brain. A pixel-by-pixel correlation and clustering analysis reveals that the activity can be functionally divided into two clusters, typically differing in their activity pattern. Further, calcium imaging from two dorsal neck muscles during flight show that their functional classification is consistent with the haltere functional division. This therefore leads to the hypothesis that the neck muscles receive functional inputs from distinct haltere clusters. Connectomics analysis revealed that the neck motor neurons receive inputs from specific haltere morphological clusters similar to the haltere's connections with wing motor system. Initial behavioral and optogenetics assays indicate that the morphological clusters lead to stereotypical head movements suggesting functional modules underlying the connectivity. Together, these results shed light on the functional dynamics underlying the haltere-neck motor system crosstalk.

| Friday, July 30 | 10:00 – 10:15

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Asleep on the move: motor control during sleep in swimming birds

Sleep is a widespread behavioral state typically characterized by immobility and sensory disengagement. Yet, in cetaceans and otariid seals, unihemispheric sleep allows swimming, vigilance, and sleep to occur simultaneously. Frigatebirds can sleep during passive flight (soaring and gliding), but it is unclear whether sleep can occur during active flapping, a flight mode some birds use throughout long-distance multiday flights. As such birds are too small for recording sleep-related EEG activity in flight, we investigated whether birds can sleep while engaging in active locomotion using an alternative experimental approach. Inspired by field observations of geese swimming with at least one eye closed, we studied captive juvenile Canada geese imprinted to follow humans, and characterized a previously undescribed behavioral state that we call "sleep-swimming". By combining behavioral analysis, EEG recordings, and accelerometer measurements, we show that geese can perform sustained, coordinated paddling movements while asleep, with one or both eyes closed. Importantly, motor output was not lateralized with respect to eye closure and sleeping hemisphere, indicating flexible sensorimotor coordination and a dissociation between sleep state and limb control. These findings suggest that avian sensorimotor systems can support continuous locomotion even when both cerebral hemispheres are asleep. Our results are consistent with the previous finding that the brainstem in decerebrate geese can support paddling and wing flapping. Sleep-swimming may allow individuals to maintain group cohesion or relocate while sleeping, and may contribute to brain-related restorative/maintenance functions and energy management under challenging environmental conditions. More broadly, this behavior provides a novel model for studying how motor circuits are modulated across brain states, offering new insights into the neural mechanisms that allow active locomotion to persist during sleep.

| Thursday, July 30 | 9:45 – 10:00

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Ultrafast signaling reflects social hierarchy in interacting mormyrid electric fish

Social animals have evolved to produce signals with diverse temporal structures that play a critical role in coordinating behavior among individuals. Mormyrid weakly electric fish use

precisely timed, pulse-type electric organ discharges (EODs) for both active sensing and social communication. Although diverse patterns and functions have been suggested for this temporal code, the social rules that govern its use during interactions remain elusive. Here, we combined a newly developed EOD assignment algorithm with pose tracking to quantitatively analyze electric signaling and swimming behavior during social interactions in novel pairs of *Brienomyrus brachyistius*. In most dyads, one fish consistently chased the other, resulting in a stable asymmetry in chase directionality that we used to operationally classify pair roles. Individuals classified as subordinate fish (tended to be chased) showed shorter inter-pulse intervals during active signaling, as well as a tendency towards signal cessation as trials progressed. At a finer temporal scale, subordinate fish were more likely to produce fixed-latency EODs following EODs produced by dominant fish (fish that chased their social partner), a pattern known as the 'echo response.' Notably, the subordinate echo response depended on the recent EOD history of the dominant fish, becoming entrained during periods of high and regular dominant EOD rates. Spatial analysis further indicated that the subordinate echo response typically occurred at the end of dominant chasing, suggesting that it functions as a submissive signal. Together, our findings demonstrate that social dominance is reflected in asymmetric signaling dynamics operating across multiple temporal scales. This work positions weakly electric fish as a model for dissecting how social context shapes ultrafast sensorimotor signaling, revealing a communication channel with behavioral structure operating on the order of milliseconds.

| Friday, July 30 | 9:45 – 10:00

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Mechanisms of adaptation to extreme cold temperature in the snow fly *Chionea alexandriana*

The *Chionea* genus, commonly referred to as the 'snow flies', represents a unique group of wingless crane flies adapted to extreme cold environments. Adult snow flies are active in winter and can move rapidly across the snow-cover even at temperatures well below the freezing point. To investigate the molecular mechanisms behind the snow fly's adaptation to extreme cold, we sequenced and annotated the genome of *Chionea alexandriana*; we then compared it to the genome of related species and to that of *Belgica antarctica*, a cold-adapted midge native to the Antarctic continent. Here, we show that ~20 unique and 8 common gene families have expanded in the lineages of *Chionea* and *Belgica* corresponding to functions ranging from sensory signaling to DNA packaging. In the *Chionea* genome, we find a variety of antifreeze proteins (AFPs) and demonstrate that transgenic expression of a highly expressed *Chionea* AFP in *Drosophila* is sufficient to protect fly larvae from freezing death. Our results also reveal a coordinated expansion of mitochondrial and peroxisomal enzymes, and of regulators of peroxisome-mitochondria interactions previously associated with mitochondrial thermogenesis in the mammalian adipose tissue. Remarkably, our experiments show that snow flies can indeed produce brief bouts of endogenous heat in response to cooling at sub-freezing temperatures, suggesting the possibility that thermogenesis may contribute to their survival in the cold. Finally, our results demonstrate that *Chionea* has evolved specific mechanisms to cope with high levels of reactive oxygen species (ROS), a hallmark of cold exposure as well as by-products of mitochondrial activity. These include a 35-fold increase in the threshold for ROS activation of the insect nociceptor TRPA1, as measured in vitro by patch-clamp electrophysiology. Together, our results reveal specific molecular adaptations that endow the snow fly with the unique ability to thrive in extreme cold conditions and suggest that selective gene family expansion may represent a key mechanism for the adaptation of insects to cold environments.

| Tuesday, July 28 | 9:45 – 10:00

Mauduit, Emilie, Carleton University, Canada
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Substrate-bound societies: vibratory sensing and communication in tiny caterpillars

Many larval insects exhibit variation in social herding behaviour, yet the functions and mechanisms underlying this variation remain largely unexplored. We study the 'how' and 'why' of caterpillar sociality by comparing two closely related Drepanidae caterpillars that share similar life histories but differ markedly in social organisation. Neonates of the warty birch caterpillar (*Falcaria bilineata*) are solitary whereas neonates of the masked birch caterpillar (*Drepana arcua*ta) form small social groups. Both of these tiny caterpillars (~2 mm long) produce complex leaf-borne vibratory signals. We first tested whether leaf-borne vibrations mediate group formation. Social caterpillars signalled more when alone, suggesting recruitment, and reduced signalling upon group formation whereas solitary caterpillars decreased signalling upon conspecific departure with no group formation. We next explored whether that herding behaviour functions to deter predators. If so, we would expect key differences in antipredator strategies and respective vibratory signalling in response to natural predators between these two species. Our results show that the two species differ markedly in their responses to predators, and that antipredator behaviours are vibratory-mediated. Solitary *F. bilineata* rely on acoustic crypsis -freezing, escaping, or dropping from the leaf via silk life-lining- while suppressing vibratory signals. These tiny solitary larvae also have finely tuned vibratory sensory systems that enable them to discriminate between predators by their footstep 'signatures' to deploy context-appropriate defences. In contrast, preliminary observations suggest that social *D. arcuata* larvae maintain or increase vibratory signalling in response to predators, suggesting that communication signals play a role in antipredator defence. Together, these results show that sociality in these tiny organisms is mediated by finely tuned vibratory senses and complex communication systems.

| Wednesday, July 29 | 10:00 – 10:15

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A 3D reconstruction of a *Portia* jumping spider wild hunt.

The salticid genus *Portia* is an exemplary model for studying computationally expensive cognition in tiny brains. While previous research suggests these spiders have spatial memory and may compute plans during their predatory stalks, documenting these behaviors in the wild is notoriously difficult due to very slow (up to 3 hours) hunting

sequences that are often aborted. We present the first documented 3D reconstruction of a complete wild hunt of any *Portia* species, recorded during a field trip to Malaysia. This reconstruction allows us to investigate behavioral metrics and statistics to a higher fidelity than usual for an observed wild hunt. We will also present a preliminary analysis of *Portia* labiata's visual field during the hunt. For the attack at the end of the hunt, we have used Deep Lab Cut in combination with a constrained model of the spider to faithfully reconstruct *Portia labiata*'s motor mechanics at 30 frames per second. This revealed a novel behavior: in the final moment of the hunt *Portia* lands on the back of the prey spider web's stabilimentum, a disk of silk around the center of the spider's web. *Portia labiata* appears to use the stabilimentum as support while it pulls the prey Argiope spider through its own web. It is possible that *Portia* chose to approach from the underside of the prey spider's stabilimentum for camouflage purposes.

| Thursday, July 30 | 10:15 – 10:30
Rutledge, Charlotte E., Senior Editor, The Journal of Experimental Biology

AI and the future of scientific publishing

| Wednesday, July 29 | 10:15 – 10:30
Thomsay, Hannah, Science journalist, Canada

Science and storytelling

| Tuesday, July 28 | 10:15 – 10:30
van Griethuijsen, **Linnea**, Maastricht University, Netherlands

Teaching neuroethology: insights from a worldwide survey

| Friday, July 30 | 10:15 – 10:30
10:15 – 10:30
Warrant, Eric, past president, Lund University, Sweden

The future of ISN: where are we heading?

| Wednesday, July 29 | 09:45 – 10:00
Zung, Jessica, Columbia University, USA
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Visual detection of jumping spiders by ****Drosophila** flies**
Innocuous and threatening sensory stimuli often share many similar features that must be evaluated in a split second to make a life-or-death decision. For example, a looming object in a fly's field of view may represent an approaching conspecific or a pouncing spider, the

latter of which should evoke a rapid escape. However, many studies of visual processing rely on simple stimuli that bear little resemblance to real scenes, often lacking critical features animals may be using to discriminate. Our work characterizes the rich, naturalistic visual features of an attack by a jumping spider (Salticidae)--a natural predator of *Drosophila melanogaster* flies--then takes advantage of genetic and connectomic tools in flies to elucidate how their visual systems recognize the threat. We captured high-resolution, multi-camera videos of interactions between flies and jumping spiders and documented the complex interplay between predator and prey, including the characteristic phases of a spider's stalking sequence. We also observed a range of predator-response behaviours exhibited by flies, including freezing, sidestepping, escape jumps, and abdominal bobbing (potentially a form of signalling to the predator that it has been detected). Next, using a novel pipeline to track animals' poses in 3D and animate digital models, we generated videos of these scenes from a fly's eye view. We used these reconstructed videos in playback experiments to probe how flies respond to different attributes of a spider attack, revealing which features may be important for predator detection and evasion. We will also discuss ongoing calcium imaging experiments in fly brains to survey the responses of visual feature-detecting neurons to our reconstructed videos. Altogether, our work will provide insight into how fly brains encode complex, ethologically relevant visual stimuli to drive an appropriate behavioural response.

III - SYMPOSIA & CONCURRENT PARTICIPANT TALKS

Chemosensory encoding | Thursday, July 30 **|** 15:00 – 15:15

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Smelling blood: evolution of olfactory receptors in a blood-feeding fly

Tsetse (*Glossina* sp.) are hematophagous flies native to the tropical regions of sub-Saharan Africa. All tsetse feed exclusively on blood, but different species have specialised on different host animals. When blood-feeding, tsetse transmit trypanosomes, parasites that cause human and animal trypanosomiasis (sleeping sickness and nagana, respectively). To identify and pursue host animals, tsetse use olfactory receptors to sense volatile odours emitted by the host.

An evolutionary analysis of the tsetse odorant receptor repertoire revealed that nine receptor families are expanded as compared to *Drosophila melanogaster*. The most dynamic of these is odorant receptor Or67d, which has five copies in tsetse. In contrast, *D. melanogaster* has only one copy: a highly selective pheromone receptor tuned to the volatile sex pheromone 11-cis-vaccenyl acetate (cVA). However, chemical analysis revealed that neither male nor female tsetse produce cVA. Here we present new results from our investigation of this enigmatic family of olfactory receptors.

We first performed a novel phylogenetic analysis to track the evolutionary history of the Or67d family over 130 million years of evolution. Next, using a combination of fieldwork and chemical ecology, we characterised the odour environment of tsetse. We then used this knowledge to deorphanise tsetse Or67d orthologs by cloning them into the *D.*

melanogaster empty neuron system and conducting single-sensillum recordings, stimulating with putative pheromones as well as host and environmental odours. Our results uncover that some Or67d tsetse orthologs have been repurposed in tsetse, revealing surprising interactions with environmental volatiles. Beyond gaining insights into the evolution and function of this intriguing olfactory receptor, this study also paves the way for future innovations in vector control strategies.

Social displays & collective behavior | Thursday, July 30 **|** 16:00 – 16:15

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Temporal structure and its nonlinear mechanism in the choruses of male treefrogs

Male insects and frogs aggregate and produce sounds for mate attraction. Acoustic communications between males realize the well-organized temporal structures in their choruses such as call alternation and call synchrony depending on species. We study calling behavior of Japanese tree frogs (*Hyla japonica*; *Dryophytes japonicus*) from the viewpoint of synchronization. Laboratory experiments and field recordings based on microphone-array system and sound-imaging system have unveiled various types of synchronization such as anti-phase synchronization of two frogs, tri-phase synchronization of three frogs, and call alternation between neighbors in natural environment. In addition, we model the acoustic communication between males as a system of coupled phase oscillators (Kuramoto 1984) and identified the model parameters from empirical data according to a Bayesian approach. Such a data-driven approach allows us to quantify and infer the behavioral mechanism of synchronization as the form of a mathematical model. Furthermore, we will explain the project to extend the sound-imaging devices, which are illuminated by responding to the calls of nearby frogs, and apply the recording system to the visualization of chorus structures in natural environment.

S13.2 **|** 11:20 – 11:40 **|** Friday, July 31

Neural basis of acoustic communication across vertebrates

Amador, Ana
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Low-dimensional dynamics underlying neural coding of rhythmic vocal behavior in songbirds

Natural vocal behaviors provide a unique opportunity to study how neural population dynamics generate structured, learned motor sequences. Here, I present neural recordings from a telencephalic nucleus of the song system in singing adult male canaries (*Serinus*

canaria). Canary song is characterized by a rich syllable repertoire and flexible sequencing, but also by a striking rhythmic structure: each syllable type is repeated at a stereotyped rate, generating temporally organized song patterns. Using machine learning approaches to uncover structure in high-dimensional neural activity, we identified a compact low-dimensional representation of population dynamics by extracting latent modes from an autoencoder neural network. These latent modes are tightly coupled to the rhythmic features of song and to peripheral motor gestures underlying vocal production, including air sac pressure patterns associated with specific syllables. Our results reveal that rhythmic vocal behavior emerges from low-dimensional neural dynamics that are closely linked to motor output. More broadly, this work introduces a powerful framework for extracting behaviorally meaningful structure from large-scale neural recordings and highlights a tight coordination between central and peripheral dynamics during natural vocal behavior.

S4.1 | 11:00 – 11:20 | Tuesday, July 28

Adaptive responses to changing internal and external environments: weathering the storm

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Overcoming glutamate excitotoxicity during metabolic stress: the bird's-brain view

Efficient energy (ATP) production via oxidative phosphorylation is essential from sensation to motor output, and all complex processing in between. While this enabled the evolution of fundamental activities such as rapid neuronal communication and synaptic plasticity, it makes neurons uniquely vulnerable to metabolic stress. Insufficient ATP supply triggers a neurotoxic cascade leading to glutamate excitotoxicity, overexcitation, dysfunction, and ultimately, cell death in most vertebrates, including humans (e.g., stroke, respiratory arrest, and neurodegenerative diseases). Nonetheless, our lab has discovered a paradoxical model of neuronal resilience: the avian brain. Despite having the highest metabolic rate and body temperature among vertebrates, which should increase vulnerability to metabolic dysfunction, avian neurons do not undergo metabolic excitotoxicity. Instead, they hyperpolarize or maintain membrane potential and firing under severe energetic stress for as long as we can record. We hypothesize that integrative mechanisms prevent excitotoxicity and control network excitability during energetic stress. Here, I will discuss the characterization of this unexpected energetic resilience and our current work on mechanisms that prevent glutamate excitotoxicity and promote hyperpolarization as a form of neuroprotection.

Acoustics & sensory mechanics | Monday, July 27 | 15:45 – 16:00

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Dieldrin resistance mutations in Rdl enhance auditory function and drive urban adaptation of malaria mosquitoes

The GABA-gated chloride channel RDL was first identified as the target of the insecticide dieldrin. Although dieldrin has been discontinued since the 1970s due to resistance and toxicity issues, Rdl resistance mutations persist in natural populations of the malaria mosquito *Anopheles gambiae*. This suggests a selective advantage that remains uncharacterized. Here, we show that RDL modulates auditory sensitivity and that Rdl-resistant mutants exhibit enhanced auditory responses. Because the mosquito auditory system is essential for mating partner recognition, we further demonstrate that individuals carrying Rdl resistance mutations have increased mating success under noisy laboratory conditions. These findings led us to hypothesize that Rdl resistance mutations may be maintained in natural mosquito populations through sexual selection, driven by an advantage in acoustically detecting mating partners an advantage that may be particularly relevant in urban environments with high levels of anthropogenic noise. Indeed, field collections in the Central African Republic revealed a higher abundance of resistance mutations in the city of Bangui compared to rural areas, and within the city, a higher abundance in the noisiest locations. Moreover, we show that susceptible females display greater mating success under lower anthropogenic noise, suggesting that resistance mutations may compensate for the acoustic masking effects of urban noise. Our results illustrate an unintended evolutionary consequence of insecticide use to drive persistence of resistance mutations and urban adaptation of malaria mosquitoes. These findings also suggest important implications for insecticide implementation strategies.

3D navigation & spatial cognition | Friday, July 31 | 16:00 – 16:15

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A comparison of rodent decision-making under diverse robotic pseudo-predator strategies

In nature, prey contend with a variety of predatory strategies. Previous work has explored how the presence of predators and changes in environmental structure influence prey behavior; however, there exist few ethologically relevant behavioral tasks that investigate how changes in predator strategy within the task influence prey decision-making behavior. In a robot-mouse interaction arena, we designed an ethologically relevant predator-prey interaction task in which mice had to contend with a control strategy uncoupled from the mouse's movement and two bioinspired predation strategies: a sit-and-wait ambush strategy and a strategy in which the predator guards resources within its territory with a movement pattern intended to increase encounters with prey, termed the patrol strategy. We found a number of differences in mouse behavior corresponding to predator strategy. Specifically, we found that when faced with the patrol strategy, behavior was more deliberative with slower moving speeds, longer wait times to enter the arena, more pauses and reroutes per trial, and greater path diversity. In contrast, with the ambush strategy, mice converged to more habitual behaviors, such as retracing cached routes, high moving speeds, and little pausing. Across the strategies, mice were sensitive to distant sightings of the predator. More distal observations of the predator predicted more deliberative behavior. This study provides insight into what matters to prey when making decisions in a dynamic environment and provides evidence for how the predator's strategy modulates prey behavior. Crucially, our findings suggest that plan-based decision-making may only be advantageous against certain types of threats, and provides a method to understand how predator strategy in a naturalistic environment influences decision-making behaviors.

S14.1 | 11:00 – 11:20 | Friday, July 31

Periphery is key: adaptations to natural scenes in the visual periphery of arthropods & vertebrates

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The colorful lamina of butterflies

The lamina of the Japanese yellow swallowtail, *Papilio xuthus*, comprises three types of cartridges, each receiving inputs from nine photoreceptors (PRs) derived from three spectrally distinct types of ommatidia. These form a complex circuit with five second-order lamina monopolar cells (LMCs). We identified ~6,500 synapses within the cartridges: 25% are inter-PR synapses, 55% connect PRs to LMCs, 10% are inter-LMC synapses, and 10% represent LMC output synapses. Inter-PR connections are absent in the fly lamina but appear to be common in flower-visiting butterflies and bees. In *Papilio*, these inter-PR connections play an essential role in sharpening PR spectral sensitivities, which may enhance spectral discrimination. In contrast, LMCs pool input from all PRs within a cartridge, producing broad spectral sensitivity suited for contrast, luminance, and motion processing. Whether and how LMCs contribute to color vision remains enigmatic.

S15.2 | 11:20 – 11:40 | Friday, July 31

Animal architecture

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Toward a neuronal understanding of spider orb-weaving behavior

The spiraling webs built by orb weaver spiders are an accessible and elegant example of animal architecture, made more impressive by the fact that this multi-hour feat is accomplished by an animal whose brain numbers only in the few tens of thousands of neurons.

Nevertheless, knowledge of the brain anatomy and connectivity of web-building spiders has generally lagged behind that of cursorial species, and functional correlates describing which regions, circuits and signals govern the behavior are essentially unknown.

We present our progress in understanding the brain of the hackled-orb weaver, *Uloborus diversus*, using immunofluorescence and fluorescence *in situ* hybridization in the whole-mounted central nervous system to describe the locations and innervation patterns of neurotransmitter and neuromodulator-expressing populations, in both known and unfamiliar neuropil features. By probing for activity-regulated gene expression, we have also created an initial mapping of the orientations and identities of populations whose activity correlates with web-building.

S5.4 | 12:00 – 12:15 | Wednesday, July 29

The neural substrate of animal collective motion

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Visual interactions in locust collective motion-related decision making

Swarming locusts are a quintessential example and a powerful model for studying animal collective motion - the coordinated, synchronized movement patterns exhibited by groups of animals across species. Collective motion-related decision-making involves the intricate processing of visual cues in complex and noisy surroundings. Our recent research provides insights into several aspects of locust swarming-related visual interactions. Using a well-established experimental setup, we presented carefully controlled visual stimuli to individual locusts tethered in a natural walking posture, and monitored and analyzed their behavioral responses to stimuli that varied in specific visual characteristics. Our results indicate that object number plays the central role in the nymph's decision-making regarding collective marching. It is the interplay between the number of objects and the moving-edge pixels that appears to determine the swarming-related behavioral response. We further utilized the individual locust's head movements as an indicator of attention-related processes involved in visual perception and integration of multiple simultaneous visual inputs. We identified a distinct head-movement pattern that occurs mainly during pauses and is associated with the decision to initiate walking in a particular direction. This movement, induced by the moving visual stimuli, differs from the head movements accompanying the motor act of turning. The frequency of monitored head movements was strongly dependent on the direction of the moving stimuli presented, further supporting their involvement in swarming-related decision-making. Together, these findings provide new insights into the fundamental visual-based mechanisms underlying information extraction and processing in a complex, cluttered social environment, specifically regarding the distinct attributes of the visual stimuli that are instrumental for collective motion-related decision-making in locusts.

Modulation of social behavior | Friday, July 31 | 15:45 – 16:00

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Bumblebees alter their attentional scope under a simulated predator attack

In humans, cognitive processes such as memory, decision-making, and attention can be influenced by emotions, such as encountering danger, facing unexpected challenges, or achieving a significant goal. Pleasant events can induce positive emotions, which are thought to broaden the scope of attention (i.e., 'seeing the whole forest'), whereas unpleasant events which elicit negative emotions can narrow it (i.e., 'missing the forest for the trees'). Cognitive processing and emotions influence each other in a bidirectional manner, as demonstrated by the systematic biases that emerge across various cognitive domains. Whether similar phenomena occur in animals with miniature brains, such as invertebrates, remains a matter of considerable debate. We assessed bumblebees' attentional scope using a human inspired paradigm after a simulated predator attack. Individual free-flying bees (N = 30) were first trained to discriminate hierarchical visual stimuli in a Y-maze, consisting of global shapes composed of local elements (e.g., a circle made of small triangles). The bees were then subjected to a conflict test in which global and local cues were swapped. Bees preferred global information over local information, relying on the global spatial configuration rather than elemental information. However, bees exposed a simulated predator attack shifted their preference from global to local information, suggesting that the induced negative emotional state narrowed their attentional scope. Furthermore, high-performance liquid chromatography (HPLC) analysis of bee brains (N = 38) revealed that only bees exposed to a simulated attack had higher levels of dopamine, while serotonin and octopamine levels remained largely unchanged. Topical administration of dopamine to bees that had not experienced a simulated attack induced a shift in attentional scope from global to local processing. Conversely, blocking dopamine receptors with a dopamine antagonist (Fluphentix) prior to testing prevented the attack-induced shift from a global to a local preference. We provide behavioural, cognitive and neurobiological evidence that negative emotional states alter cognitive processing also in miniature brain animals

S16.3 | 11:40 – 12:00 | Friday, July 31

Orientation across modalities

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Two forms, one function: connectomes of head-direction circuits

Navigation is a cornerstone of behavior, and is based on a reliable and constantly updated estimate of current heading. An internal representation of current direction is compared to internal goals in order to guide movement. In insects, the head-direction circuit in the central complex acts as an internal compass, functioning as a ring-attractor circuit that keeps track of current heading. The central complex is a set of highly conserved mid-line neuropils, found in all insect brains studied to date. The conservation is, thus far, only known at the level of cell-types and projections, and it is unknown if the topology of the circuit constructed by synapses is conserved. It is possible that insects with different ecologies will have different solutions to the problem of head-direction tracking. We use synapse-resolution circuit reconstruction to reconstruct the head-direction circuit in the sweat bee, *Megalopta genalis*, and compare it to the only other reconstructed adult central complex, that of the *Drosophila melanogaster*. Our data shows that over the 300 million years of evolution since Hymenopterans and Dipterans have diverged, the cell types and projection patterns of the head-direction circuit are generally conserved in shape and number. However, reconstruction at the synaptic level reveals fundamental differences in circuit design. Our reconstructions show that distinct wiring principles have evolved via homologous neurons, indicating substantial evolvability despite an overall conserved neuroarchitecture. Computational models directly derived from the two circuit topologies reveal that both can function as ring-attractor circuits and track rotations in the same manner. This suggests that multiple stable solutions yielding functional head direction circuits are possible within the conserved neural repertoire of the central complex. This degeneracy at the level of neural circuits might be one key factor enabling complex neural circuits to evolve. Even within the stabilizing constraints placed on the central complex, this could allow for circuit modifications to adjust for specific ecologies, while maintaining viability for necessary functions.

Rhythms & homeostatic control | Monday, July 27 | 15:30 – 15:45

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Through the looking glass: photoreceptive organs in transparent frogs?

Biological rhythms are key components of homeostasis and evolution, as they enable organisms to synchronize their behavior and physiology with environmental cycles. Mechanisms of synchronization are mostly known in structures responsible for photoreception, information processing, or melatonin production (master clocks). Much less is known about temporal synchronization and communication among peripheral organs, as

well as possible feedback mechanisms with master clocks. The ability of light to directly set peripheral clocks in most vertebrates is unclear. However, peripheral organs cannot be directly exposed to it in most vertebrates. Glass frogs are the only transparent terrestrial vertebrates as adults. With the advent of new genomic tools, these amphibians are emerging as potential model organisms for physiology and circadian research. In this study, we aim to characterize the circadian system in a transparent and a non-transparent tree frog species. To do so, we recorded the behavior of glass frogs (*Hyalinobatrachium aureoguttatum*) and tree frogs (*Boana picturata*) under constant darkness, followed by an LD 12:12 cycle. Preliminary results showed that both species free run and resynchronize with the LD cycle, even though there are behavioral differences among species. Current experiments involve mapping the expression of clock and opsin-related genes in the brain and in peripheral tissues. This characterization is key to further investigating if glass frogs' peripheral organs are truly photosensitive and their mechanisms of whole-body synchronization, which may lead to important advances in circadian medicine.

S13.3 | 11:40 – 12:00 | Friday, July 31

Neural basis of acoustic communication across vertebrates

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Fishes: antiquity and ubiquity of vocal mechanisms

At the end of Karl von Frisch's landmark paper reporting a mechanism for hearing among fishes (1938, Nature), he asks for what purpose fishes are able to hear so well in silent water'. Referencing the 'soft piping' of minnows, he writes 'we may be sure that it can be heard by the minnows. There may be much to discover in the future about the language of fishes. Perhaps fulfilling this prophecy, we (Rice et al., Ichthyol Herpetol 2022) showed that families with sonic species have about two-thirds of the extant species of ray-finned fishes, one of two radiations of bony fishes comprised almost entirely of teleosts (the other radiation, includes lobe-finned fishes which gave rise to tetrapods). We also provided evidence that, like tetrapods, sound production evolved about 155 Ma among bony fishes, although independently many more times than tetrapods. Teleosts thus present opportunities to identify shared ancestral and derived characters underlying the evolution of acoustic signaling within Actinopterygii and vertebrates in general. They have proven especially amenable to comparative studies of how the brain selects and sequences vocal signals, in part, because of the relative simplicity of their highly stereotyped calls which have a small set of acoustic features determined by topographically discrete brain regions. For example, we showed that like mammals, midshipman fish (*Porichthys notatus*) have a midbrain vocal node (periaqueductal gray, PAG) linking vocally active preoptic-hypothalamic neurons to hindbrain circuitry that directly determines spectro-temporal call properties and exhibits differential patterns of neural activation during male courtship and agonistic calling (Schuppe et al., Nat. Commun. 2024). These and other results support the hypothesis that lineages within the two major vertebrate radiations (Actinopterygii and Sarcopterygii) share functionally comparable networks determining acoustic call features.

Vertebrate motor control | Friday, July 31 | 16:00 – 16:15

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Complex social vocalizations are integrated into the bat wingbeat cycle during flight

Acoustic communication plays a central role in animal social behavior and exhibits remarkable complexity in various taxa. In bats, the emission of echolocation calls is known to be tightly coupled to wingbeat and respiratory rhythms. However, little is known about how complex social vocalizations are coordinated with the mechanics of powered flight. We investigated how complex social calls are integrated into flight of wild Nathusius pipistrelles (*Pipistrellus nathusii*). Using synchronized audio and video recordings, we quantified wingbeat and call rhythms during free flight. We incorporated these data into an inference model to reconstruct the temporal structure of complex social calls relative to the underlying wingbeat cycle, and validated the model's predictions through video-tracking of individuals emitting social calls during flight.

We found that echolocation calls are tightly coupled to the late upstroke phase of the wingbeat. In contrast, complex social calls span three consecutive wingbeat cycles and are seamlessly embedded within the sequence of echolocation calls. While social call motif durations scale with syllable number, motif onsets are phase-locked to narrow, preferential phases of the wingbeat cycle. Our findings provide evidence that complex social calls in bats are integrated into the wingbeat during flight, demonstrating that vocal-locomotor coupling extends beyond echolocation to shape the structure of social communication. By mitigating the high energetic costs of vocalizing, biomechanical integration may have facilitated the evolution of complex vocal communication in bats.

Sensory learning & decision-making | Monday, July 27 **|** 15:00 – 15:15

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Torpor depth predicts hippocampal cell density and spatial memory in hibernating chipmunks

Hibernation involves repeated bouts of torpor during which metabolic rate and body temperature drop dramatically. Although these physiological changes conserve energy, they can also alter brain structure, including cell loss and synaptic retraction in the hippocampus - a brain region critical for learning and memory. Despite these effects, the consequences of torpor for cognitive function remain poorly understood. This gap limits our ability to predict how hibernating species will respond to climate change, which is rapidly altering the timing and severity of winter conditions. Behavioral flexibility may therefore be essential for persistence in changing environments, and maintaining memory could be particularly important for scatter-hoarding species that rely on spatial memory to recover cached food after hibernation. Here, we examined how variation in torpor patterns influences hippocampal cell density and spatial memory in the least chipmunk (*Tamias minimus*), a scatter-hoarding facultative hibernator that enters torpor opportunistically in response to environmental conditions. Using captive animals housed in outdoor enclosures that maintain semi-natural social and ecological conditions, we quantified overwinter torpor patterns with implanted temperature loggers and assessed spatial memory performance after emergence. Chipmunks that experienced shallow torpor showed significantly better spatial memory recall than individuals that employed deep torpor. Deep torpor was also associated with greater cell loss in CA2 and CA3 - hippocampal subregions linked to social and spatial memory, respectively. Together, these findings demonstrate that torpor depth predicts both hippocampal cell density and cognitive performance, linking overwinter physiology to brain structure and behavior. By integrating behavioral assays with neural measurements in a naturalistic hibernation system, this work provides insight into how climate-driven shifts in winter conditions may influence neural plasticity and memory in facultative hibernators.

Insect compass systems | Thursday, July 30 | 15:45 – 16:00

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A bee's g-force: gravity processing in the compass network of honeybees

The waggle dance of the honeybee is one of the most remarkable forms of animal communication. It enables foragers to convey the location of a profitable food source to their nestmates in complete darkness inside the hive. The duration of waggle phases encodes the distance to the food source, while the dance direction relative to the gravity axis transmits the angle between the solar azimuth and the food source. The bees must therefore be able to alternate between a gravity-based compass reference and a solar-azimuth-based one. While the neural circuitry of the sun compass has been dissected in numerous insect species, it remains unexplored how gravity information is processed in the insect compass network. With extracellular tetrode recordings, we here measured the activity of central-complex neurons while rotating a bee along its longitudinal axis against the gravity axis. It has been discussed that mechanosensory bristle fields at the bee's neck and at the petiolus joint are the primary organs for sensing gravity. By comparing the neural tuning measured from a bee that was rotated with a restrained head and an unrestrained head, we can explicitly test the influence of the neck bristles on gravity coding. With this setup, we found central-complex neurons that increased their firing rate at certain head directions relative to gravity. Our preliminary results set the starting point to investigate gravity coding in the compass network of insects and how these signals are integrated with sun-compass information. The integration between gravity and solar cues is essential to transfer spatial information extracted from the waggle dance into visual spatial information used for navigation during foraging flights.

Acoustics & sensory mechanics | Monday, July 27 | 15:30 – 15:45

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Tiny but precise ears: sound source localization in a frog-biting mosquito

Sound localization in many organisms relies on interaural time (ITDs) and level differences (ILDs) generated by spatial ear separation. However, in small organisms, such as insects with tympanal or non-tympanal ears, minimal interaural spacing imposes significant challenges for encoding directional cues. Despite this limitation, insects with a body size-to-wavelength ratio below 0.1 demonstrate localization abilities comparable to those of larger animals. While various adaptations that amplify interaural cues in insects with tympanic ears are known, the mechanisms underlying sound localization in non-tympanal insects remain poorly understood. Mosquitoes detect sound through antennal flagellar displacements that activate Johnston's organs (JO) at the base of their antennae. With an inter-antennal distance of just 500 μm, mosquitoes experience an ITD of only 1.5 μs and this minimal spacing relative to sound wavelength also limits ILDs. Despite these constraints, many male mosquitoes use hearing for mating, while frog-biting Uranotaenialowii females eavesdrop on frog calls to locate their amphibian hosts. This study integrates biomechanical, electrophysiological, and behavioral approaches to

investigate how Ur. lowii achieves directional hearing. Using Laser Doppler Vibrometry, we measured antennal vibrations in response to sound, while electrophysiological recordings assessed neural activity in the JO. Phonotaxis experiments further evaluated behavioral responses to directional acoustic cues. Our findings reveal how two antennae enable precise 3D sound localization despite the absence of tympanal ears. These insights provide a novel broader framework for exploring directional hearing in insects and other small organisms operating under extreme spatial constraints.

Vision-guided behavior camouflage | Wednesday, July 29 **|** 15:00 – 15:15

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Odors can shift mosquito color preference even in stimuli of equal brightness

Mosquitos have a wide behavioral repertoire, including floral foraging, vertebrate host seeking, and oviposition, all of which depend on the combination of vision and olfaction. Our previous work has shown that odors gate and modulate behavioral responses to specific visual stimuli. Using wind tunnel bioassays with *Aedes aegypti* mosquitoes, we demonstrated that behavioral responses of mosquitoes to visual cues in the presence of CO2 can be explained through achromatic differences in brightness as mediated the outer photoreceptors (R1-6) of *A. aegypti*. This finding was confirmed in new experiments, with intracellular recordings showing the outer photoreceptors are both green and UV sensitive, with this sensitivity being inversely proportional to the spectral preferences induced by CO2 alone. However, these achromatic preferences do not explain the mechanisms for odor modulation of visual preferences in differing behavioral contexts suggesting a role for color discrimination as mediated by the central (R7,8) photoreceptors, thought to play a role in color vision in other insects. Our recordings show these photoreceptors have peak sensitivities in the UV, green, or show a dual peak in the blue and green. Modeling of the photoreceptor responses to different stimuli suggests that the differing sensitivities among photoreceptor types could allow for color discrimination through opponent processing. Next, to investigate olfactory gating of visual behaviors and the R7/R8 inputs, we presented color choices between stimuli with matching perceptual brightness. In these experiments, we found that the addition of odor to CO2 shifted the color preferences of mosquitos. The behavioral results taken in combination with the observed photoreceptor sensitivities suggest that the odor gating of mosquito behavior may be dependant on color discrimination.

Chemosensory encoding | Thursday, July 30 **|** 15:45 – 16:00

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Decoding neurogenetics of olfactory specialization in blind cavefish

Organisms often display sensory specialization adapted to their environment, yet the precise genetic mechanisms driving specialization are largely unknown. We investigated this question in *Astyanax mexicanus*, a teleost fish species with two distinct ecomorphs, using quantitative behavioral analyses, quantitative genetics and functional neuroanatomy. The blind, dark-adapted cavefish morph displays heightened olfactory sensitivity and

distinctive foraging behavioral strategies in response to low food odor concentrations, as compared to the river-dwelling, eyed surface morph.

We conducted a high-throughput behavioral assay to examine olfactory behavioral responses and sensitivity of 400 second generation hybrids (F2) resulting from cave x surface crosses. We assessed individual animals' (juveniles) olfactory sensitivity exposing fish to alanine and computed an olfactory detection behavior "score" for each fish. We then conducted a quantitative trait loci (QTL) analysis to identify genomic loci and candidate genes involved in cavefish olfactory specialization.

Previous research has also demonstrated differences between morphs in olfactory epithelium development and in the proportion of olfactory sensory neuron subtypes between the two *Astyanax* morphs. We are also seeking to determine whether, from a functional neuroanatomy perspective, the difference in behavior and sensitivity between CF and SF in response to a given amino acid correlates with differences in neuronal activation (pERK ir) in the olfactory epithelium and in the brain.

By combining behavioral studies with quantitative genetics and functional neuroanatomy, our research aims to better understand the genetic architecture of sensory behaviors and to identify new genes and neural circuits involved in olfactory processing and evolutionary specialization.

Photoreceptors & visual adaptation | Tuesday, July 28 **|** 15:00 – 15:15

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Vision in changing waters: adaptation to light environments in predatory zooplankton
Effects of human activity including pesticide and nutrient runoff, climate change, introduced species, and artificial light can alter many seldom-considered properties of the aquatic light environment, including colour, polarisation, turbidity, and navigational cues below and above the surface. How do these changes affect the visual behaviors of aquatic animals? To answer this, we have examined the optical, molecular, and behavioral adaptations of the freshwater zooplankton crustacean, *Polyphemus pediculus*. This water flea is a voracious predator with a surprisingly-sophisticated cycloptic compound eye that includes four specialized regions of photoreceptors for color and polarization vision. Furthermore, *Polyphemus* is found around the entire northern hemisphere and thus is adapted to diverse aquatic light environments. We employ new environmental light measurement techniques to link natural variation and anthropogenic impacts to the dynamic features of freshwater light fields. We show that changes to the light environment are correlated with the regulation of over 30 expressed opsin transcripts, morphological features of the eyes, and the efficacy of predatory and navigational visual behaviors in *Polyphemus*. Our results suggest that though the visual system of this water flea is surprisingly adaptable to variable light conditions, there are some anthropogenic changes to the aquatic lightscape that may be insurmountable.

Chemosensory encoding | Thursday, July 30 **|** 16:00 – 16:15

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A molecular and cellular mechanism for bitter taste in mosquitoes

An animal's sense of taste governs the final decision of whether to feed or not. In disease vectors like the yellow fever mosquito (*Aedes aegypti*), understanding the taste cues involved in nectar and blood-feeding may facilitate the development of repellents and strategies to mitigate their impact. Mosquitoes avoid ingesting bitter compounds and biting skin that has been covered in bitter compounds. However, we do not yet know the molecular mechanisms and neural circuits that underly this aversion. In *A. aegypti*, Gr14 is an orthologue to the broadly expressed fly bitter receptor Gr66a. Therefore, we wanted to test whether Gr14 and neurons expressing Gr14 were important in mediating the aversion to bitter compounds. We found that Gr14 was expressed only in the proboscis and cibarium of males and females. Two-choice feeding assays revealed that knocking out Gr14 expression reduced but did not fully abolish the aversion to some tested bitter compounds in a nectar-feeding context, suggesting that several receptors may be involved in the detection of bitter compounds. Furthermore, we found that silencing Gr14 expressing neurons had different effects on the aversion to different bitter compounds, ranging from a complete loss of aversion to partial reductions in aversion, indicating mosquitoes may have distinct but partially overlapping populations of neurons for detecting different bitter stimuli. We have therefore identified key molecular and cellular components of mosquito bitter perception, revealing insights into mosquito taste processing and the evolution of bitter taste in dipterans.

Mechano- & thermosensation | Wednesday, July 29 **|** 15:15 – 15:30

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The molecular basis of thermosensation by soil-transmitted parasitic nematodes

Soil-transmitted parasitic worms infect over a billion people and cause devastating morbidity, primarily in the world's most socioeconomically disadvantaged communities. Despite this massive health burden, we lack basic knowledge about the sensory behaviors and physiological specializations that enable parasitic worms to locate and infect human's processes that could be targets for novel therapeutic interventions.

We have developed *Strongyloides stercoralis*, a human parasite that infects around 680 million people and can be fatal, as a powerful new model for performing mechanistic studies of human parasitism and the evolution of sensory behaviors. *S. stercoralis* infective larvae live in the soil and display dramatic attraction to mammalian body heat. We investigated the molecular and cellular basis of this behavior and found that the *S. stercoralis* thermosensory system is specialized to enable robust host targeting. We used CRISPR/Cas9 mutagenesis to show that *S. stercoralis* heat seeking is dependent on a cGMP thermosensory signaling pathway that is conserved across free-living and parasitic nematodes. Next, we combined phylogenetic comparisons, neural imaging, and ectopic

expression strategies to demonstrate that *S. stercoralis* thermoreceptors are tuned for mammalian body heat. Parasitism has evolved multiple times independently in nematodes; however, we found that temperature-driven host seeking is common across an evolutionarily broad set of parasitic species. We asked whether parasite-specific adaptations in thermoreceptor tuning provide a common mechanism for attraction to mammalian body heat across evolutionarily distinct lineages of mammalian parasites. Together, our results are the first direct evidence that the sensory neurons of parasitic worms exhibit molecular and cellular adaptations that allow them to target humans, a finding with important implications for the evolution of parasitic behaviors in nematodes.

Neural mechanisms of acoustic communication | Tuesday, July 28 **|** 16:00 – 16:15

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Auditory resistance to noise damage in the FM-echolocating fruit bat, ****Carollia perspicillata*

Sensorineural hearing loss is ubiquitous among mammals, with most species exhibiting reduced auditory sensitivity over a lifetime due to the accumulation of noise-induced and age-related cochlear damage. Echolocating insectivorous bats emit high intensity sonar signals and consequentially are exposed to elevated noise levels. Although bats appear to have evolved protective mechanisms to prevent cochlear damage, resistance to noise has primarily been demonstrated in species that rely on sonar for prey tracking. In contrast, some bat species produce less intense sonar signals, orient and forage using additional sensory cues (vision, olfaction), and in the case of lingual echolocating *Rousettus aegyptiacus*, are more susceptible to cochlear aging. The effects of noise exposure on hearing sensitivity in laryngeal echolocating fruit bats that rely on vision, olfaction and hearing to forage has not yet been investigated. Here we studied noise-induced threshold shifts in *Carollia perspicillata*, a frugivore that emits FM sonar signals similar to those used by many insectivorous bats. We exposed bats to 1 hour of 110 dB SPL octave-band noise centered at 24 kHz and assessed cochlear function at several timepoints following noise exposure using auditory brainstem response (ABR) recordings. Although we observed no significant effects on ABR-derived hearing thresholds up to 3 months post-noise exposure, some bats showed marginal threshold shifts at 48 kHz, which were accompanied by non-significant reductions to ABR wave 1 amplitudes. We observed no change to outer hair cell function, measured using distortion product otoacoustic emissions. *C. perspicillata* shows robust hearing sensitivity following intense noise exposure, comparable to noise-resistant insectivorous species. However, we emphasize the importance of long-term post-exposure tracking to evaluate how auditory protective mechanisms may vary across bat species depending on the role of hearing-in-noise for survival.

Acoustics & sensory mechanics | Monday, July 27 **|** 15:00 – 15:15

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Visualising hearing in marine invertebrates: sound-driven motion of the statocyst
Growing evidence suggests that some crustaceans can detect low-frequency underwater sound, yet the mechanisms underlying sound reception in these animals remain poorly understood. In decapod crustaceans, the statocyst is a key mechanosensory organ used for orientation and balance. It contains a dense agglomerate of sand grains (the statolith) resting on mechanosensory hair cells. This configuration resembles the otolithic organs of fish, which has led to the hypothesis that statocysts may contribute to acoustic detection by responding to particle motion. However, direct experimental evidence linking sound stimulation to motion of the statocyst structures is still lacking. Here, we investigate the mechanical response of the statocyst to acoustic stimulation using synchrotron radiation imaging. Recent advances in high-speed synchrotron techniques have enabled direct visualisation of sound-induced motion of otoliths in fishes, providing unprecedented spatio-temporal resolution of auditory structures in action. Building on this approach, we use the Australian Synchrotron Micro-Computed Tomography beamline to visualise sound-induced motion within the statocyst of decapod crustaceans. Preliminary experiments using high-speed radiography revealed rocking motion of the statolith in situ during acoustic stimulation. These observations were expanded to four-dimensional imaging (three spatial dimensions through time), allowing reconstruction of the full dynamics of statocyst motion. These results provide the first direct observations of sound-induced mechanical responses in an invertebrate equilibrium organ and offer new insight into the sensory mechanisms underlying acoustic perception in crustaceans and other invertebrates

Computational sensorimotor control | Wednesday, July 29 **|** 15:30 – 15:45
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Neural architecture of image generation in cuttlefish camouflage
Cephalopods rapidly change their skin color and pattern for camouflage or communication. During camouflage, their visual system extracts statistical feature from the environment, and then their motor system reproduces key visual features as skin patterns. These patterns are formed by millions of chromatophores, each acting like a pixel in the skin display. Chromatophores are pigment cells whose size is controlled by brain motoneurons from posterior chromatophore lobe (PCL). We asked how the PCL generate outputs that coordinate the spatiotemporal patterns of millions of chromatophores and, as the only known biological image generator, whether it mirrors visual processing in reverse. As an analogues to the receptive field mapping of individual visual neurons, we first defined the effective field of individual motor neurons, by combining whole-cell patch-clamp with high-speed skin imaging in cuttlefish *Sepia pharaonis*. We found that the effective fields of PCL neurons spanned diverse spatial patterns, with size an unexpectedly large range from a single chromatophore to several hundred. Within these fields, PCL motoneuron firing rate drove chromatophore expansion size nearly linearly until saturation. The arrangement of skin fields exhibited a somatotopic trend. To test whether somatotopy is the dominant organizational principle in the PCL, analogous to retinotopy in the visual system, we first mapped the anatomical projections from the PCL to the skin. Retrograde tracing from pallial nerve branches descending from the PCL revealed PCL axes aligned with mantle anterior-posterior and mediolateral coordinates. We then mapped the functional connectivity using focal stimulation with two-photon calcium imaging of PCL and

chromatophore imaging of skin. Together, these results suggest that the PCL combines scalable single neuron output with a somatotopic organization to generate flexible, coordinated chromatophore patterns for camouflage.

Active sensing & sensorimotor gating | Thursday, July 30 **|** 15:00 – 15:15

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A brainstem efference copy hub mediates behavior-state-dependent sensory gating via two parallel subsystems

Efference copy (EC) is known to fine-tune sensory processing during movement, yet its function has been studied primarily within dedicated pathways linking specific motor modules to restricted sensory domains, leaving its effects on further sensorimotor transduction also unclear. During natural behaviors, however, animals coordinate motions across multiple parts of whole body and precisely extract exafference to maintain coherent, adaptive behaviors. Whether and how does the brain integrate and interpret multi-origin motor signals to perform precise sensory filtering that optimizes behavior? Here, using whole-brain neuronal imaging and whole-body motion tracking in larval zebrafish, we identify the cholinergic Octavolateralis Efferent Nucleus (OEN) as a hub that integrates EC from distributed motor modules controlling the trunk, eyes, jaw, gills, and fins, enabling broad modulations particularly of global hair cells. Within this hub, we further discover two subtypes: a Routine-Motion type responds to general locomotion, and a Vigorous-Motion type is selectively recruited during intense movement. With similar innervation patterns, two subtypes implement divergent forms of sensory gating: the Routine-Motion type maintains sensory sensitivity, whereas the Vigorous-Motion type globally silences sensation. Together, these parallel subsystems diversely enable optimization of sensory processing and behaviors. Our study reveals a dedicated EC hub and demonstrates how parallel subpopulations within a single hub enable state-dependent sensory filtering--shifting the EC principle from specific modulation to global, behavior-aware gating.

Insect compass systems | Thursday, July 30 **|** 15:30 – 15:45

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Australian Bogong moths employ a light-dependent geomagnetic compass for nocturnal long-distance migration

During their biannual migration, billions of Bogong moths (*Agrotis infusa*) migrate up to 1,000 km between their breeding areas and geographically restricted aestivation sites in the Australian Alps. Recent research has established that Bogong moths can navigate towards their distant goal using the stars as a compass. Moreover, they continue to navigate correctly even when the stars are obscured by clouds, suggesting that their previously discovered magnetic sense likely harnesses the Earth’s magnetic field as a compass. However, the nature of this compass, and the magnetic sense that supports it, remain unknown. Here we show that Bogong moths, tethered in a flight arena, navigate in their inherited migratory direction using the geomagnetic field alone under a full-spectrum

randomised starry night sky. If the geomagnetic field is turned by 180∞ or if its inclination is flipped, moths fly in the opposite direction. However, if violet-blue light (380 nm < l < 500 nm) is removed from the illumination spectrum, or if tethered moths are exposed to weak broadband radiofrequency fields (150 kHz - 60 MHz), magnetic orientation is abolished. Our results confirm that Bogong moths use the geomagnetic field as an inclination compass for long-distance navigation at night and that they possess a light-dependent magnetic sense likely based on cryptochromes.

Modulation of social behavior | Friday, July 31 **|** 15:15 – 15:30

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Social facilitation of feeding in the clonal raider ant

Social interactions are crucial for the survival of social animals. For example, limited social interactions during the COVID-19 lockdown caused diverse problems, including increased stress levels and sleep disturbance. The clonal raider ant, *Ooceraea biroi*, like many other social animals, lives in highly integrated groups with complex interdependences among individuals. This complexity makes it challenging to understand how the social environment influences individuals and how individuals are affected when the social environment is disrupted. Here, I examined the consequences of social deprivation in the clonal raider ant. Socially isolated ants had lower survival rates compared to socially enriched controls. Physiologically, socially isolated ants showed reduced melanization and decreased levels of cuticular hydrocarbons, the lipid-based layer on the exoskeleton that mediates desiccation tolerance and non-nestmate discrimination. At the neural level, socially isolated ants had decreased levels of inotocin, a neuropeptide homolog of vertebrate oxytocin and vasopressin, which is known to be critical for social behaviors. Behaviorally, socially enriched ants explored novel environments more than isolated ants. Notably, fewer ants fed when isolated than when housed in groups. Moreover, isolated individuals showed high variability in feeding events, whereas ants in groups exhibited coordinated feeding. This coordination likely arises from social facilitation of food finding and ingestion. A few ants are sufficient to initiate feeding by increasing the probability of feeding in consecutive encounters, suggesting positive feedback. Rescue experiments of feeding suggest that the social isolation phenotypes stem from this deficiency in feeding. Together, these experiments reveal that clonal raider ants, and possibly other group-living animals, rely on social facilitation of feeding. Disruption of the social context can therefore lead to striking deficits in nutrient intake and, therefore, a range of downstream phenotypes that affect physiology, behavior and, ultimately, survival.

Evolution of sensory & motor systems | Wednesday, July 29 **|** 16:00 – 16:15

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New insights into the sensory niches of the Dodo and Solitaire

The Dodo (*Raphus cucullatus*) is one of the most recognized symbols of extinction. Endemic to Mauritius, the Dodo generated awareness of the anthropogenic impact on the planet. Yet, despite its cultural and scientific prominence, its sensory biology remains poorly studied. Because sensory systems affect how species perceive and interact with their environment, reconstructing sensory abilities provides a critical framework for inferring behaviour in extinct taxa. Here, we use a quantitative approach to study the cranial and endocranial anatomy of the Dodo and its relative, the extinct Rodriguez Solitaire (*Pezophaps solitaria*). Using data from 36 extant Columbiform species, we assess variation in neuroanatomical and skull features associated with sensory systems to place these extinct taxa within a broader ecological and behavioural context. The Solitaire's sensory niche appears consistent with that of extant pigeons. The Dodo, in contrasts, departs from typical pigeons and doves in several respects. In particular, the Dodo has pronounced differences in visual processing abilities, that might be correlated with changes in activity patterns. Such divergent sensory niches in these two closely related species provide new insights for reconstructing their behaviour and ecologies.

Mechano- & thermosensation | Wednesday, July 29 **|** 16:00 – 16:15

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Perception of aerodynamical looming stimuli

An approaching predator generates a distinct temporal sensory signature, a looming stimulus, alerting a prey. Although the mechanisms for visual looming detection have been thoroughly investigated, those associated with aerodynamic looming— air movements induced by an approaching predator—remain largely unexamined. Given that both types of looming involve a non-linear increase in certain signal characteristics with decreasing distance, we tested whether the mechanisms of perception of aerodynamic looming are analogous with those of visual perception. We stimulated the cercal system of the cricket, a well-established model for airflow sensing, with spider-mimicking translating spheres. The size and velocity of the looming object, the two critical parameters in visual looming perception, significantly enhanced the activity of wind-sensitive interneurons and the escape reaction. Moreover, the timing of peak firing occurred after a small delay after crossing a flow threshold, a physiological property typical of visual looming-sensitive neurons. These findings suggest the existence of convergent computational principles of looming detection across different sensory modalities.

Chemosensory-guided behavior | Friday, July 31 **|** 15:45 – 16:00

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Olfaction in pelagic southern bluefin tuna: impacts of hydrodynamic flow on sensitivity

The morphology of the peripheral olfactory system directly affects the hydrodynamic conditions and delivery of water-borne odorants to the olfactory receptor neurons (ORNs) in aquatic environments. In this study, the morphology of the olfactory chamber and the olfactory epithelium is examined in the southern bluefin tuna, *Thunnus maccoyii*, to understand the impacts of hydrodynamic flow on the abundance and distribution of olfactory receptor neurons in a pelagic teleost that swims continuously in the open ocean. Using morphometrics, scanning electron microscopy, magnetic resonance imaging and theoretical biophysics, *T. maccoyii* is found to possess a thick boundary layer above the nostrils, a circular olfactory rosette and radiating olfactory lamellae in addition to a ventilatory sac. In addition to a new and unique distribution pattern of olfactory sensory epithelia, which changes with growth and likely adapts to variable hydrodynamic conditions, the distribution of ORNs is highly variable. Ciliated ORNs are dominant over microvillous ORNs with mean densities of 86,000 mm-2 and 5,600 mm-2, respectively. Ciliated non-sensory cells that are thought to propel mucus are also present in the periphery of the olfactory epithelium, with a mean density of 900 mm-2. The mORNs display a distinct, heterogeneous spatial distribution, being highly concentrated in the rostral region of the lamellar surface, especially at the entry of the interlamellar space. Based on the hydrodynamics of the incoming flow of seawater and the topography of the olfactory epithelium, the rostral distribution of mORNs is organised to optimise interactions with water-borne stimuli. The mean density of both types of ORNs (92,000 mm-2) is one of the highest among teleosts, which may serve as an anatomical indicator of high olfactory ability, despite the olfactory bulb in this obligate ram-ventilatorconstituting only 1% of the total brain volume.

S8.5 **|** 12:15 – 12:30 **|** Wednesday, July 29

Neurosustainability: how brain science is revolutionizing environmental design and policy

Cortesi, Fabio, The University of Queensland, Australia

Eyes that adapt: visual plasticity as a lifeline for reef fishes in a rapidly changing world

The visual systems of coral reef fishes are inherently highly variable, maximising performance in different light environments and generally fitting ecological demands. As the light environment on coral reefs shifts naturally over the day, between seasons, with depth, or due to changes in suspended sediments and organic matter, visual plasticity (development) or flexibility (reversible within an individual's lifetime) is likely to be a widespread trait that increases a fish's survival. However, the underwater visual habitat is also increasingly changing due to human-induced pressures. More frequent and severe storms, algal blooms, artificial light at night, and reef degradation all shift the visual habitat that fishes experience. Here, I will present our latest efforts to assess whether visual flexibility can buffer against such 'unnatural' anthropogenic changes. Using clownfish, *Amphiprion ocellaris* and its close sister species *A. percula,* as representatives of small, site-attached coral reef fishes, we exposed adult fish to UV-rich and green light, simulating a clear and an algal bloom environment, respectively, for 10 days. Bulk retinal RNA-seq and enzymatic methyl-sequencing provided insights into the molecular regulation of key visual genes, including opsins and modulators of the visual pathway. Histological analyses of photoreceptor length revealed the morphological underpinnings, while colour-discrimination experiments demonstrated the link between gene expression and visual behaviour. Much to

our surprise, *A. ocellaris* vision readily adapted to changes to the light environment, while *A. percula*'s did not. Hence, our work provides critical insights into rapid sensory adaptation, highlighting species-specific differences that may prove crucial for survival in the face of environmental change.

S12.4 | 12:00 – 12:15 | Thursday, July 30

The neuroscience of emotion

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Chronic stress impacts decision-making and neuro-behavioural plasticity in crayfish
Crustaceans represent emerging biological models for exploring the evolution of cognitive processes. Their ability to integrate environmental information and adjust their behavioral strategies suggests a high level of neuro-behavioural plasticity. However, the underlying cognitive and emotional states that modulate these responses remain poorly understood. Understanding how these animals process persistent environmental challenges is essential to deciphering the mechanisms of invertebrate cognition.

Studies have shown that crayfish can exhibit anxiety-like behaviours, naturally during moulting or after an acute stress exposure. During these events, a negative emotional state induces behavioural adaptations, such as anxiety-like responses, which prompt individuals to avoid dangerous situations and thus enhance their survival and overall fitness. We hypothesise, however, that during prolonged stress exposure, further neurobehavioural adaptations could take place, such as depressive-like states reminiscent of disorders observed in mammals.

To investigate whether chronic stress exposure induces such states, we adapted a well-established vertebrate protocol — Unpredictable Chronic Mild Stress (UCMS) — to the crayfish *Procambarus alleni*. Animals were randomly exposed to mild stressors several times per day over several weeks. To validate this state, key markers of cognitive and behavioural flexibility, such as anxiety, social behaviour, anti-predatory responses, decision-making, and daily activity budget, were evaluated. Further analysis of the neurophysiological mechanisms should elucidate these observations by measuring markers of inflammation, stress (glucocorticoids, glucose), and brain serotonin levels.

These results provide new criteria for monitoring crayfish welfare, a better understanding of their emotional states, and insights into the phylogeny and adaptive value of depressive-like behaviours.

S9.4 | 12:00 – 12:15 | Thursday, July 30

Peripheral circuits that shape descending commands to modulate motor programs

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Descending motor pathways for flexible walking in *Drosophila*

Walking is a flexible motor behavior fundamental for exploration, foraging, and courtship. Its initiation, speed, and direction are controlled by neural circuits in the brain. I will discuss recent work revealing the organization and function of these circuits in *Drosophila*. I will present evidence for a functional module in the fly brain that controls forward walking independently of turning and other aspects of movement. This module is layered, with central brain neurons encoding a high-level walking drive and a population of descending neurons conveying this drive to motor circuits in the nerve cord, where it is flexibly integrated to support the animal's behavioral goal. The module interacts with sensory pathways at multiple levels, integrating multimodal feedback in the brain and tuning mechanosensory feedback in the nerve cord. Together, these findings add to a growing body of evidence that functional modules are a general principle through which the brain flexibly controls movement.

3D navigation & spatial cognition | Friday, July 31 **|** 15:30 – 15:45

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Navigation in a three-dimensional marine landscape by wild mantis shrimp

Central place foragers, such as smasher-type mantis shrimp (Stomatopoda), must return to their home burrows after a foraging journey. However, most stomatopod behaviors have been studied under laboratory conditions, in simplistic arenas with limited natural context. Here, we studied peacock mantis shrimp (*Odontodactylus scyllarus*) in the wild, off Kuredu Island, Maldives, to describe their foraging and navigation behaviors. For this purpose, we developed a new methodology based on filming the animals whilst SCUBA diving. Two SCUBA divers each followed individual mantis shrimp with a GoPro camera on an adjustable selfie-stick, maintaining low profiles to minimize disturbances to the animals. We also collected swim-over footage of the reef with a bespoke photogrammetry rig, by filming overlapping transects, then reconstructed the 100m2 habitat in three-dimensions. Full routes taken by stomatopods were manually tracked into the 3D model. In total, we collected 20 hours of footage, encompassing 121 excursions, of four individuals navigating their shared reef habitat. The trajectories of these individuals provide a first glimpse into spatial use by stomatopods in a 3D marinescape. Our preliminary results showcase the navigational behaviors of mantis shrimp, including overlap in the trip ranges of individuals, with certain paths and temporary shelters utilized more frequently than others. Two individuals were able to travel ca. 20 meters in 7 minutes, and the longest excursion we recorded lasted longer than an hour. Our footage captures the intricate behavioral repertoires of these mantis shrimp, including competitive interactions, courtship, and suspected mating attempts. The results of this study establish a foundational dataset describing both the behaviors and spatial knowledge of peacock mantis shrimp in their wild habitat. Furthermore, our simple methods can be adapted for use in other terrestrial or aquatic environments.

Computational sensorimotor control | Wednesday, July 29 **|** 15:00 – 15:15

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Behavioral strategies underlying foraging decisions in *Drosophila*
Foraging behavior - finding and choosing appropriate food sources in the environment - is critical for survival and provides an ethological model to study the neural mechanisms of decision making. The fruit fly *Drosophila melanogaster* offers unique tools to uncover these mechanisms, but it is essential to first understand the animal's behavioral strategy. We established a paradigm where individual flies choose between food patches containing different sugar concentrations. We found that flies continually explore the environment and engage with many different patches over time, and they modulate their engagement with each patch based on its relative value compared to other patches. Food engagement varied over time and corresponded with three locomotor states: initial exploration (fast movement, short patch visits) followed by patch exploitation (slow movement, longer patch visits) and finally resting.

To explain how flies learn the value of food options in their environment and use this information to bias food engagement, we propose a 'reward expectation' model. In this model, flies store and continually update a running average of the sugar concentrations they have experienced, and this expectation is compared with the value of the current option to bias food engagement. This model provides a compact representation of past experiences that could be efficiently stored in the brain, unlike alternative models requiring animals to remember individual experiences. The expectation model makes several predictions that are supported by experimental data. We then integrated the reward expectation framework with a drift-diffusion model to create a mathematical model that predicts how long flies stay on each patch. Model simulations reproduce the experimental data and make predictions for how hunger state and other variables act mechanistically to alter foraging strategy. In ongoing work, we are using genetic manipulations to uncover the neuronal underpinnings of these computations.

S9.1 | 11:00 – 11:20 | Thursday, July 30
Peripheral circuits that shape descending commands to modulate motor programs
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Functional organization of haltere feedback for *Drosophila* flight control
Sensory feature maps are a key building block in the information-processing infrastructure of the nervous system. However, our understanding of how such maps interface with motor circuits to produce behavior remains poor. Here, we examine this problem through the lens of flight control in *Drosophila melanogaster*. Underlying the extraordinary aerial agility of the fruit fly is mechanosensory feedback from the haltere, which are tiny club-shaped structures evolved from the hindwings that help regulate the wing steering system. Although the halteres are critical for flight stability and maneuverability, the principles governing how haltere information is centrally organized remains an open question. We used a genetically encoded calcium indicator to visualize activity changes in the mechanosensors embedded in the haltere during active, visually mediated flight. We find that–contrary to decades-old hypotheses regarding haltere function–haltere feedback is continuously modulated during flight to help flies actively maneuver. We then leveraged the Female Adult Nerve Cord (FANC) electron microscopy dataset to identify and fully reconstruct the haltere's primary afferents. Morphology-based clustering analyses revealed 5 neuronal subtypes–putatively corresponding to the different haltere campaniform sensilla fields and chordotonal organ. Intriguingly, we find that each haltere afferent subtype comprises cells from multiple campaniform fields and preferentially synapses onto modules

of wing-steering motor neurons that innervate muscles with related biomechanical functions. We then designed genetic driver lines that allowed us to test these functional connections in freely flying flies. Our behavioral data support the hypothesis that the haltere subtypes control specific aspects of wing motion and thus flight behavior. Through our holistic approach, we have developed an atlas of the structure-function relationship between rapid mechanosensory feedback and motor systems.

Insect compass systems | Thursday, July 30 **|** 16:00 – 16:15
Dickinson, Michael, California Institute of Technology, USA

Flies use gyroscopes to increase the precision of their internal compass
The insect order Diptera is widely acknowledged as the most ecologically diverse groups of insects[1]. Although two other orders are larger in terms of the number of described species, the ~160,000 species of flies are noteworthy with respect to their astonishing behavioral diversity and ability to converge upon the natural history and morphology of other insects. In contrast, the members of other insect orders are far less successful at encroaching upon the life histories at which flies excel. What are the unique specializations that may have allowed dipterans to succeed at so many different flight behaviors compared to other insect orders? In this work, we show that flies use angular velocity measurements from their halteres to increase the precision on their navigational compass, thus providing them with unique capabilities that may have catalyzed their remarkable behavioral diversification.

Halteres function as gyroscopes to encode angular velocity during flight. Their likely ancestral role was to detect perturbations about the yaw, pitch, and roll axes during flight and initiate rapid compensatory reflexes via rapid local connections to steering motor neurons in the ventral nerve cord. Here, we show that the haltere sensory pathway also provides critical input to the animal's navigation system within the specialized region of the brain called the Central Complex. By exploiting the underlying physics, we implemented a method for accurately simulating angular velocity using micro-oscillation of the fly's body that is phase-locked to the haltere stroke cycle[2], allowing us to perform 2-photon imaging and whole cell patch recording of individual neurons in the brain of flying animals subjected to rotations exceeding 2000 deg s^{-1}. Because the mechanosensory-based halteres can encode high angular velocities that are well beyond the temporal resolution of the visual system, flying flies can accurately update their compass heading during rapid turns, providing a distinct performance advantage over all other insects. We propose that this unique role of the halteres in the compass system is responsible for the extraordinary ecological diversity of flies.

1. Grimald, D & Engel, M (2005). *Evolution of the Insects*. Cambridge.
2. Nalbach G, and Hengstenberg, R (1994). *J. Comp. Physiol. A*, 175, pp.695-708.

S4.3 **|** 11:40 – 12:00 **|** Tuesday, July 28
Adaptive responses to changing internal and external environments: weathering the storm
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Filling in the gaps: the auditory midbrain supports flexible navigation behaviors in bats
In daily life, sensorimotor coordination demands the continuous integration of dynamic sensory input with adaptive motor commands. Although visually guided tracking has been studied extensively, auditory-guided behavior remains less understood, leaving major gaps in how the brain encodes auditory motion and transforms it into action. The inferior colliculus (IC) has been implicated in sensorimotor integration and stimulus tracking, but the mechanisms by which it supports auditory-guided behavior under natural conditions remain unclear. To address this, we leveraged the echolocating big brown bat, Eptesicus fuscus, a mammal specialized for pursuing erratically moving insect prey in three-dimensional, cluttered environments. Its tightly coupled audiomotor feedback system offers a powerful model for dissecting how the brain sustains goal-directed behavior in the face of sensory challenges. We quantified adaptive flight behavior in bats following DREADDs manipulations that transiently suppressed IC activity during a naturalistic obstacle-navigation task. We found that while bats showed navigation performance deficits following DREADDs treatment, they manage to navigate around an obstacle by making dynamic modifications to their flight behavior that compensated for missing sensory cues. These behavioral findings motivated a deeper interrogation of the circuit-level mechanisms supporting this adaptive motor control. We recorded large-scale IC population activity while bats listened to naturalistic call-echo sequences simulating auditory objects moving toward or away from the bat, along with shuffled controls. Responses reflected sensitivity to both echo timing and the broader temporal organization of auditory motion cues, consistent with a rich population code for dynamic sensory scenes. Together, these experiments demonstrate that the IC contributes to the flexible coordination of the sensorimotor computations underlying robust, real-world tracking behavior.

Developmental plasticity & evolution | Tuesday, July 28 **|** 15:30 – 15:45
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Elucidation of the neural circuit regulating the initiation of ascidian metamorphosis
The metamorphosis of ascidian *Ciona intestinalis* type A can be artificially induced by continuous mechanical stimulation of the papillae, leading to early metamorphic events such as tail regression, backward movement of epidermal cells, and mesenchymal cell extravasation from epidermis (Wakai et al., 2021; Totsuka et al., 2023). According to the connectome, primary sensory neurons (PSNs) in the papillae sensing mechanical stimulation connected to neurons in the brain vesicle (BV) 'the central nervous system' via rostral trunk epidermal neurons (RTENs). Our previous study revealed that the specific activation of PSNs by optogenetics is enough to induce the initiation of metamorphosis (Totsuka et al., 2025). The aim of this study is to elucidate the neural circuits controlling metamorphosis initiated from PSNs through imaging analysis of neuronal activity before and after the onset of metamorphosis. We applied mechanical stimulation to Ciona embryos expressing GCaMP6s in neurons and measured neural activity before and after the onset of metamorphosis. In PSNs, intracellular Ca++ levels increased immediately after mechanical stimulation and gradually decreased thereafter. In contrast, in RTENs, sporadic increases in Ca++ were observed during mechanical stimulation until the onset of mesenchymal cell extravasation. Furthermore, in BV neurons, an increase in Ca++ was observed prior to the backward movement of epidermal cells. These results revealed differences in the response of each neuronal subtype at the onset of metamorphosis. Considering the relationship between timings of each neural activity, the metamorphic events and neuronal connectivity, it was suggested that different neuronal subtypes may

control the different initiation of early metamorphic event. Future studies using optogenetics will clarify the roles of these neurons in metamorphosis initiation.

S7.2 | 11:20 – 11:40 | Wednesday, July 29

The evolutionary, behavioral, and neural bases of synchrony

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Neural synchrony and transcriptional concordance in relationships

As relationships mature, partners share common goals, improve their ability to work together, and experience coordinated emotions. However, the neural underpinnings responsible for this unique, pair-specific experience remain largely unexplored. Here, we used recordings of neural activity and single nucleus RNA-sequencing to examine alignment of biology between bonded partners. Using monogamous prairie voles, which form selective and enduring pair bonds, we show that bonding drives dynamic changes in interbrain synchrony: paired voles exhibit greater prefrontal cortical calcium co-activity with a partner than with a stranger. We developed an unsupervised machine-learning classifier for freely interacting voles and applied a Bayesian modeling framework, which revealed that interbrain synchrony remains modulated by relationship type across behavioral states, suggesting that relationship history shapes coordinated neural activity even when behavior is held constant. Performing single nucleus RNA-sequencing to examine the transcriptional landscape of the nucleus accumbens (NAc), we further show that prairie voles exhibit transcriptional concordance with a bonded partner, identifying genes expressed in oligodendrocyte progenitor cells that are concordant between partners and correlated with dyadic behavior. Transcriptional concordance is disrupted by forming a new primary relationship but is not eroded by partner separation. Together, our data indicate that the pair-specific environment shapes transcription in the NAc, superceding other factors such as pair type and sex. These studies provide a potential biological mechanism by which shared experience reinforces and strengthens relationships.

Arthropod locomotion & motor programs | Tuesday, July 28 | 15:45 – 16:00

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Adapting a comprehensive, spike-resolved motor program to changing body mass

Mass perturbations are ubiquitous in nature, and nervous systems must adapt their motor output to maintain control. Many such perturbations, such as pregnancy and ontogeny,

happen on timescales long enough for muscle physiology to adjust alongside them. Changes from feeding, however, can be rapid and drastic and the nervous system cannot rely on physiological changes and must instead adapt behavior through motor output. The foraging hawkmoth Manduca sexta provides an excellent system for exploring how the nervous system adapts to such perturbations because it increases its body mass by 50% in just 60 seconds while simultaneously hovering, feeding from, and tracking a moving flower. Moreover, in Manduca we can record the set of all muscle action potentials that primarily control the wings, a comprehensive, spike-resolved flight motor program. While subsets of muscles are coordinated in the control of turns, a large portion of behavioral variance remains unexplained without the full population of muscles. Therefore, in response to a mass perturbation, we hypothesize that the moths' behavioral change will manifest as coordinated changes in spike timings across the entire motor program. In free flight, Manduca responds to added mass with a consistent increase in sensorimotor gain across all frequencies at which it tracks the flower. We observe this response in a tethered, open-loop experiment as well. We find certain pairs of muscles with coordinated timing relationships that covary both with turning behavior and lift produced, however, these relationships still only explain portions of the behavioral variability we observe. Looking beyond pairwise relationships, we find more intricate patterns of timing coordination distributed across the full motor program. Together, these results show how a relatively simple behavioral response to a mass perturbation can manifest as complex changes in the precise spike timings of a comprehensive motor program for insect flight.

Rhythms & homeostatic control | Monday, July 27 **|** 15:45 – 16:00

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A signaling hub in the mosquito rectum coordinates host-seeking behavior and blood nutrient utilization

Female *Aedes aegypti* mosquitoes require a blood meal to develop eggs and are highly motivated to feed on humans, transmitting pathogens in the process. However, host seeking is transiently suppressed after a female feeds to repletion and remains low until egg laying several days later. Building on our previous finding that conserved Neuropeptide Y-related signaling suppresses human attraction after blood feeding, we investigated how Neuropeptide Y-like Receptor 7 (NPYLR7) regulates this behavioral switch. NPYLR7 is most closely related to mammalian receptors that signal satiety and suppress feeding and are broadly expressed in the nervous system and gut.

Although npylr7 mutant females consume normal-sized blood meals, they fail to properly provision their eggs with protein and exhibit persistent host seeking and blood feeding after a nutritive meal, consistent with a loss of satiety signaling. Using a transgenic driver line, we identified npylr7-expressing cells and found that, unlike related receptors in other species, *Aedes aegypti* npylr7 expression is highly restricted to the rectal pads, a poorly characterized hindgut tissue. In cell-based assays, NPYLR7 responds to multiple peptide ligands, including RYamide. RYamide-expressing neurons project from the ventral nerve cord to the rectal pads, and npylr7-expressing cells show RYamide-induced calcium responses that are abolished in mutants. These cells also respond to amino acids, suggesting potential integration of nutrient and neuropeptide signals.

Despite being non-neuronal, rectal pad cells display neuron-like features, including calcium excitability and expression of secretory and neurotransmitter synthesis machinery. Electron microscopy reveals structural changes consistent with vesicle release following blood feeding. Together, these findings identify a previously unknown gut-based signaling system in which neuron-like rectal pad cells use NPYLR7 to regulate host-seeking behavior and nutrient allocation, revealing a novel peripheral-to-brain pathway controlling mosquito biting and reproductive investment.

Young investigator symposium | Monday, July 27 **|** 11:00 – 11:20

England, Sam, Museum für Naturkunde - Leibniz Institute for Evolution and Biodiversity Science, Germany

The ecology of electrostatics: pollination, parasitism, and predator-prey interactions

Electricity, a fundamental force in the universe, is all around us. The potential for this force to play a role in ecological interactions, moving organisms and objects in the environment, or being sensed, is therefore a promising avenue for biomechanical and neuroethological research. Here, I put forth my case for naturally occurring static electricity to be considered a driver of ecology and perhaps even evolution. I present our findings that pollen is attracted by the natural static charges of butterflies and moths, and similarly how ticks are electrostatically pulled onto hosts. From this, I build to our new evidence of an electrostatic sense in insects, in the context of predator detection by caterpillars and treehoppers – showing that this sense may be widespread and even a driver of morphological evolution.

Social displays & collective behavior | Thursday, July 30 **|** 15:30 – 15:45

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Neural and behavioral basis of individual-level social recognition in fire ants

Social recognition, the ability to identify other individuals during interaction, is a foundation of social behavior. In eusocial insects such as ants, social recognition is largely mediated by cuticular hydrocarbons (CHCs). Differences in CHC profiles allow ants to discriminate nestmates from non-nestmates and to distinguish workers of different castes or task roles. To what extent ants can recognize one another, whether they can distinguish every individual within colonies that may contain millions of members, and how social recognition contributes to coordinating colony organization and division of labor remain key questions in social biology. To address these questions, we developed a pipeline to systematically compare the behavioral outcomes after social interactions, neural representations of chemosensation, and CHC profiles in fire ants Solenopsis invicta. We developed a head-fixed in vivo calcium imaging approach that monitored large populations of mushroom body Kenyon cells at single-neuron resolution, while keeping the antennae freely moving for natural social interactions. We found that mushroom body Kenyon cells showed sparse and distinct responses to different odor stimuli and to CHC extracts from different individuals. This finding was further complemented by quantitative behavioral measurements. By tracking movements of antennae and mandibles during encounters with other individuals, including nestmates versus non-nestmates and workers with different tasks, we found that ants exhibited distinct behavioral signatures toward different individuals, indicating higher recognition resolution than previously reported. Furthermore, recognition ability varied across individuals, which might correspond to their differences in division of labor. Together, these results revealed unexpectedly high-resolution social recognition in fire ants and began to elucidate its role in organizing division of labor in ant societies.

S3.4 **|** 12:00 – 12:15 **|** Tuesday, July 28

Evolution of sleep: A comparative perspective to unravel the biological function of sleep?

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Sleep, Dragons, CPGs

Sleep occupies roughly a third of our lifetime, yet an understanding of its mechanisms and functions, its evolution, or of how precisely it differs from awake states, remains rudimentary at best. Typically associated with physical inactivity and rest, the sleeping brain expresses rich patterns of activity that are relatively unconstrained by active motor behaviour or sensory drive, providing a unique window into the internal dynamics and functional organization of neural circuits. I will discuss our neuroethological approach and describe a series of recent experiments that start to reveal the unexpected complexity, coordination, and generation of sleep activity in the brain of a reptile, the Australian dragon Pogona vitticeps.

S7.3 | 11:40 – 12:00 | Wednesday, July 29

The evolutionary, behavioral, and neural bases of synchrony

Fernandez-Duque, Facundo
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Synchronizing care: neuroendocrine networks underlying avian facultative biparental care

Parental care is costly yet vital for offspring survival, driving variation in how care is expressed across sexes and contexts. In facultatively biparental species, where one sex cares obligately and the other conditionally, the neural mechanisms enabling transitions into caregiving remain poorly understood. We investigated the neuroendocrine architecture underlying flexible parental care in red-winged blackbirds (*Agelaius phoeniceus*), where females always provision nestlings while males range from none to rates rivaling females. Previously, we showed that circulating multihormone profiles are strongly structured by breeding stage and sex, yet provisioning and non-provisioning males overlap broadly in hormonal space, consistent with a shared permissive milieu rather than discrete hormonal "types." This raised a critical question: if circulating hormones do not categorically distinguish caregiving males, does the neural transcriptome? Using the same individuals, we use bulk RNA sequencing of the preoptic area (POA), a conserved region central to parental behavior across vertebrates, to compare courtship-stage males, nestling-stage provisioning and non-provisioning males, and provisioning females. Through differential expression, pathway enrichment, and co-expression network analyses, we characterized the POA transciptomic landscape across groups. While we will save the full reveal for the talk (a speaker has to keep some intrigue for the live audience), we will present how POA transciptomic architecture maps onto the behavioral and endocrine variation in this system, graded modulation within shared networks, or sex-specific wiring of conserved pathways. By integrating field behavior, multihormone profiling, and brain transciptomics from the same individuals, this work offers a mechanistic account of how synchrony and flexibility in biparental care are organized at the neuroendocrine level.

S6.2 | 11:20 – 11:40 | Wednesday, July 29

Brains in the wild A

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Neural mechanisms of rodent foraging and social natural behaviors

Most animals live in complex, perpetually changing environments. To search for food, or shelter, animals learn how to navigate those environments by displaying a remarkable array of flexible behaviors. These behaviors are supported by cognitive operations including learning and remembering food sources, navigating and planning routes. Furthermore, for animals that live in social groups, like rats and mice, these behaviors are strongly influenced by the presence and interactions with other conspecifics. Traditional neuroscience studies aimed at investigating the neural mechanisms of navigation, foraging or social interactions in rodents typically employed highly simplified behavioral paradigms and reduced laboratory apparatus that cannot capture the richness and complexity of rodent spatial and social natural behaviors. To bridge this gap, we have developed a first-of-its-kind experimental platform to conduct mechanistic studies of the neural basic of rodents' natural behaviors in outdoor environments. We performed wireless large-scale neural recordings in groups of mice and rats living in outdoor enclosures, while continuously tracking their spatial and social behaviors. In this talk, I will describe our recent findings on how natural environments are represented in the brain, how rodents encode the social structure of the environment and the neural mechanisms that support navigation and social group behaviors in these settings. These experiments have uncovered previously unobserved mechanisms of spatial navigation, foraging and social interactions that were not feasible to study in traditional laboratory paradigms. I will also describe technological developments we made for long-term, low-weight, wireless neural interfaces and our plans to disseminate them to the broader community.

S5.3 | 11:40 – 12:00 | Wednesday, July 29

The neural substrate of animal collective motion

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Mechanisms of social cue integration underlying the safety in numbers effect in flies

A major benefit of being in a group is the possibility of integrating social information with directly-perceived information about the environment to guide behaviour. Across the animal kingdom, social information acquired via specific signals or cues is used for decisions in reproduction, foraging and protection against predation. Acute fitness benefits of the usage of social information are flagrant in the context of a response to a potential threat: failure to detect a predator can lead to an animal's immediate demise, whereas needless engagement in metabolically costly defence responses can unnecessarily impact fitness. Given its role as a primordial driver of group formation, and its importance for immediate survival, we study social modulation of behaviour in groups in the context of predation threat. We previously showed that female flies exposed to a predator-mimicking visual threat in groups show a 'safety in numbers' effect — they decrease their active immobility defence responses (freezing) compared to when they are alone. Crucially, by exposing wild-type female flies to surrounding flies whose movement we could control, we uncovered

social motion cues as key mediators of the ‘safety in numbers’ effect. Recently, we have shown that an evidence accumulation model accurately predicts our freezing data, a crucial step for understanding the underlying neuronal mechanisms. Furthermore, we have identified that flies scale their responses to social motion cues with group size, hence uncovering a complex interplay between detection of biological movement and numerosity in group-modulated behaviour. Interestingly, these two aspects of the perception of social cues seem to be mediated by different sensory modalities. Our work opens up the possibility to study sensory-motor transformations in the context of group behaviour in detail, providing insight into the evolution of social behaviour.

Urban stressors & adaptation | Monday, July 27 **|** 15:15 – 15:30

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Human specialization and predator avoidance: trade-offs for the dengue mosquito

The arbovirus transmitting mosquito *Aedes aegypti* has African origins where it maintains generalist and human specialist feeding ecotypes, the latter of which has expanded their range worldwide in the last 200 years. In the native range the generalist primarily resides in forest or more rural habitats whereas the human specialist dominates urban areas. While host preference has received the most attention, successful adaptation to respective urban or forest environments likely represents a blank of trait divergence, spanning different life stages. Here we focus on predator avoidance behavior, with the hypothesis that the human specialist form should be worse at escaping predation due to relaxed selection in urban environments. With a combination of survival assays and video tracking, we test this hypothesis and evaluate whether differential predation reflects evolutionary changes in escape behavior or life-history evolution influencing survival capacity.

Insect compass systems | Thursday, July 30 **|** 15:00 – 15:15

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Neuroethological evidence for particle-based magnetoreception in *Cataglyphis* ants

Cataglyphis desert ants are solitary central place foragers. At the start of their foraging career outside the nest, they perform learning walks during which they learn the nest’s panoramic surroundings and calibrate their celestial compass systems. The ants use the geomagnetic field to align their gaze directions accurately and precisely towards the nest entrance while performing pirouettes, rotational body movements during learning walks. Consequently, *Cataglyphis* ants use their magnetic sense for path integration, a non-migratory navigational task over short distances. In contrast to many migratory species such as e.g. Lepidoptera that rely on the inclination of the geomagnetic field, desert ants have a polarity-sensitive magnetic compass. We show that desert ants can sense the magnetic field already in darkness, for example before leaving the nest to perform learning walks. Furthermore, a brief, strong magnetic pulse disrupts both the ants’ behavior and related neuroplasticity in the central complex and in the mushroom bodies. Both results are highly suggestive that sensory reception of the magnetic field in *Cataglyphis* ants is most likely particle based.

S16.5 | 12:15 – 12:30 | Friday, July 31

Orientation across modalities

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Honeybees at high noon keep their celestial compass accurate

The honeybee's celestial compass makes use of the position of the sun and the associated pattern of polarized skylight [1], helping them to navigate between the hive and distant food sources. As the sun approaches high elevations, orientation accuracy decreases as the sun's direction becomes harder to discern [2]. Under these conditions, the pattern of skylight approaches rotational symmetry, making polarized light information directionally ambiguous [3]. East African lowland honeybees, *Apis mellifera scutellata*, regularly experience high sun elevations in their native range during the Summer months, and must therefore navigate under these challenging conditions.

We present data from field experiments, investigating how honeybee celestial orientation is affected by high sun elevations. We recorded repeated waggle-dances by returning foragers presented with a controlled view of the clear midday sky. We also recorded full-sky polarization images, to quantify the available celestial compass information. We find that while bees with a restricted view are indeed unable to distinguish the solar and antisolar sky at midday, they orient accurately when viewing the broader polarization pattern. These results indicate critical roles for minor asymmetries in the skylight polarization pattern for orientation during high sun elevations.

1. Rossel S, Wehner R & Lindauer M (1978) E-Vector Orientation in Bees. J Comp Physiol A 125, 1–12.
2. Lindauer M (1959) Angeborene und erlernte Komponenten in der Sonnenorientierung der Bienen. Z Vergl Physiol 42, 43–62.
3. Kolyfetis G, Gkanias E, Aliyam AA, Jie V, Baird E, Galizia CG, Webb B, Foster JJ. From eye anatomy to navigation: a biologically accurate model of bees' polarisation vision. BioRxiv https://doi.org/10.64898/2026.06.01.729196

S8.1 | 11:00 – 11:20 | Wednesday, July 29

Neurosustainability: how brain science is revolutionizing environmental design and policy

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Can the study of coyote pair-bonding improve public perception and predator management?

Canidae is one clade of highly social mammals that has been understudied with respect to the biological basis of social attachment. While monogamy is relatively rare in mammals (3-9% of mammals; 16% of carnivores; 15-25% of primates), all wild canid species studied to

date exhibit monogamy. In no other group of mammals is the pair bond this prevalent. This feature renders canids particularly suitable for the biological study of social attachment. In particular, coyotes (*Canis latrans*) form lasting pair bonds as a feature of a genetically monogamous mating structure, providing the unique opportunity to investigate this rare and strict form of long-lasting social attachment. Like humans, coyotes are highly intelligent and adaptable and have expanded rapidly across North America. They have successfully infiltrated nearly all available ecological niches—a rare achievement for a carnivore. Despite our similarities, coyotes have a tumultuous relationship with humans, who often consider coyotes to be pests. Nationally, coyotes are responsible for most predator-related losses of livestock, and the number of breeding pairs of coyotes in an area is positively associated with incidences of sheep depredation. As a result, livestock producers are motivated to remove coyotes, despite decades of research showing that most lethal efforts to remove coyotes fail to control population numbers. Advancing our understanding of the biological drivers of coyote pair bonding and translating that knowledge to the public may inform population control strategies and increase the public's understanding of their capacity to form life-long pair bonds, potentially leading to increased support for and use of non-lethal management tools as part of an integrated management strategy.

Chemosensory-guided behavior | Friday, July 31 **|** 15:30 – 15:45

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Neural mechanisms of chemosensory-guided settlement and feeding in reef-building corals

Coral survival depends on critical behavioral transitions, including larval settlement and adult feeding, yet the neural mechanisms underlying environmental cue detection in reef-building corals remain poorly understood. As reefs face accelerating environmental change, understanding how corals sense, integrate, and respond to chemical signals is essential. Here, we investigate the neural circuits mediating chemosensory-guided behaviors across life stages in *Galaxea fascicularis*, *Acropora cervicornis* and *Stylophora pistillata*. In larvae, immunohistochemistry (IHC) revealed a dense population of FMRFamide-positive neurons within the aboral epidermis of *G. fascicularis* and *A. cervicornis*, forming an organized nerve net positioned to detect settlement cues. Ongoing neural mapping using additional antibodies against various neuropeptides, including newly developed GLWamide-specific

antibodies, is expanding our characterization of larval neuronal subtypes. Hybridization Chain Reaction Fluorescence In Situ Hybridization (HCR-FISH) and single-nuclei RNA sequencing are being used to identify molecular markers of neural cell types and candidate chemosensory receptors. To link circuit structure to function, we are developing GCaMP-based calcium biosensors to measure neural activity in freely behaving larvae exposed to ecologically relevant cues. In adults, we examine how corals detect feeding-related signals. Pharmacological manipulation with fluoxetine (Prozac), a selective serotonin reuptake inhibitor, altered tentacle extension behavior, implicating serotonergic modulation in feeding responses. In *S. pistillata*, IHC revealed FMRFamide-positive neurons in the epidermis, WLWamide-positive neurons, and serotonin in the gastrodermis adjacent to symbiotic dinoflagellates. This spatial organization suggests potential coordination between neural signaling, feeding behavior, and host-symbiont interactions. Together, these findings provide a comparative framework linking molecular identity, circuit architecture, and behavioral output in early-diverging metazoans. By integrating larval settlement and adult feeding, this work advances neuroethological theory on how simple nerve nets support ecologically essential decision-making in changing environments.

Evolution of sensory & motor systems | Wednesday, July 29 **|** 15:30 – 15:45

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Electric signal polymorphism predicts dietary niche partitioning in a weakly electric fish

Electric organ discharge (EOD) waveform diversity in African elephantfish is often attributed to sexual selection, yet EODs also mediate active electrolocation during prey detection, raising the possibility that natural selection on foraging ecology contributes to waveform divergence. *Paramormyrops kingsleyae* exhibits an intraspecific polymorphism where certain populations emit biphasic (BP) EODs whereas other populations emit triphasic (TP) waveforms. The genes underlying this polymorphism show signatures of selection; the polymorphism persists despite gene flow, and is behaviorally discriminable by the fish themselves. If waveform differences influence prey detection during active electrolocation, biphasic and triphasic fish should consume systematically different prey. We tested this prediction using DNA metabarcoding of gut contents from 186 mormyrids representing 16 species across eight sites in Gabon, employing two independent COI primer sets for cross-validation and pairing dietary data with environmental invertebrate sampling to distinguish active prey preference from passive availability. At the community level in the diverse Balè Creek mormyrid assemblage, species identity was the dominant predictor of diet composition (R≤24%), consistent with phylogenetic signal in foraging ecology. Within P. kingsleyae, waveform type was the strongest independent predictor of dietary composition (R≤ = 5-6%), explaining variance independently of geographic region, sex, body size, and parasitism status - a result concordant across both primer sets. Dietary differences were driven by prey species turnover rather than differential abundance of shared prey, and prey selectivity analyses confirmed that waveform types differ in which prey they actively prefer, not merely in what is locally available. These findings are consistent with natural selection on foraging ecology contributing to the maintenance of EOD waveform polymorphism, though the sensory mechanisms linking subtle waveform differences to prey detection remain an open question.

Photoreceptors & visual adaptation | Tuesday, July 28 **|** 16:00 – 16:15

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Vision in a single cell

The discovery of eye-like structures, ocelloids, with both lens and retina, in unicellular dinoflagellates challenges the notion that vision and visually guided behaviors require a multicellular eye and a nervous system for image processing. Working with the North-Atlantic species of dinoflagellate Nematodinium parvum we used micro-interferometry and ray tracing to investigate the optics and image forming capacity of ocelloids. Our results show that the lens-like hyalosome of the ocelloid has a refractive-index gradient much like the lenses in many camera-type eyes and that it projects an image onto a retina-like structure. We model the spatial resolution and visual field to approx. 10 and 50 degrees, respectively, and this acuity is high enough to detect their phytoplankton prey items within realistic attack range. Behavioural experiments verify that the swim patterns of the cells are largely guided by the light environment and they display fast directional swimming in straight lines putatively guided by the 'eyes'. Curiously, the ocelloid vanishes at night where the cells divide and then a new one is built in the morning. The discoveries raise questions of how a single cell manages to build structures that otherwise require numerous coordinated cell types and accomplish functions that normally involve information processing in a brain.

S12.5 **|** 12:15 – 12:30 **|** Thursday, July 30

The neuroscience of emotion

George, Zaria, University of Illinois, USA

Context-driven behavior operates independent of physiological responses in *R. aegyptiacus*

The socio-emotional context of sound is essential to how we communicate throughout our day-to-day lives. However, how we as mammals contextually modulate those auditory cues and assign them social value remains largely unknown. A tractable mammalian model for investigating this knowledge gap is the bat *Rousettus aegyptiacus*. *R. aegyptiacus*, like most bats, is an auditory specialist that can emit echolocation calls used for navigation, as well as social communication calls used to convey their internal state. Using physiological methods, we investigate the distinct mechanisms underlying the perception of different calls from the repertoire of *R. aegyptiacus*. Heart rate monitoring during playback experiments was used to identify the physiological valences of specific call types within *R. aegyptiacus*'s repertoire. We further employed in vivo electrophysiological recordings of the primary auditory cortex (A1) to investigate the neuronal mechanisms underlying the perception of these calls. Both physiological practices provided direct insight into how social sounds are processed independent of a social setting. The speaker test, a playback experiment, allowed us to determine the role of context on the behavioral valence of distress calls in this species. This work establishes foundational links between contextual modulation and auditory processing of social communication in mammals.

S16.1 **|** 11:00 – 11:20 **|** Friday, July 31

Orientation across modalities

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Mapping polarised sky views to the behaviour of oriented animals under clouds and trees.
Many navigating animals must be able to extract reliable directional information from visual scenes cluttered by vegetation and clouds. Building on a computational model of the insect polarised light compass, I combine behavioural experiments, polarisation and colour imaging, anatomical reconstruction and modelling to uncover how ball rolling dung beetles cope with such environmental noise. Using µCT based 3D reconstructions of individual ommatidia, I quantify spatial resolution across the visual field and simulate how eye design limits access to celestial compass cues. In parallel, I challenge the orientation of *Kheper lamarcki* under natural clouds and foliage in South Africa, while simultaneously recording the skylight and surrounding scene with a polarisation camera, providing a matched description of the beetles' available visual input in the field. By integrating these skylight statistics with my anatomical model and trajectory data, I test how beetles reweight allothetic celestial information and idiothetic self-motion cues when the sun and polarised light pattern are degraded. Preliminary results show that foliage has little impact on compass performance, whereas clouds strongly disrupt celestial guidance. When allothetic and idiothetic cues are in conflict, the beetles climb onto their dung ball and rotate, remapping their internal compass to the current skylight. The beetles seem to rely more heavily on celestial cues under a clear sky and more heavily on idiothetic cues under overcast skies to maintain straight paths. This work provides the first mechanistic framework that links natural skylight structure, eye anatomy and behaviour in dung beetles, and outlines general principles for robust celestial compasses that could inspire autonomous systems operating in visually variable outdoor environments.

Mechano- & thermosensation | Wednesday, July 29 **|** 15:00 – 15:15
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The TRP-channel painless mediates substrate stiffness sensing during *Drosophila* oviposition
The distinct textural properties of fruits in varying stages of ripening present unique ecological opportunities for several species of fruit flies, resulting, over evolutionary times, in specialized egg-laying behaviors. We identified a TrpA channel-dependent mechanosensory pathway in the legs, through the gene painless, that modulates the discernment of softer patches for oviposition in gravid *D. melanogaster* females. We report that the stiffness-sensing role of tarsi is mediated through external sensory organs housed, namely ventral mechanosensory bristles and subsets of campaniform sensilla present primarily at the joints between tarsomeres. Our findings provide new evidence that campaniform sensilla function as indirect stiffness sensors of oviposition substrates, owing to their placement at joints that experience maximal cuticular distortion. We show that Painless is expressed in mechanosensory neurons innervating peripheral organs where it likely participates in the transduction of stiffness-evoked stimuli. Furthermore, we observed that overexpression of painless in both campaniform sensilla and mechanosensory bristles

partially rescues preference for the softer substrates in painless mutants, indicating that painless activity in these organs is necessary to mediate the preference. We propose that different interactions with a soft vs. a hard substrate (compression of the cuticle, distribution of contacts) results in differential mechanotransduction in painless-expressing neurons, determining oviposition preferences.

S7.4 | 12:00 – 12:15 | Wednesday, July 29

The evolutionary, behavioral, and neural bases of synchrony

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Neural mechanisms underlying family coordination in poison frogs

Parenting is one of the most common forms of social behavior across Life. In extreme environments, biparental care – mothers and fathers working together as a team – evolves as a strategy to improve offspring survival, but the behavioral and neural mechanisms driving teamwork within families remain relatively understudied. Here, we use biparental poison frogs (*Ranitomeya imitator*) as a model for understanding how synchrony improves familial communication and offspring fitness. We identified variable parenting effort across families, with high or low-investment corresponding to care efforts of fathers rather than mothers. Finally, we describe a highly conserved opioidergic cell type between amphibians and mammals residing in the hypothalamus that likely underlies this caring behavior, highlighting the ancestry of this circuit in caregiving over vertebrates that may contribute to synchrony between partners.

S11.5 | 12:15 – 12:30 | Thursday, July 30

The neuroethology of water stress: thirst, desiccation risk and water-seeking behavior

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The role of dopamine in the resilience of collective behavior to water stress

Water stress is an urgent and growing problem for all organisms. Drought conditions, with high temperatures and low humidity, cause evaporative water loss with physiological costs. The project examines how dopamine mediates variation among ant colonies in the collective regulation of foraging, through individual forager decisions about the risk of water loss. Selection on variation among colonies in neurophsyiology may allow colonies to adapt to increasingly severe conditions. A >30-year long-term study of a population of colonies of the desert red harvester ant (Pogonomyrmex barbatus) shows that colonies must spend water to obtain water and food. Ants lose water while foraging but gain it by metabolizing fats from collected seeds. A forager inside the nest decides whether to leave the nest on the next trip, by integrating social, olfactory encounters with returning foragers, a cue to food availability, and its assessment of desiccation risk from its previous foraging trip outside. Colonies differ in forager decisions. Risk-averse (RA) colonies reduce foraging in dry conditions to conserve water, sacrificing food intake. Risk tolerant (RT) colonies

continue foraging despite the cost. Previous transcriptomic and pharmacological studies showed that dopamine (DA) mediates forager decisions. Higher DA is associated with increased foraging in dry conditions. We are measuring DA titers in forager brains from RA and RT colonies using near-infrared fluorescence assays in pooled brain samples. Experimental and lab studies indicate that RT colonies upregulate DA to support risky foraging under desiccation stress. We mapped dopaminergic neurons (DANs) in P. barbatus using tyrosine hydroxylase immunolabeling and confocal microscopy. Comparison with *Drosophila* reveals conserved DAN clusters. Differences between RA and RT colonies in DAN cluster architecture and downstream synaptic projections can mediate dopamine release and thus forager decisions about the risk of water lo

S11.1 | 11:00 – 11:20 | Thursday, July 30

The neuroethology of water stress: thirst, desiccation risk and water-seeking behavior

Gracheva, Elena, Yale University, USA

Neurophysiological mechanisms of thirst suppression during hibernation

Vertebrate motor control | Friday, July 31 | 15:30 – 15:45

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Dual control of feeding and singing in the songbird motor system

Many skilled behaviors rely on the same muscles to produce functionally distinct movements. How the nervous system has evolved to selectively coordinate muscle activity to flexibly execute discrete behaviors is unknown. Zebra finches are an excellent model to study this question, as they rely primarily on their highly adapted beaks to perform a large repertoire of skilled behaviors. Although beak movement is critical for both vocalization and eating in songbirds, relatively little is known about the neuromuscular control of the jaw muscles during these behaviors. Using electromyography (EMG), we recorded high-resolution muscle activity from the output of these motor systems to understand how muscles are utilized in different motor control strategies. We collected chronic EMG recordings from the adductor (jaw closer) and depressor (jaw opener) muscles during undirected song and seed-handling, revealing that both muscles are rhythmically active during both singing and eating. We observed that adductors and depressors alternate activity in individual gape cycles for both song and eating, suggesting a potential shared motor pattern across these naturalistic behaviors. In parallel with these behavioral and electrophysiological studies, neuroanatomical studies revealed projections from the lateral arcopallium (Ail) to motor nuclei involved in innate vocalizations, raising the possibility that shared brain circuits have evolved for feeding and vocalization. Overall, this work aims to identify how patterns of muscle activity drive diverse behaviors that may have evolved from a single circuit.

S15.4 | 12:00 – 12:15 | Friday, July 31

Animal architecture

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Is nest building in birds a cultural behaviour?

Culture, learned behaviours that are shared among members of a group and persist over time, are documented across diverse species. For culture to persist, newcomers must adopt the norms of the group, a process called conformity. We examined conformity in zebra finches (*Taeniopygia guttata*) by testing whether newly introduced males (n = 75; the primary nest-builders) conform to the nest material preferences of an established population. Each male's preferred colour (blue or yellow) was identified as the colour of string he interacted with most, and bias strength was measured as the percentage of total interaction time spent with his preferred colour. Each male, with a female partner, was then introduced into a population of birds using nests that either matched, clashed, or were neutral to his initial preference. After observing the population for three days, males were given access to both string colours to build a nest. We found that nest material use depended on the interaction between bias strength and population composition. More weakly biased males in populations that clashed with their preference conformed, while more strongly biased males maintained their preference, regardless of population composition. These findings suggest that individual biases influence conformity and may affect the spread and persistence of culture.

Vertebrate motor control | Friday, July 31 | 15:00 – 15:15

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Neural correlates of seed dehusking in songbirds

Seeds are highly nutritious but also hard and enclosed by an indigestible testa. Some songbirds process seeds intraorally and remove the hard seed husk before swallowing. Seed dehusking in songbirds is a complex sensorimotor task that requires precise coordination of the beak and tongue and extensive tactile feedback from the orofacial region. Whether this behavior is correlated with changes in the brain of birds is currently unknown. We tested whether this behaviour is associated with predictable changes in brainstem somatosensory and motor nuclei. We measured the volumes of the principal

sensory nucleus of the trigeminal nerve (PrV), the trigeminal motor nucleus (MV), and the facial motor nucleus (MVII) across 92 passerine species and combined these data with information on diet and beak morphology. Using phylogenetic comparative analyses, we found that species belonging to families that dehusk seeds exhibit a selective enlargement of PrV relative to brain size, whereas MV and MVII show smaller differences. This enlargement is best predicted by the presence of seed dehusking behaviour rather than by overall seed consumption or beak shape alone. Moreover, seed-husking species display a disproportionate expansion of the lingual representation within PrV, indicating enhanced somatosensory processing of tactile inputs from the tongue. These results suggest that the evolution of seed dehusking in songbirds is primarily associated with increased sensory, rather than motor, specialization in the trigeminal system. More broadly, our findings highlight convergent principles linking dexterous food manipulation and the expansion of neural substrates for haptic feedback across vertebrates.

Photoreceptors & visual adaptation | Tuesday, July 28 **|** 15:15 – 15:30

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Comparative connectomics provides new insights into the rod pathway of vertebrate retinas

To explore the anatomical similarities and the potential evolution of the rod bipolar cell (RBC) pathway in the vertebrate retina, we analyzed 3D EM datasets from seven vertebrate species: two nocturnal and two diurnal snakes, a diurnal turtle and chicken, and a nocturnal owl. We first focused on the snake retina. PKC-a labelling revealed a rod-selective ON bipolar cell in nocturnal snakes, and an LWS-cone-selective bipolar cell in diurnal snakes. Our large-scale EM reconstruction showed that in the nocturnal snakes, RBCs contacted about 20 rod terminals and appeared like typical mammalian RBCs, whereas in the diurnal snakes, RBCs contacted only two to three rod terminals, similar to what has been show in the diurnal ground squirrel retina. As in zebrafish and in mammals, RBCs primarily synapse onto AII-like and A17-like amacrine cells. In addition, however, we found ganglion cells with highly selective RBC input in all four species. This is the first time that RBC-selective ganglion cells have been found in a vertebrate retina, and our ongoing studies will show whether this is specific to snakes or evolved in other vertebrates as well. The datasets from central chicken and turtle retina provide no evidence for a rod-specific bipolar cell pathway. The owl retina is under investigation, and datasets from two fish and two amphibian species are in preparation.

S6.3 **|** 11:40 – 12:00 **|** Wednesday, July 29

Brains in the wild A

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Neurophysiology in wild songbirds reveals the neural mechanisms of duet singing

Cooperation is an important key for success in any social animal system. A prerequisite for cooperative behavior is the ability to coordinate motor actions with other individuals. Mated

pairs of the cooperatively breeding white-browed sparrow weaver (*Plocepasser mahali*), for instance, precisely coordinate their vocalizations to generate duet songs, which they use for territory defence. While the ecological benefit of cooperative behavior has widely been studied in different animal taxa, the underlying neural mechanisms are still poorly understood. We try to fill this gap by investigating the brain's role in duet singing. We perform telemetric recordings of vocal motor or auditory activity in parallel with recordings of the individual vocal activity in wild and free-ranging male and female white-browed sparrow weavers while they sing duet songs in their natural habitat, the South African Kalahari. We found that this bird species produces one of the most complex duet songs amongst songbirds. The male and the female duet partner precisely alternate sex-specific song syllables without large gaps or overlaps, which requires a rapid auditory-to-vocal motor translation. White-browed sparrow weavers don't repeat song elements in their duet songs, but seem to exploit a syllable categorization system to choose the syllable type that corresponds to the last syllable sung by the partner. Neurons in the vocal motor brain area HVC show different activity patterns prior and during the production of syllables of different categories. While in both sexes the partner's contributions to the duet elicit auditory activity in the forebrain, which indicates that both sexes listen to their partner during duetting, only females can adjust their song to syntax changes in the male duet part. Our study encompasses the first extracellular neural recordings done in wild animals outside a laboratory setting and empathizes the importance of studying brain function in natural social settings.

Vertebrate motor control | Friday, July 31 **|** 15:15 – 15:30

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Neuromuscular organization and the geometry of facial motor control

A central challenge in systems neuroscience is understanding how neural circuits generate coordinated, multi-muscle motor output. Facial movements provide a powerful model because dozens of small muscles generate high-dimensional yet structured and rapid movements under the control of compact brainstem circuits. At the same time, the same set of muscles supports multiple ethologically relevant behaviors, offering a rare window into how circuits flexibly repurpose a single motor apparatus. Yet how neuromuscular organization shapes the space of possible movements and how circuits exploit this structure remains largely unexplored.

We combine quantitative behavioral analysis, anatomy, and physiology to dissect the circuit logic of facial motor control in mice. Using Cheese3D, a calibrated six-camera 3D tracking system, we capture whole-face kinematics with high temporal and spatial resolution. We will present new results revealing the geometric structure of facial movement and its neuromuscular basis, uncovering the space of facial patterns constrained by neuromuscular organization.

We further use this framework to systematically map facial motor programs across sensory-driven behaviors. These experiments uncover structured variation across conditions that is conserved across individuals. Together, this work establishes facial motor control as a tractable system for uncovering general principles of sensorimotor transformation.

S10.1 **|** 11:00 – 11:20 **|** Thursday, July 30

Brains in the wild B

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From branch to branch: visually guided navigation in early primates
Arboreal foraging and leaping were likely defining features of early primates, placing strong demands on visuomotor control and thus shaping key primate traits ranging from forward-facing eyes and grasping hands to advanced cognition. To safely leap from branch to branch, animals must estimate distance, transform it into precise take-off parameters, and commit to a high-risk ballistic trajectory that cannot be corrected mid-flight. This tight coupling of vision, action, and outcome offers a unique window into how the primate brain computes internal models that map whole-body motion onto future states.

We study these processes in the gray mouse lemur (*Microcebus murinus*), one of the smallest living primates and likely the closest extant proxy for early primates, using a deliberately integrated wild–lab approach. Rather than adapting behaviors to the laboratory, we bring quantitative ethology into the animal's natural context. Using high-speed 3D tracking and wireless automated reward systems, we first established highly reproducible leaping behavior directly in the canopy of trees in a deciduous dry forest in Madagascar. This "lab in the wild" paradigm preserves the ecological validity of natural behavior while achieving the precision and repeatability typically restricted to laboratory settings. We then close the loop by recreating the same 3D foraging task in a large-scale, naturalistic laboratory environment, enabling systematic manipulation of key variables such as distance, branch compliance, lighting, and perceived risk (e.g., predator cues).

Across both settings, mouse lemurs systematically tune their take-off in ways consistent with an internal model of projectile motion. Rather than minimizing immediate effort, they balance the mechanical costs of take-off and landing within clear biomechanical constraints. These findings reveal precise predictive control over future trajectory and landing state.

Overall, our findings demonstrate that combining field-based ethology with controlled laboratory neuroscience can uncover fundamental computational principles of behavior. They support the idea that visually guided leaping played a key role in the evolution of forward models linking vision and action in the primate lineage.

S4.5 | 12:15 – 12:30 | Tuesday, July 28
Adaptive responses to changing internal and external environments: weathering the storm
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Temperature compensation across neural and neuromuscular functions in *Cancer borealis*
Understanding how warming affects life-critical physiological processes is increasingly important as ocean temperatures rise at unprecedented rates. We studied the stomatogastric system of the crab *Cancer borealis*, focusing on the pylorus, involved in food filtering. In this system, muscle contraction depends on multiple temperature-sensitive levels of organization, from motor pattern generation to neuromuscular transmission and the contractile machinery. Previous studies examined these levels separately: warming increases pyloric rhythm frequency until the rhythm crashes at extreme temperatures. How

the neuromuscular system responds to this increase in motor pattern remained unknown. Here, we jointly measured neuronal motor input and muscle responses using simultaneous recordings of nerve activity, muscle fiber membrane potential, and contraction. As temperature increased, rhythmic nerve activity and excitatory junctional potentials were maintained, whereas contraction declined and failed first. When muscles were stimulated at a fixed low frequency mimicking cold neuronal activity, contraction decreased with warming. Increasing stimulation frequency to mimic warm neuronal activity partially rescued contraction, showing that the temperature-dependent rise in neuronal firing provides partial compensation, but not enough to fully prevent the loss of contraction at high temperatures. We further show that warming hyperpolarizes muscle fibers, moving membrane potential farther from contraction threshold, protecting against over-excitability. However, high-potassium induced contraction reveals that the contractile machinery remains functional at high temperature. These results show that warming acts differently across levels of organization and that temperature-dependent compensatory overlap to preserve function over a broad temperature range.

S13.4 | 12:00 – 12:15 | Friday, July 31

Neural basis of acoustic communication across vertebrates

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Rules underlying vocal exchange across species

Vocal interactions are widespread across animals, including humans, and are important for many social behaviors. The rules underlying these exchanges remain poorly understood, partly because of limitations in data and analysis tools, while emerging AI technologies offer promising avenues for discerning communication dynamics. We analyzed >1,000 hours of vocal exchanges between pairs of female zebra finches, and found consistent patterns of rapid structural modulation, response selectivity, and vocal covariation during interactions. We leveraged generative AI-based playbacks as well as non-interactive playbacks to test the factors driving this vocal flexibility observed during live interactions. We then applied this same analysis framework to data from other species (including other birds, as well as frogs) to compare the strength of these vocal flexibility metrics across species. Together, these results reveal central rules underlying vocal exchanges across species and demonstrate how AI can be leveraged to understand animal communication.

Sensory learning & decision-making | Monday, July 27 | 16:00 – 16:15

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Cue-guided decision-making in the echolocating bat

Goal-directed navigation requires flexible decision-making. Sensory cues acquired during navigation may guide decision-making strategies to assess potential outcomes. Bats, known for their reliance on sonar for 3D orientation, provide powerful research models for investigating decision-making during cue-guided navigation. Vicarious trial and error (VTE), a future-oriented decision-making process characterized by head-scanning in rodents, has been observed following navigational errors. While the cognitive processes underlying VTE remain debated, it is not known whether bats exhibit comparable overt decision-making behaviors during navigation. Here, we investigate whether big brown bats increase head-scanning and modulate sensory sampling via echolocation following navigational errors and under conditions that vary the temporal delay between cue onset and action. Four bats were trained to locate a landing perch in the dark and associate distinct sensory cues with the perch's physical location. We systematically varied the working memory demands required to maintain cue information prior to action by manipulating the delay between cue presentation and choice. We compared sonar beam direction, call rate, and head angular displacement between successful trials, those following invalid trials that misdirected the animal, and across delay conditions. The directional aim of the bat's sonar beam and head angular displacement at the choice point served as a metric for deliberative decision-making. This research offers insight into future-oriented decision-making behavior in echolocating bats and memory demands on adaptive navigation strategies.

Developmental plasticity & evolution | Tuesday, July 28 **|** 16:00 – 16:15

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Plasticity and evolution coordinate predictions and behavior through a sensorimotor hub

Mormyrid fish communicate using an electric organ discharge (EOD) produced with a variable sequence of interpulse intervals (IPIs). EOD duration varies widely across species and, in some species, is reversibly elongated by testosterone (T) in males during breeding periods. It is unclear how patterns of IPI production relate to differences in EOD duration. Both species differences and T-induced differences in EOD duration are matched precisely by delays in a corollary discharge circuit that mediates sensory predictions of the timing of responses to self-generated EODs. This circuit also projects to inhibitory neurons that regulate the timing of EOD production through recurrent feedback, but the effects of these shifts on IPI patterns are unknown. Based on this shared circuitry, we hypothesized that long-EOD fish have larger baseline IPIs. To test this, we treated *Brienomyrus brachyistius* with T to induce EOD elongation and corollary discharge plasticity, and recorded IPIs of individual, freely swimming fish during treatment. We also recorded IPIs in two *Campylomormyrus* species with dramatically different EODs: one with short-duration EODs (~0.2 ms), and one with long EODs and pronounced ontogenetic plasticity of EOD duration (2-26 ms). Using spike train analysis, we quantified species differences and hormonal effects on baseline IPIs and burst displays. Consistent with our hypothesis, long-EOD groups had larger baseline IPIs than short-EOD groups. However, EOD bursts were more frequent in long-EOD groups. Curiously, these long-EOD bursts were more stereotyped and shorter compared to short-EOD fish, which had more infrequent bursts that were longer and more variable in duration. Our results suggest that motor pathways modify patterns of signal production to accommodate both evolutionary and plastic change in signal duration. Further, our results suggest that a single locus in the brain regulates sensory predictions and motor output to match changes in signal duration.

Social displays & collective behavior | Thursday, July 30 | 15:00 – 15:15

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Impact of social isolation on the neural responses of a wasp with identity recognition

Polistes fuscatus wasps possess individually distinctive color patterns on their face, which they can use to visually recognize and discriminate each other. The development of this ability is dependent upon social experience. Previously, we found a localized physiological population of neurons in *Polistes fuscatus* that are selective to forward-facing wasp images in the lateral protocerebrum. Additionally, the synaptic volumes of high-order visual centers in these same brain areas are differentially impacted by social experience. We now perform multichannel extracellular electrophysiology recordings in the brains of P. fuscatus wasps that have been isolated for their entire adult lives and have never seen another adult wasp. We find a striking difference in the relationship between the selectivity for forward-facing wasp images with and without color across the brains of these animals. In normally reared animals there is a very tight relationship between a unit's selectivity for wasp shape with and without wasp internal features present. Here in isolated animals this relationship is almost entirely gone. However, we do still find units that are selective for forward facing wasp images with and without internal wasp features. This suggests that there is a developmental program in *Polistes fuscatus* that produces wasp cells in appropriate regions of the brain and visual hierarchy, and that experience is not necessary for social image selectivity to develop in these circuits. However, the proportion of selective units and their degree of selectivity across wasp features is greatly impacted by social experience. This finding suggests that connectivity between these circuits may be what is shaped by social experience, and likely gives rise to the different social discrimination abilities of socially reared versus socially isolated animals.

S14.3 | 11:40 – 12:00 | Friday, July 31

Periphery is key: adaptations to natural scenes in the visual periphery of arthropods & vertebrates

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Neural adaptations to the statistical properties of natural vision

The statistics of natural scenes are dynamic, varying across environments and time of day. To effectively process visual information under these changing conditions, sensory systems adapt to optimize information transfer. This adaptation is consistent with the efficient coding framework, which states that sensory systems evolve to maximize information transfer while minimizing redundancy and metabolic cost. In the early visual system, this principle has been widely used to determine the optimal structure and function of receptive fields. Here, I examine how receptive fields properties in the retina and superior colliculus have adapted to the challenges of an ever-changing visual environment. While our work and that of others shows that retinal adaptations largely conform to predictions of efficient coding, the superior colliculus exhibits notable deviations, particularly in its response to luminance. I will discuss the evidence for these differences and propose that such deviations from efficient coding principles are essential for maintaining visual computations that rely on relative temporal coding.

Modulation of social behavior | Friday, July 31 **|** 15:00 – 15:15

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Female-specific parental care in a cichlid fish is enforced by pheromones and androgens

Parental behavior is found across numerous clades of invertebrates and vertebrates, suggesting that the control mechanisms have deep evolutionary origins. Significant progress has been made in identifying genes, hormones, and neurons that regulate parental care in rodents, but the vertebrate bauplan for parenting circuits, and the evolutionary changes that lead to variations in its function, remain elusive. Cichlid fish exhibit very high levels of parental care, but across their ~2000 species the behaviors vary in form, extent, and sex of caregiver. We have used molecular approaches to understanding cichlid behavior, including CRISPR gene editing and transgenesis. We find that olfaction plays a central role in enforcing female-only care in which cichlids carry developing offspring in the mouth for ~2 weeks. We discovered a specific pheromone receptor that drives avoidance of mouthbrooding, and males lacking this receptor initiate care. In addition, a cichlid species in which males provide care carries a mutation in this receptor, indicating that both sexes have circuits for parenting, but evolution of olfactory signaling regulates the parenting strategy. These circuits for parental care are also regulated by gonadal hormone signaling: males in which androgen receptor beta signaling is disrupted also exhibit parental care. These results suggest that androgens alter the processing of olfactory information that guides parental care decisions, enabling the flexible expression of behavior across sex and species.

Rhythms & homeostatic control | Monday, July 27 **|** 15:15 – 15:30

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Characterization of active sleep in cuttlefish *Sepia pharaonis*

Cephalopods and vertebrates diverged approximately 550 million years ago; however, their sleep behaviors appear to reflect convergent evolution. Recent studies on octopuses and cuttlefish (*Sepia officinalis*) have identified at least two sleep states: active sleep and quiet sleep. Active sleep (AS) is described as involving eye movements, body twitches, and rapid body pattern changes.

To characterize AS in cuttlefish *Sepia pharaonis*, individuals were exposed to four conditions: daily water-flow disturbance, a checkerboard background during the daytime, a checkerboard background throughout the day, and a control condition without manipulation. Each animal was recorded continuously for two weeks using an overhead

camera under dim red-light illumination (620-660 nm) at night and normal ceiling light at day.

Results showed that AS occurred at least once per week and mostly at night. On days when AS was observed, individuals exhibited 1-11 bouts per night (average 6.2 bouts per night), marked by rapid changes in body patterning separated by prolonged inactivity. The mean interval between AS bouts was approximately 17 minutes, and the mean bout duration was around 2 minutes. Compared with the control condition, the three experimental conditions exhibited slightly longer intervals between AS bouts and slightly longer AS durations; however, no significant differences were found among conditions.

During AS, we identified a previously unreported component, the extended tentacle, in which the cuttlefish darkened its entire body and extended its tentacles near the end of AS. We also observed dark eye patches, previously described by Nakajima and Ikeda (2017), appearing at the beginning of nearly every AS event. The functional significance of these patterns remains unclear.

In future work, we plan to use automated analysis to clarify the relationship between AS and body patterns, and to examine the potential function of AS in cuttlefish.

S14.5 | 12:15 – 12:30 | Friday, July 31

Periphery is key: adaptations to natural scenes in the visual periphery of arthropods & vertebrates

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Of sharks and mice: evolutionary origins of vertebrate visual circuits

The basic blueprint of retinal organization is remarkably conserved across vertebrates. Yet our detailed understanding of retinal function is derived from only a handful of model species that poorly capture the ecological diversity and behavioral repertoires of vertebrates. To illuminate the origins of vertebrate visual processing in structure and function, we study the retina of the catshark *Scyliorhinus canicula*, a representative of the evolutionary pivotal yet historically understudied elasmobranch lineage, using single-cell RNA sequencing, electron microscopy, and electrophysiology. By integrating our multimodal insights with knowledge from established vertebrate models, we propose a unifying framework for the origins of vertebrate retinal circuits and the independent emergence of common solutions to lineage-specific behavioral needs.

S1.1 | 11:00 – 11:20 | Tuesday, July 28

Principles of sensory navigation across species & habitats

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Neural dynamics for working memory and evidence integration during olfactory navigation in *Drosophila*

Working memory and evidence integration are fundamental components of cognition thought to arise from distributed circuits throughout the brain. Theoretical and behavioral studies suggest that both processes are required for plume navigation, an innate task in which animals use stochastic sensory cues to locate an odor source. Most experimental approaches probe this behavior using simplified odor pulses, leaving open how these computations operate under naturalistic sensory statistics. Here, we identify a small population of local neurons in the navigation center of *Drosophila* that exhibits both evidence integration and working memory dynamics during goal-directed olfactory navigation. Using a closed-loop virtual navigation paradigm driven by simulations of turbulent plumes derived from real plume measurements, we show that a localized "bump" of activity in this population ramps up with successive odor encounters and can persist for variable intervals after odor loss. While this activity persists, flies maintain the goal heading adopted during odor exposure. Silencing these neurons selectively impairs the persistence of upwind heading after odor loss. Computational simulations further show that the observed persistence time constant optimizes navigation in turbulent boundary-layer plumes. Together, these results localize working memory and evidence integration to a specific, genetically identified neural population operating under naturalistic sensory conditions. Ongoing and future work will extend this framework to freely walking animals navigating real-world odor landscapes.

S15.3 | 11:40 – 12:00 | Friday, July 31

Animal architecture

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From sand to species: how courtship construction drives diversification in cichlids
Animal architecture provides a unique opportunity to study internal state through physical record. In Lake Malawi, more than 800 cichlid species have arisen within the past million years despite relatively limited genomic divergence. A key contributor to this radiation is male courtship construction of bowers, species-specific sand structures, that function as mating arenas within lekking systems and directly influence reproductive success. These extended phenotypes emerge from hundreds of repeated sand-manipulation acts, providing a tractable system for linking behavioral execution and evolutionary diversification. In this presentation, I will describe our work to understand how bower shape evolves, comparing the building behaviors of two benthic cichlid species that produce divergent architectures: one constructing rounded bowers and the other excavating deep territorial pits. Using machine learning based behavioral quantification, we decomposed construction into discrete motor acts and analyzed their frequency, sequencing, and temporal organization including where mating behaviors occur with respect to the bowers. Although both species share a common behavioral repertoire, they differ in how these actions are deployed, producing distinct building algorithms that reliably generate alternative structures. Taking advantage of the ability to interbreed Lake Malawi cichlid species, we quantified construction behavior in F1 hybrids and backcross males. Hybrids exhibited intermediate combinations of parental building motifs, indicating that species differences in architecture arise from heritable variation in behavioral organization. Ongoing QTL mapping aims to identify the genetic and neural substrates underlying these divergent construction strategies. Together, this work demonstrates how analyzing animal architecture can reveal the behavioral and genetic mechanisms that link courtship behavior to rapid speciation in African cichlids.

S3.1 | 11:00 – 11:20 | Tuesday, July 28

Evolution of sleep: A comparative perspective to unravel the biological function of sleep?

Keene, Alex C., Texas A&M University, USA

Genetic and evolutionary analysis of sleep and aging in cavefish

The biological functions of sleep remain among the most fundamental unanswered questions in neuroscience. We are leveraging the Mexican cavefish, *Astyanax mexicanus*, to investigate conserved biological processes that have been implicated in sleep across model systems within the context of a naturally evolved short-sleeping vertebrate. *A. mexicanus*is represented by multiple independently evolved cave populations that have converged on dramatic reductions in sleep relative to extant river-dwelling surface fish, providing a powerful comparative framework to identify shared and population-specific mechanisms associated with sleep loss. Our current work examines how pathways linked to DNA damage repair, protection against reactive oxygen species (ROS), and the regulation of synaptic strength and connectivity are altered in short-sleeping cavefish, testing hypotheses that have emerged from studies in flies, rodents, and other model organisms. By comparing multiple independently evolved cave populations, we can distinguish conserved biological signatures of sleep loss from population-specific adaptations, providing a rare opportunity to identify evolutionary principles underlying sleep function. To extend these findings beyond laboratory stocks, we are also integrating analyses of wild-caught cave and surface fish to determine how these mechanisms operate under natural ecological conditions. Combining neurogenetics, whole-brain activity mapping, single-cell genomics, computational approaches, and CRISPR-based functional studies, this work establishes a comparative framework linking evolution, neural circuits, and molecular pathways to uncover the core biological functions of sleep.

Photoreceptors & visual adaptation | Tuesday, July 28 | 15:45 – 16:00

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Rethinking rods and cones: photoreceptor identity in deep-sea pearleyes

Deep-sea fishes inhabit one of the most light-limited environments on Earth. Accordingly, their retinas are typically dominated by rod photoreceptors specialized for high sensitivity in dim-light conditions. However, most deep-sea fishes begin their lives in shallow waters where cone-mediated color vision is advantageous. Consistent with this ontogenetic shift in habitat, we show that comparative transcriptomic studies have revealed a developmental switch from cone-dominated gene expression in larvae to rod-dominated expression in adults. Yet in some aulopiform species, particularly pearleyes (Scopelarchidae), rod opsin expression remains paired with a cone-like phototransduction cascade even in adults, suggesting a mismatch between rod and cone photoreceptor molecular identities and here we specifically focus on these unusual photoreceptors.

This mismatch raises the question of whether rods and cones exist as distinct photoreceptor types in these species or whether photoreceptors exhibit mixed rod-cone molecular signatures. Apart of comparative transcriptomics, we apply single-nucleus transcriptomics of pearleye retina, providing the first cellular-resolution view of retinal gene expression in these enigmatic deep-sea fishes. By examining the expression of opsins and phototransduction cascade genes across individual photoreceptor cells, we assess photoreceptor identity at the single-cell level. This work provides new insight into photoreceptor diversity in deep-sea fishes and reveals previously unrecognized plasticity in photoreceptor cell identity, possibly challenging the traditional view of the rod and cone photoreceptors being distinct cell types.

Mechano- & thermosensation | Wednesday, July 29 **|** 15:30 – 15:45

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Understanding mosquito aging and stylet mechanosensation

Female *Aedes aegypti* mosquitoes spread diseases by feeding on human blood. They use sensory appendages to locate humans, acquiring viruses by biting infected humans. These viruses take 8-14 days to mature inside the mosquito before transmission, making the mosquito's age vital for its ability to transmit viruses among humans. Mosquitoes that die young do not transmit viruses to humans. Despite the critical importance of mosquito age to viral transmission and public health, there has been almost no investigation of the basic biology of mosquito aging. This work defines natural and accelerated aging in *Aedes aegypti* using survival analyses to establish quantitative lifespan curves, linking these lifespan trajectories to behavioral decline over time and changes in the biophysical properties of the mosquito stylet--the proboscis-associated needle-like sensory appendage that functions not as a passive syringe, but as a compact sensory microcircuit. The stylet contains a small ensemble of mechanosensory and chemosensory neurons that coordinate probing, blood vessel detection, and blood feeding. I also examine drastic lifespan shortening in *Aedes aegypti* mosquitoes infected with the wMelPop strain of the intracellular symbiotic bacterium Wolbachia pipientis that was originally derived from *Drosophila melanogaster*. These Wolbachia-infected mosquitoes display defects in blood feeding similar to those of aged female mosquitoes, suggesting that aging mosquitoes faster could help eliminate disease transmission altogether. To understand the mechanisms by which Wolbachia shortens mosquito lifespan, I characterize the behavioral and cell biological impact of wMelPop infection in mosquitoes of varying ages. While the overarching goal of contemporary aging research is to understand mechanisms of aging to increase lifespan and longevity, my research project will do the opposite, with the goal to reduce rather than to extend the lifespan of this dangerous insect.

Spatial orientation and navigation

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Using spatial orientation to assess blast-induced neurotrauma in an animal that uses shock waves as weapons
Snapping shrimp close their snapping claws so quickly they form cavitation bubbles. When these bubbles collapse, they release supersonic high-amplitude pressure waves, known as shock waves. Shock waves cause blast-induced neurotrauma when they transfer kinetic energy to neural tissues. Snapping shrimp use the shock waves they create with their claws during head-to-head combat with conspecifics. Along with this damaging weapon, snapping shrimp have evolved an extension of their carapace, the orbital hood, that damps shock waves. To learn how orbital hood protects the brains of snapping shrimp, we first established a metric for evaluating damage. We used spatial orientation to infer damage in a behavioral context since snapping shrimp with blast-induced neurotrauma display behavioral deficits. To approach this, we quantified path tortuosity, fractal dimension, distance traveled, and movement speed in the snapping shrimp Alpheus heterochaelis navigating to their burrow. Snapping shrimp exposed to shock waves without their orbital hoods exhibited longer, more tortuous paths that they travel at slower speeds compared to animals with unaltered orbital hoods. Then, we asked how the material properties of orbital hoods contribute to the preservation of spatial orientation in animals exposed to shock waves. Finite element simulations of interactions between shock waves and orbital hoods suggest orbital hoods reduce shock wave-induced strain and stress in the neural tissues of shrimp. Simulated increases or decreases in their material properties reduce the protective capabilities of orbital hoods and result in greater predicted damage. These features indicate that orbital hoods are optimized for shock wave damping which limits the transfer of kinetic energy to the neural tissues of snapping shrimp. Thus, we find snapping shrimp maintain spatial orientation following repeated exposure to shock waves through energy dissipation by their orbital hoods.

Photoreceptors & visual adaptation | Tuesday, July 28 | 15:30 – 15:45

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Naturalistic image processing across bumblebee photoreceptors
Bumblebees rely on vision to navigate complex natural environments, and the spatial organization of their eyes shapes how visual information is processed before reaching the central brain. Photoreceptor properties vary across the eye, with the frontal region providing the highest spatial resolution, and dorsal receptors showing specializations for polarization vision. We are developing methods to understand the temporal properties of bumblebee photoreceptors, as well as how the dorsal and frontal receptors differ in processing naturalistic stimuli. Using electrophysiology, we have characterized photoreceptors using a broad set of stimuli presented via an LED. In both frontal and dorsal photoreceptors, we successfully applied white noise stimuli to reveal contrast coding and low pass filtering properties similar to flies (Hornstein et al., 2000). Frontal receptors resolved frequencies well above 100 Hz.   At 23∞C, responses to bright flashes were fast in both receptors, with an average time to peak of 0.0124 s in frontal, and 0.011 s in dorsal recordings. Similarly, average sigma values in each type of receptor were close, with 0.2439 in frontal and 0.2371 in dorsal receptors. Dark flashes result in slightly slower responses in all receptors (frontal: 0.0137 s to peak, sigma 0.3, dorsal: 0.0136 s to peak, sigma 0.3287). To explore responses under naturalistic conditions, we also presented artificially generated patterns and selected panoramic natural scenes sequentially, allowing photoreceptors to effectively ‘scan’ entire environments. We can then reconstruct ‘neural’ images from the photoreceptor responses

to examine the contributions of nonlinear properties (e.g. Adaptation) to natural and naturalistic scenes. Combining flash responses, modulation transfer functions, and naturalistic stimuli will provide a detailed understanding of photoreceptor specializations, with responses to natural scenes allowing us to unravel ecologically relevant photoreceptor functions.

S11.2 | 11:20 – 11:40 | Thursday, July 30

The neuroethology of water stress: thirst, desiccation risk and water-seeking behavior

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The role of learning in the satiation of thirst

The sensation of thirst motivates animals to find and consume water. Under most circumstances, thirst is triggered by dehydration of the body, which occurs gradually over hours during water deprivation. However, drinking can quench thirst within seconds, long before the ingested water has been absorbed and rehydrated the body. This raises the question of how animals are able to meter their water intake to precisely match their level of physiologic need. Previously, we and others have shown that presystemic signals from the oral cavity and GI tract are essential for rapid thirst quenching, but how these signals is established is not understood. I will describe our recent work investigating the role of learning in this process.

Chemosensory-guided behaviour | Monday, July 27 | 16:00 – 16:15

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Real-time mosquito biting behavior above and below human host skin

Female mosquitoes rely on chemical and physical cues to locate hosts for blood feeding. Upon landing, they explore the host skin surface to select suitable bite-sites. While surface activities of females can be observed via high-speed videography, synchronizing these surface behaviors to real-time biting activities occurring below the skin surface remains challenging. We used high-speed videography and deep-learning video tracking analysis to describe real-time surface biting activities of *Anopheles coluzzii* females on a human host. We alsoused an electrophysiological assay to compare the below-skin biting profiles of wild type *An. coluzzii* mosquitoes to sensory-impaired mutant counterparts (orco and IR76b co-receptors mutants). We compared genera-specific biting behaviors of wild type *An. coluzzii* and *Aedes aegypti* mosquitoes, which might have developed unique biting strategies. Surface body-part tracking of high-speed videography revealed distinct mouthpart-leg coordination during probing of the host skin. Using a computational analysis pipeline of the electrophysiological results, we confirmed 5 distinct components of mosquito biting behavior below the skin surface: skin piercing, blood vessel searching, blood ingestion, mouthpart retraction, and mouthpart withdrawal. Temporal analysis of the electronic biting profiles indicated the duration of certain phases differed between the mosquito genera (faster piercing, searching, and withdrawal in *An. coluzzii* vs. *Ae. aegypti*). Time-series feature analysis comparing shapes of biting phases revealed genera-specific and genotype-

specific differences in the skin piercing, blood ingestion, and mouthpart retraction patterns. These findings suggest: i) females modify certain components of their biting behavior when orco or IR76b chemosensory pathways are impaired; and ii) *Anopheles* and *Aedes* mosquitoes use distinct biting strategies. These results provide new insights into the biting behaviors of mosquitoes on a human host.

Spatial orientation and navigation

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A behavioural and electrophysiological framework for studying the neural basis of navigation in freely moving Fiddler Crabs

Afruca tangeriis a semiterrestrial crab that relies on its burrow as the main spatial reference point. At low tide, fiddler crabs emerge from their burrows to feed along the intertidal zone and upon threat detection perform rapid escape responses directed towards the burrow. Field studies suggest that fiddler crabs use an egocentric frame of reference and idiothetic information to update their position and continuously estimate their distance from the burrow during exploration. From an experimental perspective and in contrast to other well-characterised arthropodal model systems, the exoskeletons of crustaceans have the potential to support freely moving in vivo recording approaches to directly monitor neural activity under ethologically relevant behavioural scenarios. Such methodological advances can provide an opportunity to gain mechanistic insight into how internally generated spatial representations of location, heading direction, and distance to goal are formed and guide goal-directed actions. To implement electrophysiological recordings in freely moving fiddler crabs, we constructed a parametric environment that allows precise control over visual statistics, burrow availability, and burrow location. In this setting fiddler crabs exhibited homing and escape behaviours comparable to those described in the field, allowing precise quantification of their dynamics. We then developed a protocol for chronic extracellular recordings from the central complex using tethered Neuropixel silicon probes, which enabled stable monitoring of neuronal activity during behaviour. Chronically implanted fiddler crabs explored the arena and performed homing and escape responses, and single unit activity was stable across extended recording sessions. This work provides a foundation for the future use of Afruca tangerias a model system to study sensorimotor integration and navigation.

3D navigation & spatial cognition | Friday, July 31 | 15:45 – 16:00

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Predictive coding of moving objects in the bat hippocampus

Central to many natural behaviors is the use of past and current information to predict future states. For example, echolocating bats must anticipate target trajectories to intercept erratically moving prey in cluttered environments. However, predictive internal models of

target motion remain poorly understood. Here, we bridge this gap by training echolocating bats to track targets moving along naturalistic 2D trajectories and quantifying head direction and sonar beam aim to assess predictive target tracking. When bats tracked targets moving along an ‘S-shaped’ trajectory, containing both linear and erratic turn components, they exhibited predictive (lead) tracking during linear segments but non-predictive (lag) tracking during turns. Quantification of head direction dynamics over time revealed that bats progressively transitioned from lagging to leading target motion throughout the trajectory, indicating experience-dependent refinement of predictive tracking. Critically, when an occluder transiently blocked sensory access to the moving target during a segment of its trajectory, bats rapidly oriented their heads toward the occluder exit and maintained this orientation until the target emerged, supporting the existence of a forward internal model of target motion. Building on this behavioral framework, we are now investigating the neural mechanisms underlying predictive tracking, focusing on the hippocampal formation. We previously demonstrated that the bat hippocampus encodes the location of a moving object actively tracked by the animal. Here, we extend this work to probe hippocampal representation of 2D object trajectories, when the animal has sensory access to the target’s position and when the target is temporarily hidden. We are also investigating how experience-dependent transitions from lag to lead tracking are implemented at the hippocampal population level. Collectively, these findings lay a foundation for uncovering the neural mechanisms that support predictive models of dynamic objects.

Evolution of sensory & motor systems | Wednesday, July 29 **|** 15:45 – 16:00

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Eye movements evolved via sequential innovations preserved across true flies

Eye movements are ubiquitous across animals with high-acuity vision, yet their evolutionary history remains elusive because behavior does not fossilize and the soft tissues underlying sensory movements are rarely preserved. Insects provide a rare opportunity to reconstruct an evolutionary trajectory of eye movements thanks to their unrivaled biodiversity and lineages preserving ancestral characters. By combining broad comparative anatomical and behavioral sampling across insects with dense sampling in true flies, we reconstruct a stepwise pathway from absence of retinal movements to self-timed retinal movements and finally an optokinetic reflex (OKR). Eye movements are rare across insects and OKR was not found outside Diptera. Most species either lacked musculature attaching to the circumocular ridge (COR) or possessed only unspecific muscles. In *Drosophila*, retinal movements are actuated by two muscles, the Musculus orbito-scapalis (MOS) and the Musculus orbito-tentoralis (MOT). Within Diptera, MOS-like muscles occur in early branching lineages, whereas the specific retinal muscle MOT appears later and likely represents a synapomorphy of Eumuscomorpha. Quantitative variation in COR thickness relative to head capsule cuticle correlates with retinal movements: COR thinning precedes or coincides with their emergence and gates the functional impact of retinal muscles. Self-timed retinal movements were observed in early Brachycera, particularly in predatory families, and preceded OKR. The earliest taxa exhibiting OKR-like movements are also the earliest taxa that developed an MOT muscle. Across Diptera, OKR-like retinal movements were consistently present in taxa possessing MOT, and evolutionary modelling disfavored direct transitions from absence of retinal movements to the OKR. Our findings support a hierarchical assembly in which quantitative tuning of the COR precedes retinal movements, and self-timed movements precede the optokinetic reflex. In contrast to the view outlined for vertebrates, which posits visual stability reflexes as the earliest eye movements, we provide evidence that in Diptera self-timed movements appeared first and OKR-like movements evolved later.

S2.1 | 11:00 – 11:20 | Tuesday, July 28

Principles of communication in social groups: from behavior to neuron

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Social context modulates hygienic behaviour in *Apis mellifera*

The hygienic behaviour of honey bee workers contributes to the social immunity of colonies. The ability of workers to detect and remove unhealthy or dead brood prevents the transmission of brood diseases inside the colony. It is a very important part of the defence against parasites such as the deadly mite *Varroa destructor*, indeed colonies bred for hygienic behaviour show lower levels of *Varroa* infestation. Selecting colonies for their hygienic behaviour represents a very promising path toward containing the infestation from *Varroa*; however, the way this behaviour is regulated within the colony is still poorly understood. Here we decided to investigate the influence of social context on workers' hygienic performances, postulating that individual honey bees might be able to amplify the signal from damaged brood and thus recruit more workers to clean the brood. To test that hypothesis, we developed a new behavioural assay that allows to decouple the number of bees present in the experiment and the number of bees actually involved in hygienic behaviour. We showed that the social context does affect hygienic behaviour and that an increased number of surrounding bees increases the hygienic performances of worker bees. These results deepen our understanding of hygienic behaviour mechanisms at the colony level, and open new perspectives to unravel how individual honey bees become involved in such social immunity related tasks.

S11.3 | 11:40 – 12:00 | Thursday, July 30

The neuroethology of water stress: thirst, desiccation risk and water-seeking behavior

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The cellular and molecular basis of mosquito humidity-guided behaviors
Mosquitoes face a constant threat of dehydration due to their small body size and high surface area-to-volume ratios. To maintain homeostasis, they use specialized hygrosensory receptors that detect local humidity gradients to guide them to hospitable locations. Additionally, mosquitoes have evolved to use humidity cues to locate water for egg-laying or hosts for blood feeding—a behavior that leads to the transmission of deadly pathogens that kill hundreds of thousands of people annually. Despite their importance for survival, reproduction, and disease transmission, the cellular and molecular mechanisms underlying mosquito humidity detection have remained poorly understood. Using genetic approaches, physiological recordings, and behavioral analyses in the malaria vector *Anopheles gambiae* and the arbovirus vector *Aedes aegypti*, we identify the location of a conserved hygrosensory system dependent on members of the Ionotropic Receptor (IR) family. We show that discrete subpopulations of Ir93a-expressing neurons are activated by air of different relative humidity. Systematic genetic ablation of the IRs involved abolishes humidity-evoked responses in dry- and/or moist-activated cells, leading to profound defects in mosquito host-seeking, blood-feeding, and oviposition site detection. Together, our results demonstrate that hygrosensory pathways are integrated to support distinct, context-dependent behaviors and that members of both subfamilies of vector mosquitoes use overlapping molecular mechanisms to locate hosts and oviposition sites.

Vision-guided behavior camouflage | Wednesday, July 29 **|** 16:00 – 16:15
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Neural co-option of prey circuits enables a deceptive lure in *Ceratophrys* frogs
Deceptive signals that exploit receivers' sensory biases are powerful evolutionary strategies, yet the neural mechanisms underlying their efficacy remain unknown. Horned frogs (*Ceratophrys spp*.) are cannibalistic ambush predators that perform conspicuous hindlimb movements hypothesized to lure conspecific prey. We integrated high-speed kinematics, in vivo tectal electrophysiology, and behavioral assays to test whether this lure functions as a sensory trap by co-opting the receiver's conserved prey-detection circuitry. Behavioral screening (C. ornata n=8, C. cranwelli n=7, C. cornuta n=2) revealed luring was elicited almost exclusively by moving conspecifics, not by insects, static frogs, or lines ($p<0.0001$). DeepLabCut tracking showed the lure combines slow limb oscillation (~2 Hz), matching vermiform prey kinematics, with rapid digit vibration (~4 Hz), matching arthropod appendage movements. Species differences in luring investment paralleled dietary reliance on anuran prey. Retinotectal mapping (n=200 units) revealed 79% of receptive fields represented the upper anterior visual field, where a luring limb would appear. Extracellular recordings showed tectal neurons responding to insect prey were activated with nearly identical firing patterns by the lure ($r>0.9$, $p<0.001$). Of 120 prey-responsive units, 85 responded equivalently to both insects and the lure, constituting direct evidence of neural co-option at the circuit level. Receiver frogs struck at luring conspecifics at rates indistinguishable from strikes at insects ($p=0.75$) but far exceeding strikes at non-luring frogs ($p<0.0001$). These results demonstrate that a complex deceptive signal achieves its efficacy by mapping onto the pre-existing response properties of the anuran tectum's ancestral prey-detection circuit, illustrating that behavioral innovation can arise through neural reuse without novel perceptual architecture.

S8.4 **|** 12:00 – 12:15 **|** Wednesday, July 29

Neurosustainability: how brain science is revolutionizing environmental design and policy

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Informing coral resilience through neurobiology

Reef-building corals are experiencing unprecedented ecological crisis under rapid ocean warming, reducing reef cover and function worldwide. While research has largely focused on bleaching and symbiosis breakdown, the neurobiological mechanisms by which corals detect, process, and respond to environmental stress remain largely unexplored. Understanding these mechanisms is essential for predicting and enhancing coral resilience. We address this gap using integrative transcriptomic and population genomic approaches in reef-building corals. In Stylophora pistillata, we combined single-cell and bulk RNA-seq data to identify neuronal genes responding to heat stress, yielding high-confidence neuronal gene candidates, including thermosensory channels such as TRPA1, alongside functionally uncharacterized genes that may represent lineage-specific coral neuronal pathways. In parallel, genome-wide association analyses in Acropora palmata identified loci associated with heat tolerance and symbiont community composition, with candidate genes enriched for neuronal and sensory functions, linking neurogenetic variation to ecologically relevant traits at the population level. These results establish coral neurobiology as a useful, but largely overlooked, aspect of reef conservation. Identifying the molecular basis of these processes provides targets for conservation approaches, including the prioritization of resilient genotypes, guiding assisted gene flow, and improved prediction of reef responses under future climate scenarios. More broadly, this work shows that incorporating neurobiology into coral research can reveal mechanisms of environmental response that are otherwise missed, and improve coral resilience in the changing environments.

Sensory learning & decision-making | Monday, July 27 **|** 15:45 – 16:00

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Affective pain experience induces conditioned place avoidance in the cuttlefish *Sepia pharaonis*

Cephalopods such as cuttlefish exhibit highly sophisticated behaviors and neural complexity, making them valuable comparative models. Therefore, it is vital to recognize subtle behavioral alterations during invasive procedures to improve animal welfare. It is known that cephalopods are capable of perceiving pain and responding to it. For example, grooming directed at the injection site has been documented in both cuttlefish and octopus after acetic acid administration (Crook, 2021; Kuo et al., 2022). In addition, previous research has demonstrated that octopuses avoid contexts associated with affective pain experiences (Crook, 2021). However, whether cuttlefish exhibit similar behavioral modifications following painful experiences remains unknown. To address this question, the present study conducted a conditioned place preference assay in the cuttlefish *Sepia pharaonis*. A preliminary evaluation of 2%, 4%, and 8% acetic acid (AA) injections revealed marked grooming at the 2% and 4% concentrations; thus, the 2% dose was selected for subsequent trials. Animals were placed in a three-chamber apparatus consisting of two

conditioning chambers with distinct environments and a central start chamber. The responses and swimming trajectories were recorded by an overhead digital camera. Following a subcutaneous injection of 2% AA (2 µL) into the right second arm, subjects demonstrated avoidance behavior away from their baseline preferred chamber. These results indicate that cuttlefish can form aversive associative memories regarding environments that predict noxious experiences. Such cognitive complexity regarding pain processing highlights the ethical imperative to refine invasive procedures and utilize appropriate analgesia to safeguard cephalopod welfare.

Active sensing & sensorimotor gating | Thursday, July 30 **|** 16:00 – 16:15

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Tracking octopus arm movements at single-sucker resolution

Octopus arms exhibit exceptionally high degrees of freedom through their unique distributed nervous system, enabling bending, elongation, rotation, and changes of stiffness at any location along the arm. Previous studies have attempted to quantitatively characterize octopus arm motion. However, the use of gross measurements without tracking the spatial coordinates of individual suckers limited their ability to capture complex arm movements, particularly elongation and rotation. Here, we developed a method that enables three-dimensional reconstruction of octopus arm and allows tracking of hundreds of individual suckers at sub-millimeter resolution. Using this approach, we quantitatively analyzed octopus arm movements during exploration in the absence of visual guidance. We found that the arm frequently generated characteristic wave-propagation movements. During these waves, the orientation and propagation speed of bending were continuously and actively controlled. Within this control process, we further resolved a limited spatial extent of motion correlations, spanning approximately ten suckers, consistent with a distributed movement control. Based on arm musculature and Cosserat theory, we built a digital arm and used reinforcement learning to reproduce observed movements, infer underlying control principles, and translate these insights into thermally actuated soft robotic arms. Together, these findings reveal a distributed neural control system underlying complex octopus arm movements and suggest new paradigms for soft-robotic control.

Active sensing & sensorimotor gating | Thursday, July 30 **|** 15:15 – 15:30

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Drowning in their own wake: insights into lateral line function in self-generated flow

A central problem in neuroethology is how animals must distinguish external sensory cues from the noise they generate themselves. For fish, every tail beat produces hydrodynamic signals that directly stimulate the lateral line, raising a fundamental question: how does this system remain sensitive to biologically relevant flows? Here, we combine experiments and computational fluid dynamics (immersed boundary DNS) to quantify drag forces and cupular deflections in 5 dpf larval zebrafish (n = 16). In a custom micro-flow tank, we measured cupular deflections of 49∞, 56∞, and 67∞ at flow speeds of 0.8, 1.4, and 2.1 BL∑s?π- conditions at or below routine swimming speeds. Given an average cupula length of 27.2 µm, these correspond to tip displacements of 20-25 µm. When mapped onto established afferent response functions, these values fall within or exceeds the saturating range of neural activity. Even at higher speeds (3.1 BL∑s?π), simulated deflections remain well above activation threshold. Importantly, sensory output lags peak hydrodynamic forcing by ~22 ms, and undulatory swimming drives repeated reversals in cupular deflection with each tail beat. Together, these results indicate that the lateral line is not intermittently engaged, but continuously driven into high activity during normal locomotion. This pervasive self-stimulation reframes the lateral line as a system operating under near-constant sensory load, underscoring the essential role of efferent modulation in preserving sensitivity to external flow cues.

S13.5 | 12:15 – 12:30 | Friday, July 31

Neural basis of acoustic communication across vertebrates

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Acoustic context modulates natural sound discrimination in the auditory cortex of vocal mammals

Call discrimination is essential for vocal communication in all mammals, yet how auditory cortical neurons encode transitions between different vocalizations remains unclear. We first examined how acoustic context influences neuronal responses in the auditory cortex of bats. Using sequences in which a leading context (echolocation or communication sounds) preceded a target sound, we found that context dynamically reshapes neuronal selectivity for different vocalizations. Neurons that are nonselective during silence become category-selective with context, whereas neurons selective for communication sounds lose their preference. A computational model incorporating convergence of frequency-tuned inputs, presynaptic and postsynaptic adaptation reproduced these effects found in bats. We propose that this model can provide a general mechanism for context-dependent call discrimination extended to other vocal mammals.

S5.1 | 11:00 – 11:20 | Wednesday, July 29

The neural substrate of animal collective motion

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Neurobiology of social action detection in schooling fish

Animals use social information to coordinate group behavior, but the neural mechanisms that allow individuals to detect and respond to the actions of their social partners remain poorly understood. My lab investigates this problem by studying collective behavior in the glassfish, *Danionella* cerebrum, a small translucent vertebrate that schools using vision. I will discuss our recent work on collective escape, using behavioral tracking, virtual reality, and neural imaging to investigate how the visual system detects and encodes the actions of social partners.

S9.2 | 11:20 – 11:40 | Thursday, July 30

Peripheral circuits that shape descending commands to modulate motor programs

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Egocentrically organized lateral line inputs project to motor command neurons for spatially guided locomotion

Animals navigate by transforming distributed sensory inputs into discrete motor actions, yet how stimulus features such as intensity, frequency, and duration are integrated with spatial information to bias action selection remains poorly understood. A major challenge in vertebrate species has been finding emerging principles of how graded sensory signals are converted into categorical motor commands in the brainstem. The lateral line (LL) system of zebrafish constitutes an ideal model to investigate principles in the brainstem underlying the integration of sensory inputs across the body. With responses to directionality across virtually all LL sensors along the larval zebrafish, we uncovered that processing occurs via a simple egocentric framework, in which spatial and directional flow cues converge onto functionally distinct motor command pathways. Building on this foundation, we now ask how variation in stimulus strength and temporal structure shapes the recruitment of sensory interneurons and downstream motor command circuits to determine behavioral output. The LL links peripheral sensors to reticulospinal neurons through only a few synapses, offering a unique opportunity to follow the transformation from stimulus to action at cellular resolution. By systematically varying stimulus direction, intensity, frequency, and duration at each sensor position, we determine how key parameters are encoded within the brainstem to bias the selection of forward locomotion, avoidance turns, and approach behaviors. By systematically varying both the sensor position and temporal or intensity structure of sensory inputs, this work reveals how vertebrate sensorimotor circuits route multidimensional signals along distinct motor command pathways that bias action selection.

S16.4 | 12:00 – 12:15 | Friday, July 31

Orientation across modalities

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Behavioral and neural correlates of magnetic sensing in poison frogs

Diverse animals sense Earth's magnetic field and exploit it as a cue during orientation and navigation, but the neural mechanisms underlying the detection and processing of magnetic cues remain poorly understood. Poison frogs perform complex navigational tasks related to territoriality and parental care and use multiple sensory cues to guide themselves through their environment. To explore whether the green-and-black poison frog (*Dendrobates auratus*) can orient using Earth's magnetic field, we conducted behavioral experiments with frogs inside a magnetic coil system that allowed for manipulation of the ambient magnetic field. Under these conditions, frogs exhibited spontaneous magnetic alignment, in which they oriented approximately toward magnetic northwest or southeast in the absence of other sensory cues. Using immunohistochemistry for phosphorylated ribosomes (pS6) as a neural marker, we next investigated brain regions involved in the processing of magnetic cues. Relative to controls, frogs exposed to a slowly changing magnetic field displayed altered neural activity in two brain areas, the lateral pallium and habenula, important for sensory processing, memory, and navigation. These findings demonstrate that poison frogs can sense Earth's magnetic field, an ability that may facilitate navigation in their rainforest environment and represents a new system for investigating the neural processing underlying magnetoreception.

S12.2 | 11:20 – 11:40 | Thursday, July 30

The neuroscience of emotion

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Integrative evidence for a fear-like state in honeybees

The idea that invertebrates may express internal states analogous to emotions is gaining attention; however, meaningful discussion of such states must be preceded by extensive multi-scale analyses. Here, we used a multicomponent approach combining behavioral, physiological, and neurobiological analyses to test whether honeybees (*Apis mellifera*) exhibit coordinated responses consistent with a fear-like state when confronted with a predictor of threat after aversive conditioning. In our ICARUS paradigm, bees learned to inhibit spontaneous phototaxis by associating entry into a blue-illuminated chamber with electric shock. Bees that acquired this association showed elevated respiration dynamics and increased thoracic temperature at the physiological level upon blue light perception, even in different experimental contexts. Behaviorally, they produced distinctive acoustic signals, with harsher and more irregular buzzing sounds when exposed to this conditioned stimulus. Locomotor analysis revealed reduced speed and increased thigmotaxis across training, compared to controls. Finally, HPLC–MS analyses showed higher brain serotonin and octopamine levels in learners, suggesting a neuromodulatory correlate of anticipatory aversion rather than a simple response to shock. Together, these findings indicate that aversive conditioning in honeybees cannot be simply viewed as the automatic acquisition of an association between a conditioned stimulus and an aversive unconditioned stimulus, but instead recruits multiple, functionally distinct systems that align toward defensive, negative-valence responses. While our work does not assess subjective experience, it identifies convergent markers of a fear-like state, highlighting honeybees as a tractable model for probing the building blocks of emotion and contributing to the broader debate on invertebrate sentience.

The neuroscience of emotion

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Interoceptive cardiac signals shape affective state coding in mice

Emotions are evolutionary conserved functional states eliciting prominent changes in behavior and bodily physiology. Classical and modern theories of emotion suggest that emotions drive peripheral physiological responses, but also that changes in bodily signals themselves can influence the emergence and persistence of emotions. A key brain region implicated in emotions as well as interoception across species is the insular cortex. Specifically, the posterior Insular Cortex (pInsCtx) is a highly multimodal brain region processing and influencing interoception. Recent research has demonstrated that artificially elevating heart-rate increases pInsCtx activity and is sufficient to induce anxiety (Hsueh*,

Chen*, et al., 2023). Furthermore, disrupting heart-to-brain communication impedes fear extinction, a process dependent on pInsCtx activity (Klein, et al., 2021). However, we currently lack a mechanistic understanding of how the pInsCtx processes cardiac signals at the cellular level, and how this processing influences emotions. To investigate the relationship between heart-rate and pInsCtx activity, we conducted whole-cell and silicone probe recordings in awake, head-fixed mice. By monitoring heart-rate, pupil diameter, and locomotion, we characterized the behavioral and physiological responses associated with positive and aversive emotion states. Finally, we used the adrenergic beta-blocker metoprolol to manipulate heart-rate. Our findings reveal that cardiac signals are the strongest modulator of insula activity. pInsCtx neurons can become tuned to single heartbeats, with both their membrane potential and firing rate modulated by the cardiac cycle. Cardio-insular coupling is increased during emotion states. Finally, long-lasting decrease in heart-rate prevents the representation of cardiac signals by the pInsCtx and disrupts emotion state encoding. Taken together, our study shows that processing of cardiac signals by the pInsCtx shape the encoding of emotion states.

S7.1 | 11:00 – 11:20 | Wednesday, July 29

The evolutionary, behavioral, and neural bases of synchrony

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Social physiology: the metabolic roots of social bonding

Why do social animals devote substantial resources to social life, and what makes social connections biologically indispensable? This talk presents evidence for a novel physiological principle: Social Physiology, proposing that the physiology of social animals functions more efficiently together. Using human data, I show that across multiple homeostatic systems, including glucose metabolism, thermoregulation, and sympathetic arousal, physiological regulation operates more efficiently in social proximity than in isolation, producing measurable Social Physiological Gains. I propose that interpersonal synchrony may be a key mechanism underlying this effect, coordinating physiological processes across individuals and reducing the metabolic costs of regulation. Social Physiology shifts our understanding of the biological benefits of sociality, suggesting that social animals seek companionship not only for protection and reproduction, but also for enhanced metabolic efficiency. From an evolutionary perspective, by improving the efficiency of homeostatic regulation, Social Physiology may have contributed to the emergence and maintenance of sociality.

Young investigator symposium | Monday, July 27 | 11:20 – 11:40

Matheson, **Andrew**, Columbia University, USA

Environmental transitions drive plasticity of the body, behaviour, and nervous system of the newt

Animals must adapt to their surroundings in order to survive, and those that experience changing environments often employ phenotypic plasticity to enhance their fitness. Newts, a subfamily of salamanders that lead semiaquatic lives, face this challenge in the extreme: as adults, they must survive in water and on land, where they are exposed to distinct sensory environments. Here, we establish the Iberian ribbed newt (*Pleurodeles waltl*) as a new model to study phenotypic plasticity in a vertebrate. We find transitions between aquatic and terrestrial laboratory environments recapitulate morphological changes previously observed in the wild. Newts reversibly reduce their tail and head width, alter their gait, and structurally remodel their nasal epithelia when transitioning between environments. Using a naturalistic food odour search paradigm on land, we find terrestrial, but not aquatic, newts follow food odours to the source. To determine whether molecular changes in the olfactory system drive this change in olfactory behaviour, we molecularly profiled the cells of the nasal epithelium using single-cell RNA sequencing. We identify canonical cell types in the newt nasal epithelium and show that transitions between aquatic and terrestrial environments induce transcriptomic changes in multiple cell types, which are more pronounced in secretory and support cell types rather than sensory neurons. Additionally, we observe an increase in the number of neurons in the newt's nose after transitioning to life on land, driven by the proliferation of nasal stem cells. We believe this increase in neuron number functions as a form of gain control to help adapt to the lower concentration of airborne odours relative to aquatic odours. Our findings suggest that environmentally-driven and reversible remodelling of the peripheral olfactory system supports sensing between air and water, providing a framework for understanding how nervous systems achieve functional plasticity across changing environments.

Neural mechanisms of acoustic communication | Tuesday, July 28 **|** 15:00 – 15:15

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Mapping the global architecture of birdsong in a neurally relevant acoustic space

Birdsongs are classic models in neuroethology for studying vocal learning, motor control, and sensory perception. However, traditional bioacoustic analyses used to describe birdsongs often rely on simple metrics (e.g., mean frequency, duration) that fail to capture the rich spectro-temporal dynamics essential to sound processing in the avian brain. Auditory neurons are not merely frequency detectors; they are tuned to specific spectro-temporal modulation rates, encoding the ‘texture’ of sound through combined amplitude and frequency modulations. To understand the evolution of birdsong, we propose characterizing songs in a space that reflects these neural processing mechanisms. Here, we analyze the acoustic architecture of 116,792 song bouts from 3,160 passerine species using the Modulation Power Spectrum (MPS). This method transforms the spectrogram into a 2D representation of temporal and spectral modulations. MPS is biologically salient because it mimics the receptive field properties of neurons in the auditory system, decomposing sounds into specific modulation rates that drive neural spiking responses. By mapping this ‘neural acoustic space’ across a global dataset, we reveal that the enormous diversity of passerine songs is not a random continuum. Instead, songs converge on a limited set of eight elementary ‘acoustic motifs’. These building blocks, ranging from simple flat whistles to complex frequency-modulated trills and harmonic stacks, represent distinct

clusters of spectro-temporal modulation. These results suggest that the evolution of birdsong is channeled by the neurophysiological system's capacity to produce and perceive specific spectro-temporal modulations. By characterizing songs using MPS, we provide a unified framework that links the physics of sound production and environmental transmission to the sensory biology of the receiver, offering new insights into the neuroethology of communication.

Rhythms & homeostatic control | Monday, July 27 **|** 15:00 – 15:15
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Time to Shine: Two clocks drive courtship in bioluminescent ostracods to occur in darkness
Biological clocks have evolved in a diverse array of organisms to prevent detrimental mismatches in the timing of behavior. In courtship behavior, animals may use clocks to determine when to increase courtship activity, such as producing signals to attract mates when conditions are optimal for signal perception. For bioluminescent animals that use light to attract mates, a dark period, defined as the time when both the sun and moon are below the horizon, provides optimal conditions for signal visibility. However, the differing lengths of the solar day (24 hours) and the lunar day (24.8 hours), result in a dark period that has nightly variance in onset, offset, and duration. Circadian (24 hours) and circalunidian clocks (24.8 hours) could provide a way to reliably time their behavior to this period. However, there is little evidence of bioluminescent courtship driven by clocks to target the dark period. Bioluminescent ostracods have been shown to time their courtship signals to match the dark period, yet it is unknown if they use clocks to do so. Here we show, bioluminescent ostracods are able to match their displays to the dark period in the absence of external stimuli. By recording bioluminescent courtship displays under varying light conditions, we found significantly more courtship activity during the dark period than any other time, even when they did not have sunlight or moonlight to cue them. This strongly suggests they use endogenous circadian and circalunidian clocks to match the timing of their displays to the dark period, using both clocks to determine the onset, offset, and duration of courtship signaling. Our data demonstrate the presence of two endogenous clocks that simultaneously drive the timing and duration of courtship signaling in a bioluminescent animal. This work highlights biological rhythms as valuable tools for animals to optimize the timing of courtship behavior, and provides a promising system for the study of biological clock interactions.

Social displays & collective behavior | Thursday, July 30 **|** 15:15 – 15:30
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The neural basis of social learning in a schooling fish
Social collectives are found throughout nature, ranging from flocks of birds to colonies of bees, troops of primates, and schools of fish, each capable of using visual cues for sociality. This capacity, ‘social vision,’ requires the brain to use subtle cues to interpret the meaning of a social event. Central to social vision is an ability to identify members of the same species, conspecifics. However, it has remained enigmatic precisely how the visual

system accomplishes this feat, and how social experiences during development shape adult social vision. Herein, we have used the small schooling micro glassfish, *Danionella* cerebrum, as a model for understanding visual conspecific detection. By leveraging virtual reality based behavioral assays, we have identified shape, textural, and movement features required for social attraction in this fish. Despite possessing a retina <1 mm in diameter, *Danionella* can readily discriminate between virtual schools of con- and heterospecific fish. This ability, however, depends on *Danionella*'s social experiences during development. *Danionella* raised in isolation with visual access to virtual heterospecific fish lose their attraction to visual depictions of conspecifics, suggesting that social learning engenders adult sociality. To identify neural correlates of conspecific detection, we have performed large-scale two-photon imaging experiments on live fish, expressing a pan-neuronal calcium indicator GCaMP6s, shown visual depictions fish and fish-like stimuli. These efforts have revealed a population of forebrain neurons within the subpallium putatively tuned to detect conspecifics. In total, this work demonstrates that *Danionella*'s developmental social experiences allow adult fish to accurately identify conspecifics by weighing several visual features: shape, texture, and movement, none of which in isolation is sufficient for social attraction.

Arthropod locomotion & motor programs | Tuesday, July 28 **|** 15:00 – 15:15

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Traversing a tangled web: locomotion in black widow spiders

Black widow spider females (*Latrodectus hesperus*) make a highly irregular three-dimensional cobweb, which they then have to traverse as they capture prey or find mates. Thus, female widows provide an ideal model for studying locomotion on complex terrain. Indeed, the locomotion of web walking spiders has rarely been characterized. Here, we quantified their movement as they walked across different substrates using DeepLabCut and Anipose for 3D tracking. We then characterized their stepping patterns, inter-leg coordination, and postural dynamics. We found that unlike other arthropods, widows do not use a consistent discernible gait, and that their legs showed very broadly distributed ipsilateral and contralateral phase relationships, suggesting fluid interleg coordination. The kinematics of their forelegs, which are widely considered sensory, show that they are highly mobile and active in searching for footholds. We suggest that widows, who have fragile exoskeletons which rupture easily upon falling, have evolved to walk safely on complex substrates like their cob-webs. We believe that his has led to the evolution of a unique and distinct control mechanism, which maximizes the number of feet attached to the substrate, requires active foothold finding and reduces inter-leg coordination.

S2.5 **|** 12:15 – 12:30 **|** Tuesday, July 28

Principles of communication in social groups: from behavior to neuron

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Neural mechanisms of alarm call production in wild free-living songbirds

Across a wide range of animal taxa, alarm calls are used to vocally signal the presence of a threat. This behavior has been the subject of many scientific studies yet, the neural mechanisms underlying alarm calling remain poorly understood. My project aims at elucidating which brain areas are involved in the production of alarm vocalizations in

songbirds. I focus on two candidate brain regions: HVC, a vocal premotor nucleus classically associated with the learning and production of song, and the dorsomedial nucleus of the intercollicular complex (DM), implicated in the production of innate vocalizations. My main study system is the South African white-browed sparrow weaver (Plocepasser mahali), a territorial songbird that lives in small social groups. To capture brain function in parallel to individual vocal behavior in completely natural situations, I use two radio-telemetric devices. A miniature microphone transmitter on the bird's back records the subject's vocalizations without any latency. A transmitter connected to a recording electrode, implanted in the animal's brain, records multi-unit extracellular neural activity in perfect synchrony with the bird's vocalizations. I equip several members of sparrow weaver groups with these devices, release them back to their original territory, and record their vocal and brain activity continuously for several days while they encounter natural and simulated threats. Against expectations, the data indicates that both HVC and DM are involved in the production of alarm calls. While HVC was considered only involved in learned vocal behavior, I detected HVC activation also before and during the production of innate alarm calls. DM was also activated during alarm calling, but slightly later than HVC, suggesting a top-down pathway between the two brain regions. This study shows the most realistic glimpse into an animal's brain in response to environmental and social inputs, focusing on the response to threatening stimuli.

S7.5 | 12:15 – 12:30 | Wednesday, July 29

The evolutionary, behavioral, and neural bases of synchrony

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Neuromolecular coordination of reproductive behavior in a highly social cichlid fish

Human and non-human animals often coordinate their behavior, a phenomenon thought to facilitate prediction and strengthening of relationships. Behavioral coordination also enables sequential assessment of an interaction partner's quality as a mate or rival, a process that directly affects evolutionary fitness. Yet to achieve such coordination during mating requires individuals from different life histories (e.g. sex) responding to different social signals and producing different behavior, all while maintaining the appropriate rhythm of reproduction. There is increasing evidence that behavioral coordination is reflected by synchronized neural activity of interacting partners, though few studies have examined synchronization at the transcriptomic level. Here, we use Burton's Mouthbrooder cichlid, *Astatotilapia burtoni*, to examine whether neural transcriptomes are synchronized in male-female pairs engaged in more or less reproductive behavior. *A. burtoni* females naturally engage in highly coordinated reproductive behavior with a male only directly prior to spawning. This behavior can be experimentally induced with exogenous prostaglandin F2 α (PGF2a), which also promotes male courtship behavior via the release of pheromones by the female. We first quantified reproductive behavior of PGF2a-treated pairs (n=22), followed by assaying circulating sex steroid hormones. With RNA-sequencing of each individual's preoptic areas (POA) – a key node in the regulation of vertebrate reproductive behavior – we discovered several gene co-expression modules that co-varied with behavioral coordination across mating pairs. However, mechanisms regulating behavior in the two sexes were not completely shared, suggesting that – even within the synchronized act of reproduction – the same social experience is encoded by each sex differently. Our results point towards the molecular mechanisms by which interacting individuals align their experience and behavior.

S10.4 | 12:00 – 12:15 | Thursday, July 30

Brains in the wild B

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Behavioural Observatory: Cross-species comparison of continuous behavioral decision-making
Through their lives, all animals exhibit a continuous series of behavioural states. Behaviour is a fundamental dynamic process, allowing animals to flexibly respond to variable environments. For a holistic understanding of behaviour, we must understand the underlying decision-making systems through which animals determine their actions instant-to-instant. The Behavioural Observatory is an ongoing venture to quantitatively study such decision-making systems across at least 500 individuals from fifty species. Using methods derived from physics and linguistics, I demonstrated the existence of a near-identical complex ('long-range') decision-making system across three very dissimilar species: hyenas, meerkats, and coatis. Under the Behavioural Observatory project, we have already discovered similar long-range decision-making systems in another eight mammal species.

The Behavioural Observatory Project aims to:
1. create an unsupervised machine learning method to automatically infer behaviours in accelerometer data; 2. make available the inferred behavioural sequences of all 50+ species as a first-of-its-kind dataset; 3. using this dataset, quantify and explore the underlying behavioural decision-making systems for all individuals; and 4. use these decision-making systems as a proof-of-concept diagnostic tool for animal welfare.

This project will be the first massively cross-species study examining decision-making rules from long, continuous behavioural sequences, and it will grant novel insights into the principles upon which behaviour in the wild is structured. The dataset and open-source methods we publish will be very helpful to many future studies in behavioural ecology.

Modulation of social behavior | Friday, July 31 | 15:30 – 15:45
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Parasites target neuroplasticity to reprogram social wasps
Prolonged coevolution between hosts and parasites can generate novel and complex host phenotypes. Intriguingly, neuroplasticity, intended to provide advantages to hosts, can instead be exploited to enable rapid phenotypic change that benefits the parasite. We leveraged the parasitic insect *Xenos peckii* (Strepsiptera), which infects the social wasp Polistes fuscatus to elucidate how traits can be decoupled to generate an extended phenotype. Both parasite sexes inhibit reproduction and manipulate the social behavior of female workers, but not of male hosts that do not have castes. In addition, only adult female *X. peckii* remain as obligate endoparasites and extend the lifespan of workers, but not of male wasps. Therefore, we hypothesize that the parasite controls neuroplasticity that mediates caste-related traits that are critical for parasite survival and fitness. We first utilized a time series of females hosts that revealed how parasites manipulate key genes in the developing brain of hosts. Second, multi-omic signatures of infected adult brains

showed similarities with uninfected gyne brains, highlighting pathways shown to regulate longevity, reproduction, diapause, and neuromodulation. However, parasites cannot effectively manipulate some of these traits in male hosts, which supports our main hypothesis. Together, our results reveal novel insights about how neuroplasticity facilitates reprogramming female wasps into an extended phenotype that decouples behavior, reproduction, and lifespan.

Neural mechanisms of acoustic communication | Tuesday, July 28 **|** 15:15 – 15:30

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Neurons on reassignment: reinforcement repurposes auditory circuits in chorus frogs

Closely related species that breed at overlapping locations and times face the challenge of identifying conspecifics to avoid heterospecific mating. In such cases of sympatry, selection against hybridization, called reinforcement, often leads to divergence in communication traits and sensory preferences. Although such reproductive character displacement is well established, comparatively little is known about how neural circuits evolve to ensure accurate conspecific mate recognition in sympatry. We investigated the neural basis of divergence in acoustic communication in upland chorus frogs. Populations sympatric with heterospecifics have diverged in call temporal properties and female preferences. Our findings revealed that reinforcement reshaped auditory midbrain circuits by repurposing standing neuronal variation. In allopatry, long-interval neurons (LINs) and interval-counting neurons (ICNs) exhibited overlapping functional roles, responding to both advertisement and aggressive call temporal patterns. In sympatry, reinforcement drove a functional reorganization of these circuits. LINs became specialized as filters against heterospecific calls, while ICNs assumed a dominant role in recognizing local conspecific advertisement signal properties. Importantly, ICNs diverged along distinct, nonparallel evolutionary trajectories depending on social context: populations sympatric with a single heterospecific increased the representation of ICNs selective for fast pulse rates (PR), whereas populations sympatric with multiple heterospecifics amplified an ancestrally rare ICN phenotype that showed pulse-number-dependent PR tuning. Together, these results demonstrate that reinforcement acted on existing neural diversity to generate rapid behavioral diversification.

Chemosensory encoding | Thursday, July 30 **|** 15:30 – 15:45

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Neuronal basis of behavioural repellence in mosquito larvae

Anopheles gambiae mosquito is the primary vector of malaria in sub-Saharan Africa, contributing to a significant number of fatalities, particularly among children under the age of 5. While current strategies target adult mosquitoes, challenges such as insecticide resistance and rising malaria cases demand innovative solutions. A promising approach involves disrupting mosquito larvae development by manipulating their olfactory senses, which they use to locate food and predators. The peripheral olfactory system of larval mosquitoes consists of olfactory sensory neurons (ORNs) in the antennae and maxillary palps. These ORNs express only 12 distinct olfactory receptors (ORs), co-expressed with the odorant receptor co-receptor (ORCO) to form ORx/ORCO complexes that exhibit either narrow or broad tuning to a variety of host-derived odours. Larval olfactory system is thus much simpler than that of adult mosquitoes and enables the investigation of individual ORCO-positive cells' responses to different concentrations of soluble compounds, predicted to bind to olfactory receptors. Previous research, including unpublished work from our laboratory, has established the behavioural valence of some soluble compounds in larvae. The primary objective of this project is to understand the neuronal basis of olfactory repellence in mosquito larvae. I characterised, through live calcium imaging, cellular responses to behaviourally relevant compounds. I used a newly developed transgenic line (Orco-QF2, QUAS-GCamp6s) to directly visualize the responses of ORCO neurons in the larval antennae and maxillary palps. I observed different ORN activation patterns in response to repellents and non-repellents stimuli, establishing a possible correlation between neuronal activity and larval behaviour. These findings suggest ORN activity could predict repellent behavioural outcomes. By uncovering the molecular and cellular mechanisms of odorant perception, this research lays the groundwork for developing novel, olfaction-based larval control methods. This strategy could reduce adult mosquito populations and provide a sustainable tool for malaria management.

Urban stressors & adaptation | Monday, July 27 **|** 15:00 – 15:15

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Is all disruption created equal? Evaluating how sensory inputs affect sleep behaviour in fish

Sleep is a ubiquitous behaviour across the animal kingdom but remains majorly understudied in fish, although interest in the field is growing. While there is an increase in experiments investigating how sleep disruption affects fish physiology and behaviour, these studies use a variety of methods, such as visual or mechanosensory disturbances. This raises a key question: how does the specific sensory channel disrupted during enforced wakefulness dictate subsequent behavioural and physiological outcomes? In this study, we investigated how the method of disruption may alter next-day behavioural and stress responses. Using Trinidadian guppies (*Poecilia reticulata*), we performed comparisons of light-based, sound-based, and water flow-based sleep disruption to deduce how methodology may impact outcomes of sleep disruption experiments in the lab. This study represents a novel methodological evaluation, critically examining how different anthropogenic sensory inputs may uniquely impact sleep and the consequences of disrupted sleep in aquatic environments.

S3.3 **|** 11:40 – 12:00 **|** Tuesday, July 28

Evolution of sleep: A comparative perspective to unravel the biological function of sleep?

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Sleep-dependent neural processes that support natural-like experiences

Recently acquired memories are reactivated in the hippocampus during sleep, an initial step for their consolidation. This process requires an increase in the coordinated firing of neurons that have been recently active during experience. However, in nature, animals are exposed to a continuum of experiences that need to be incorporated into memory for guiding behavior, escape from predators or find shelter. How the processes that regulate memory consolidation during sleep translate to the enriched natural environment is not known. We found that distinct experiences are consolidated during alternative substates that follow the slow oscillation during, and this process can be tracked using pupil recordings. Such segregation for the consolidation of distinct memories, could prevent memory interference. Furthermore, we found that distinct hippocampal substates during NREM sleep regulate memory replay and memory reset, to maintain network homeostasis that allows new experiences to be integrated into memory. Yet, the natural environment can be variable, and change dynamically in unpredictable ways. We are currently investigating how distinct experiences in an animal's natural environment are prioritized during sleep-dependent memory consolidation and how distinct environmental factors that impact animal behavior shape sleep dynamics.

S12.1 | 11:00 – 11:20 | Thursday, July 30

The neuroscience of emotion

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Emotion-like states in (zebra)fish: cognitive appraisal, cognitive bias, and social contagion of fear

The behavioral components of emotions (aka emotional expressions) act as honest signals of internal affective states available to conspecifics that can adjust their behavior accordingly, in order to increase their Darwinian fitness. Social contagion and social buffering are fundamental processes through which affective states spread and are regulated within groups, providing a window into the evolutionary origins of emotion. The social modulation of negative internal states elicited by the perception of the presence of a threat in the environment (aka fear) has been a core study model in this respect. Social buffering and social contagion of fear can be seen as functionally antagonistic manifestations of social information use in threat detection. We have been using zebrafish as a vertebrate model to investigate these phenomena due to its genetic tractability, conserved neurobiology, and robust social behaviors. In brief we have found that: (i) both social phenomena are present in zebrafish; (ii) oxytocin is necessary and sufficient for both; (iii) specific neural circuits in the ventral telencephalon are involved in these behaviors; (iv) an autism related gene (shank3a) is also necessary for social contagion; (v) shank3a and oxytocin affect social contagion through different endophenotypes, with the former acting on social attention and the latter on social information encoding/recall; (vi) oxytocin also affects consensus assessment when conspecific demonstrators exhibit conflicting social information. The fact that oxytocin also regulates emotional contagion in mammals, acting in homologue subcortiocal regions to those identified in zebrafish, suggests that this elementary form of empathy is evolutionary conserved and could have evolved in a common ancestor of teleosts and mammals.

Arthropod locomotion & motor programs | Tuesday, July 28 **|** 15:15 – 15:30

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Prosthetic leg integration reorganizes walking coordination in crickets

Understanding how animals regain coordinated locomotion after injury is a central question in neuroethology, biomechanics, and bioinspired robotics. Insects provide powerful model systems because their locomotion emerges from distributed neural control tightly coupled with body morphology and sensory feedback. Previous studies have shown that leg amputation alters gait patterns yet preserves functional walking through adaptive reorganization of inter-leg coordination. However, whether coordinated locomotion can be selectively reconstructed through targeted morphological intervention remains unclear. Here, we investigate the self-organized recovery of walking coordination in the cricket *Gryllus bimaculatus* via prosthetic limb integration. Using a spherical treadmill, we quantitatively compared locomotor performance across intact, amputated, and prosthesis-attached individuals. Kinematics were captured with a deep-learning-based markerless tracking algorithm, DeepLabCut, enabling precise quantification of spatiotemporal gait parameters and inter-leg phase relationships. Leg amputation induced systematic shifts in coordination, including altered inter-leg phase coupling, while maintaining overall locomotor stability. Strikingly, prosthetic attachment selectively reinstated coherent temporal and spatial coordination patterns. Rather than simply reproducing intact kinematics, prosthetic integration reorganized the sensorimotor loop and stabilized phase relationships among the legs. These findings demonstrate that locomotor recovery is not solely neuronally predetermined but emerges from dynamic interactions between morphology and sensory feedback. Our results show that embodied locomotor control can be reconstructed through structural intervention, establishing a rigorous biohybrid framework that links neuroethology and robotics, elucidates resilience mechanisms in biological motor systems, and informs the design of embodied control architectures.

Young investigator symposium | Monday, July 27 **|** 11:40 – 12:00

Palgi, **Shaked**, Weizmann institute of Science, Israel

Neuroethology on an island: from spatial coding to ecology

In my talk, I will describe our approach of using the Egyptian fruit bat as an animal model for studying the neural basis of navigation in natural environments. In recent years, we conducted electrophysiological recordings in bats flying unconstrained and navigating outdoors on a remote oceanic island in east Africa. In the first project, we recorded head-direction cells in the bat presubiculum – a major hub of the head-direction network. We discovered that the directional tuning of these cells showed remarkable stability over the geographical scale of the island, and were not influenced by the movement of celestial cues, suggesting that they can serve as true neural compasses. In the second project, we quantified potential sources of danger to the bats on the island, namely the ocean and a large colony of predatory sea birds. Behavioral analyses confirmed that bats visited less the dangerous areas on the island – both the birds and the sea – consistent with the framework of ecology of fear. We recorded >100 neurons simultaneously in hippocampal area CA1 and found that many of these neurons encoded the bird density on top of their classical place-coding. We then used the neural population activity to transform the external variables of bird-density and distance-to-ocean into an internal representation of fear, which we could decode from the network activity. This also allowed us to generate the map of fear from the population activity in the bat hippocampus. Together, these projects demonstrate the power of large-scale neural recordings during natural

behavior in the real world.

3D navigation & spatial cognition | Friday, July 31 **|** 15:00 – 15:15
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Experience-dependent hippocampal plasticity in African elephants: a multi-scale approach

Elephants are long-lived, large-brained mammals that rely heavily on spatial memory to navigate vast and seasonally variable habitats. They possess one of the largest hippocampi among terrestrial mammals, a structure central to spatial navigation that retains lifelong plasticity, including adult neurogenesis. Here, we investigate hippocampal plasticity in African elephants by comparing wild and captive individuals, whose environments differ markedly in spatial complexity and navigational demand. Using post-mortem MRI, we found that wild elephants have significantly larger hippocampal volumes than captive individuals. High-resolution synchrotron imaging enabled subregional volumetric analyses, while histological approaches revealed differences in cellular organisation across hippocampal subfields in both groups. Ongoing immunohistochemical and molecular work aims to determine whether variation in adult neurogenesis underlies these volumetric differences. Together, these findings demonstrate experience-dependent hippocampal plasticity, offering a rare multi-scale perspective in a large-brained species, with implications for comparative neuroscience and captive animal welfare.

Insect compass systems | Thursday, July 30 **|** 15:15 – 15:30
Patel, Rickesh, Lund University, Sweden
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Navigation by vector addition in the brains of bees

Some animals, like bees and ants, can easily return to their homes after navigating unknown, featureless terrain in convoluted paths. I will talk about my research investigating how insects overcome these navigational challenges. I will first show how walking bumblebees construct and use spatial vectors to return to their hive while foraging in the lab. We show that walking bees 1. integrate foraging paths to construct path integration-derived home vectors, 2. store path integration home vectors in long term memory and recall memorized vectors at a familiar location, and 3. have access to multiple vectors simultaneously with which to navigate. Using what we found, I will discuss how bees have the potential to use vectors to construct a flexible spatial representation to allow them to perform complex navigation behaviors, including making novel shortcuts between locations of interest. In this model, spatial vectors are tied to familiar locations, providing a vector-reliant web-like map of their surroundings. Finally, I will discuss our current work to test this vector-map hypothesis using a new laboratory-based behavioral assay that allows us to track the complete foraging history of a whole hive of bees over their entire lives in the lab,

and an investigation of the neural basis of these spatial vectors using neurophysiology informed by the detailed neuroanatomy of the insect brain.

S10.2 | 11:20 – 11:40 | Thursday, July 30

Brains in the wild B

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Collective sensing in electric fish

Active sensory systems, such as those of dolphins, bats, and electric fish, rely on self-generated signals to probe the environment. In social contexts, these signals have typically been viewed as sources of interference to be minimized. Here, we challenge this view and show that conspecific signals (electric organ discharges, EODs) can instead enhance perception. Using a combination of modeling, neural recordings, and behavioral experiments, we demonstrate that the African weakly electric fish Gnathonemus petersii exploits the electrical pulses of nearby individuals to extend its electrolocation range, to improve object discrimination, and to increase information transmission. These results reveal a previously unrecognized collective mode of active sensing in which individual perception is enhanced by the energy emissions of nearby group members. This constitutes a biological example of multistatic sensing. Building on this framework, ongoing work investigates how information is encoded and used within groups through the temporal structure of EODs, which are controlled with millisecond precision. To exploit this temporal structure, we are developing automated methods to track individual identity and behavior while attributing EODs to specific individuals in freely interacting groups, enabling large-scale analyses of communication and sensing dynamics.

S5.5 | 12:15 – 12:30 | Wednesday, July 29

The neural substrate of animal collective motion

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Synchronization and signal diversity in firefly swarms

Many animal groups communicate with discrete, pulse-like signals, from crickets and frogs to woodpeckers and fireflies. Fireflies offer a particularly tractable case because their signals are light pulses that can be simultaneously recorded from many individuals using off-the-shelf cameras, and perturbed with controlled light stimulus in both lab and field settings. At a first approximation, each species advertises with a stereotyped on/off flash pattern. The digital structure of these signals invites information-theoretic analysis of detectability (signal-to-noise), compression (minimization of bits), and robustness to errors, and it highlights how collective synchronization can amplify signals at the group level. Using recordings of fireflies in the field together with light-playback experiments, we connect individual response rules to swarm-level timing. We then place flash codes in an evolutionary context, using phylogenetic reconstructions to infer ancestral patterns and to test hypotheses about adaptation under changing environments. As an outlook, I will sketch how physiological constraints in sensing and light production may set the feasible space of flash codes, shaping both synchronization and recognition.

Neural mechanisms of acoustic communication | Tuesday, July 28 **|** 15:30 – 15:45

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Larval-like brains in transparent adult fishes: flipping the script on brain-behavior complexity

Seemingly complex social and cognitive behaviors are often assumed to require large, complex brains. The relatively compact nervous systems of insects challenge this assumption, as do miniaturized vertebrates. Among the latter are *Danionella* fishes, which possess one of the smallest adult vertebrate brains. Their close relationship to zebrafish, lifelong transparency, and larval-like skeleton make them uniquely amenable to whole-brain optical imaging at single-cell resolution and large-scale connectomics. This remarkable phenotype results from progenetic paedomorphosis, a developmental process in which adults retain larval and juvenile characteristics. For example, the adult *Danionella* skeleton resembles that of 21-day-post-fertilization zebrafish. Is the brain similarly developmentally truncated? To address this question, we compared the telencephalon, a crucial locus for cognition, between adult *Danionella* zebrafish across developmental stages. Using a combination of molecular markers, we found that adult *Danionella* possess the pallial and subpallial divisions characteristic of adult teleosts, yet many features remain strikingly larval-like. Cell migration appears reduced, most prominently in the caudal pallium, which retains lobe-like compartments. Most notably, the caudal central pallial zone (Dc)—a teleost region frequently compared with the mammalian isocortex—occupies a larval-like position in the adult brain. Does this developmental truncation impose functional trade-offs? *Danionella* perform spatial navigation tasks, social-place learning, courtship, and territorial aggression. In our focal species, *Danionella dracula* (Dracula fish), males produce acoustic pulses and extend a hypertrophied, fang-bearing lower jaw as part of a multimodal agonistic display. The coexistence of a larval-like telencephalon with an adult behavioral repertoire suggests a decoupling of brain and behavioral complexity. We have developed behavioral assays, transgenic lines and multiphoton functional imaging techniques for Dracula fish, providing a unique opportunity to determine how adult vertebrate behaviors emerge from a developmentally simplified brain.

Developmental plasticity & evolution | Tuesday, July 28 **|** 15:45 – 16:00

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Evolution and integration of a novel cell type for target detection in housefly retinas

The evolution of complex nervous systems required the emergence of novel types of neurons, yet the genetic changes that increase neural diversity remain poorly understood. We examined the evolution of a novel R7 photoreceptor subtype in the house fly Musca domestica. In males, a dorso-frontal eye region known as the 'Love Spot' enables rapid detection and tracking of females during mating flights. In this region, R7 cells - normally dedicated to color vision - are repurposed for target detection through changes in rhodopsin expression, physiology, and circuit connectivity. Using single cell sequencing, CRISPR/Cas9 gene knockout, and by making transgenic house fly lines, we show that

these specialized love spot R7s (LsR7) are initially specified as canonical R7 photoreceptors but later adopt a chimeric fate that combines transcription factors associated with both color and motion vision. The sex-determination transcription factor Doublesex (Dsx) is strongly upregulated after R7 specification and, together with Spineless, regulates downstream targets required for LsR7 identity. Dsx gain-of-function is sufficient to induce LsR7 identity in female and ventral male eyes. Unexpectedly, LsR7 axons initially project to the medulla before Dsx can be upregulated and are later shortened to instead connect with lamina neurons. These findings show that new combinations of cell-identity regulators can generate new types of neurons with novel function, though their developmental integration may remain constrained by evolutionary history.

S8.2 | 11:20 – 11:40 | Wednesday, July 29

Neurosustainability: how brain science is revolutionizing environmental design and policy

Pinter-Wollman, Noa, University of California Los Angeles, USA

Feedback between nest architecture and ant collective behavior

Social behavior emerges from interactions among animals. Such interactions often require spatial proximity and are therefore influenced by the ways in which animals move throughout their environment. Animal movements are in turn impacted by the spatial structure of the environment. Ant interactions occur inside nests that they build and therefore are a fantastic study system in which to study the feedback between the (built) environment and social behavior. The collective behavior of social insects has inspired solutions to engineering problems, including providing sustainable solutions that have been shaped by millions of years of evolution. In this talk I will examine the relationship between social behavior and the structure of the environment and explore the potential feedbacks between environment and behavior.

S4.2 | 11:20 – 11:40 | Tuesday, July 28

Adaptive responses to changing internal and external environments: weathering the storm

Powell, Daniel, Bowdoin College, USA

Seasonal differences in the physiology and modulation of the cardiac neuromuscular system in the American lobster

Nervous systems must be able to maintain function despite fluctuations in ambient temperature. Because temperature affects the kinetics of all cellular processes (e.g., ion channel function), it is not immediately clear how temperature compensation is achieved at the level of single neurons or whole circuits (i.e., how does a nervous system maintain stability despite temperature change?). This is particularly true for organisms that do not homeostatically regulate their internal temperature. In tidal areas, the nervous systems of decapod crustaceans are at times exposed to fluctuations > 10°C in a day. The nervous systems of the American lobster (H. americanus) can maintain function across a wide range of temperature (~5-30°C). Neuromodulators (e.g., amines, peptides, hormones, and gases) can influence this temperature range such that some modulators limit this range while others extend it. That said, we lack a concrete understanding of how nervous systems and neuromuscular systems maintain stability while both temperature and modulation both influence neuron and muscle physiology.

Here we use the cardiac neuromuscular system of the American lobster to study how the modulated and unmodulated heart is affected by neuromodulation across a limited

temperature range, 7°C -16°C. This preparation includes the cardiac ganglion (CG), a nine-neuron circuit that generates the heartbeat, and the associated cardiac muscles that the CG motor neurons innervate. For these experiments, we perfused three neuromodulatory peptides SGRNFLRFamide (SGRN), GYSDRNYLRFamide (GYS), and myosuppressin at four temperature steps 7°C, 10°C, 13°C, and 16°C, to understand how temperature influences the cardiac response to these modulators. These modulators are known to regulate distinct aspects of cardiac physiology. We observed differences in the temperature-dependencies of each modulator. For example, in the unmodulated heart, the heartbeat contraction force tended to decrease as temperature was increased. However, both SGRN and GYS stabilized the heart contractile force as temperature was increased. Interestingly, myosuppressin increased the contraction force with temperature across that same temperature range. These data were collected from summer-caught animals. The physiology of winter-caught animals responded differently to both modulation and temperature change. For example, the heart contraction force was not temperature-sensitive over this range of temperatures. We also observed differences in the modulated physiology of these winter-caught animals.

Vertebrate motor control | Friday, July 31 **|** 15:45 – 16:00

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Silent preparation precedes song in birds without introductory notes

Male zebra finches produce short, repetitive, vocalizations called introductory notes (INs) before their song and these INs have been suggested to reflect motor preparation. However, ~5% of zebra finches do not produce INs before song and in these birds without INs, it is unclear if motor preparation is absent or there is silent motor preparation. Here we address this question by recording respiratory pressure in birds without INs as respiratory pressure changes occur as part of motor preparation for song. In birds without INs (and birds with mean IN number < 2.5) we found 0 - 3 silent expiratory pulses just before the start of song. These silent expiratory pulses were similar to IN related expiratory pulses; (1) they were variable in number from bout to bout, (2) their amplitude was significantly higher than baseline expiration amplitude, (3) expiratory pressure increased as song approached, and (4) there were more expiratory pulses when males sang to a female. In a separate set of birds without INs, we recorded singing-related multiunit activity from premotor nucleus, HVC, and found phasic increases in activity before song onset. These phasic increases were similar to increases in activity associated with IN in birds with INs. These data suggest that birds without INs produce silent INs before song. To uncover the mechanism underlying this silence despite increased expiratory pressure, we compared respiratory pressure between vocalized and silent INs. We found that silent INs were typically associated with lower respiratory pressure when compared to vocalized INs. Further, in 66.67% of birds, silent INs continued to remain silent after removal of neural input to the syringeal muscles suggesting that the silence was due to reduced respiratory pressure. Overall, these data demonstrate the presence of motor preparation before song in all zebra finches and suggest that changes in respiratory pressure and HVC neural activity are important for song initiation.

Evolution of sensory & motor systems | Wednesday, July 29 **|** 15:00 – 15:15

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One and done or back for more: stinging strategies in bees and ants

Insects utilise modified ovipositors for stinging in a variety of different contexts. Here we examine two different stingers used for defence and predation, the honeybee and bull ant stingers. The stinger of the honeybee worker (*Apis mellifera*) is famous for its ability to autotomise; that is, after initial insertion the bee flies away leaving the stinger to continue to pump venom and insert deeper into tissue. This often kills the bee and makes the stinger a high cost, single use defensive strategy. In contrast, Australian bull ants from the genus *Myrmecia* are extremely territorial and ferocious hunters. Workers will bite down with their large mandibles and sting many times in quick succession. A single worker can sting many times over its lifetime. We examine the anatomy and kinematics of these two radically different approaches to stinging. We describe the stingers of A. mellifera and two species of bull ant, the large bodied *Myrmecia brevinoda* and the smaller *Myrmecia nigrocincta*. We used high-speed videography to determine the differences in the two stinging approaches. While the bee stings with a single downward trajectory the bull ant partially withdraws and re-inserts as many as 14 times in a single stinging event. Furthermore, the re-insertions often result in a fan-shaped pattern within the tissue, potentially maximising the area over which the venom is delivered. Another key difference lays in that the inward propagation of the stinger is obligately coupled to the venom pumping for the bee, whereas in the ant these can be carried out independently. This difference is imposed by adaptations required by autotomy, and it radically changes the venom delivery mechanics. The bee stinger acts as a powerful one-shot deterrent (high risk, high reward), while the bull ant sting can be wielded more flexibly. This poses interesting questions about the evolutionary pressures that shaped these two radically different stingers and the stinging strategies these animals use.

Chemosensory-guided behavior | Friday, July 31 **|** 15:15 – 15:30

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Characterization of neural mechanisms underlying coral larval recruitment

Coral reefs are facing rapid decline globally due to climate change. In their early life stage as free-swimming larvae, corals encounter numerous environmental cues that influence their settlement and metamorphosis into adult polyps. This transitional event is crucial for

the survival of coral reef ecosystems; however, the neural mechanisms by which larvae sense and transduce environmental cues are understudied. Here, we aim to characterize the nervous system of coral larvae using single-nuclei RNA sequencing (snRNASeq) and Hybridization Chain Reaction Fluorescence In Situ Hybridization (HCR-FISH). We performed snRNASeq on 2-3 dpf Galaxea fascicularis larvae using 10x and BD platforms, and identified three distinct neural clusters. HCR FISH probes designed against top neural markers, including otoferlin, CAC1G, SCN4A, and NMDZ1, showed widespread localization in the larval epidermis, with increased localization in the apical organ at the aboral pole of the larvae. As the apical organ is a sensory structure that plays an important role in larval settlement, our findings indicate that these neural genes may be involved in the detection of environmental settlement cues. Of particular interest is the gene otoferlin, which is critical to synaptic transmission by the sensory hair cells of the ear in vertebrates but has not been described in corals. There is evidence that healthy reef sounds may be an important recruitment cue for coral larvae, and mechanosensory hair-like cells have been described in cnidarians. Thus, otoferlin may play an important role in the detection of recruitment cues in cnidarian hair-like sensory cells. Next steps involve developing knockdowns and transgenic neural GCaMP lines to functionally test the role of otoferlin and other identified neural genes in larval recruitment behavior, and how these functions are impacted by natural and anthropogenically-induced variations in their environment.

Acoustics & sensory mechanics | Monday, July 27 **|** 16:00 – 16:15

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Tiger moth clicks are directional warning signals and optimally unveiled

The aerial interactions of echolocating bats and tiger moths is the quintessential example of an acoustic arms race escalation in real-time. Tiger moths possess bat-detecting ears, and many are presumably chemically defended. Most can produce ultrasonic clicks using a pair of thoracic tymbals. These clicks are evoked by the echolocation calls of aerially hawking bats and may function (i) to remind experienced bats of their toxicity (or mimic those of chemically defended species), (ii) to acoustically startle naive bats, (iii) to interfere with bat echolocation, or (iv) via a combination of these functions. To test these hypotheses, we first undertook the real-time analyses of tiger moth defensive signalling to a spatially-calibrated aerial hawking echolocation call attack sequence from a big brown bat (*Eptesicus fuscus*) hawking in nature using wild-caught dogbane tiger moths, *Cycnia tenera*. We also ascertained the presence of chemical defences beyond pyrrolizidine alkaloids (ancestral to the subfamily) using gas chromatography-mass spectrometry to identify cardiac glycosides and iridoid glycosides in these same wild-caught moths. We demonstrate for the first time that tiger moths' clicks are directional, with most energy directed backwards and, while as loud as ever previously reported, that the clicks will arrive at a bat's ears at a level just above the echolocation calls reflected from these insects (i.e. at roughly the same level as the echoes). We also clearly demonstrate that this species sequesters cardiac glycosides from dogbane (*Apocynum cannabinum*). Our results support the hypothesis that against hawking bat attacks *C. tenera* clicks function primarily as revealed aposematic signals and thus credible threats of chemical defence.

S6.5 | 12:15 – 12:30 | Wednesday, July 29

Brains in the wild A

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Sleep research goes wild: from sloths to penguins

Sleep is a poorly understood behavior shared by animals ranging from jellyfish to humans. For technical reasons, efforts to understand the functions of sleep have traditionally been performed on captive animals, disconnected from the real-world ecological context in which sleep evolved. Although behavioral studies of animals in the wild can provide insight into sleep, in some species, electroencephalogram (EEG) recordings are needed to distinguish between wakefulness and sleep, and to measure the intensity and type of sleep. The recent development of portable EEG data loggers has allowed comparative sleep researchers and their study animals to escape the confines of the lab. Using this technology, I will show that wild sloths are not as slothful as previously thought, male pectoral sandpipers that sleep the least sire the most offspring, great frigatebirds sleep unihemispherically and bihemispherically on the wing, but very little, and nesting penguins obtain large amounts of sleep via thousands of seconds-long microsleeps. Overall, these studies reveal that the time spent sleeping, and ways of obtaining it, are more flexible than previously recognized from lab studies. However, in no case, has a truly sleepless animal been identified, underscoring the importance of obtaining at least some sleep.

Young investigator symposium | Monday, July 27 | 12:00 – 12:20

Rauscher, **Mike,** Case Western Reserve University, USA

Low frequency auditory stimuli provoke rapid ascent in free-flying Aedes aegypti mosquitoes

Can mosquitoes use their sense of hearing to detect and escape from approaching aerial predators? Mosquito audition has been extensively studied in the context of courtship and mating, but save for an auditory-gated collision avoidance behavior (Gupta et al., 2024) the role of this sense modality remains underexplored in other contexts. Here, we characterize flight trajectories in the yellow fever mosquito *Aedes aegypti* following exposure to loud (>80dBC) environmental sound stimuli. We demonstrate that 180-300Hz sound stimuli provoke a rapid increase in flight speed and upward ascent not observed following presentation of stimuli of equivalent acoustic loudness in the conspecific female (450Hz) or male (700Hz) wingbeat frequency ranges. Similar results are observed in tethered flight experiments showing rapid increases in wingstroke amplitude and frequency following presentation of stimuli in these frequency ranges, resembling responses to visual looming stimuli. In line with prior work characterizing a negative phonotaxis in response to low frequency stimuli in another Aedes taxon (Lapshin and Vorontsov, 2018), we hypothesize that this behavior may reflect an escape response to the acoustic signatures of aerial odonate predators such as dragonflies and damselflies.

Neural mechanisms of acoustic communication | Tuesday, July 28 | 15:45 – 16:00

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Harbor seals as mammalian models for vocal production learning

Vocal production learning (VPL) is the capacity to modify acoustic output or learn new sounds that do not belong to one's natural repertoire. Among mammals, only a few taxa show promise of VPL: phocid pinnipeds are among those. I will synthesize our work from the last 6 years, integrating operant conditioning, playback experiments, and bioacoustic analyses. I will show that harbor seals (*Phoca vitulina*) have developed capacities for VPL in the three key subsystems of sound production: the respiratory system (lungs), the larynx (source), and the upper vocal tract (filter). Regarding the respiratory system, I will show that seals have control over timing and duration of vocalizations. With limited training, they can control vocalization duration across two orders of magnitude. Spontaneously, newborn pups can precisely time their vocalizations' onset. Regarding the larynx, I will show evidence of source plasticity, where seal pups shift their fundamental frequency in response to playbacks. Finally, I show filter control through conditioned vocalizations where adult seals volitionally modulate formants via upper vocal tract movements. Some of these building blocks appear remarkably early in life, as neonatal auditory input significantly shapes vocal ontogeny. Our behavioral findings dovetail with neurobiology: recent comparative work from other labs show that pinnipeds have gradually acquired the neural circuitry required for such control. Specifically, while pinnipeds in general have a robust connection between the nucleus ambiguus and the vocal motor cortex for volitional laryngeal control, harbor seals in particular show specialized thalamocortical and auditory-to-motor pathways that likely support the VPL capacities we observed behaviorally. By mastering the coordination of lungs, source, and filter, phocid seals provide a unique case of mammalian vocal plasticity, and one of the best model species to understand the neuroethology of mammalian VPL.

S5.2 | 11:20 – 11:40 | Wednesday, July 29

The neural substrate of animal collective motion

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Neural organization of social identities and classes in a group of bats

Social group behavior in the natural world is complex, one may choose to mate with one individual, fight with another, and play with a third. Such real-life situations require the representation of multiple individuals' identities and of features pertinent to it – such as their sex, social hierarchy, and social affiliation. Further, real life encounters can happen not only with members of your own species (conspecifics), but also those of other species (heterospecifics) and objects. Here I will describe our findings from Egyptian fruit bats, of how neurons in the hippocampus encode classes and identities of agents. These neural representations are organized as a hierarchical code in the brain – with the codes of individual identities being nested within those of agent types. In a social network of freely-flying bats, these neurons not only represent the identities of others, but encode important parameters of their social network – such as the sex, social hierarchy and social affiliation of other individuals. Overall, we find that the hippocampal cognitive map forms an organized hierarchical representation of real-world societies.

S1.3 | 11:40 – 12:00 | Tuesday, July 28

Principles of sensory navigation across species & habitats

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Task representations and context-dependent navigation strategies

Sensory navigation is often informed by the statistics of the sensory stimuli an animal experiences in its environment. However, sensory statistics can themselves be widely variable — a moth navigating a pheromone plume in an open field on a windy day experiences starkly different sensory statistics than one navigating through a calm forest. One plausible mechanism is that animals gradually acquire an internal representation of "context", which modulates their reactive response to sensory stimuli. But it is unclear how such a mechanism could be implemented in neural circuits. In this talk, I will show that a minimal artificial neural network, meta-trained over a sufficiently diverse set of contexts, learns to rapidly adapt to environmental statistics. Meta-trained networks acquire one of two distinct strategies: a strategy that builds a map-like representation of the environment, and another that utilizes a dynamic internal state that gates the network's instantaneous response to a new stimulus. I'll conclude with a minimal mechanistic model for how context representations could gate sensory processing to support robust navigation across environments.

Social displays & collective behavior | Thursday, July 30 **|** 15:45 – 16:00

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Audio-visual timing underlies sex differences in the perception of social displays

Sex differences in responses to social signals are traditionally attributed to downstream processes of receiver motivation and signal valuation. However, an alternative hypothesis suggests that such dimorphism originates earlier at the level of perceptual organization. Multimodal communication provides an ideal model to test these possibilities, as sensory streams must be bound before valuation. Here I examine sex-specific sensitivity to the temporal structure of audio-visual displays in the starling Sturnus vulgaris. Using a robotic taxidermic model in field conditions, I examined early reflexive reactions to distinguish how each sex groups song and wing movements into perceptual events. I manipulated the temporal relationship between these components while keeping the signals identical. The results reveal systematic sex differences in sensitivity to temporal shifts. While adding a visual component to an acoustic baseline triggered renewed responses in both sexes, only females showed dishabituation when the timing between familiar modalities was altered. Males failed to react to those shifts even at a low-cost reflexive level. These findings demonstrate that the same physical display does not constitute the same perceptual event for both sexes. I conclude that sex differences in social behaviour are rooted in sensory dimorphism that constrains how information is bound into discrete events.

S1.2 **|** 11:20 – 11:40 **|** Tuesday, July 28

Principles of sensory navigation across species & habitats

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Swimming in the dark: sensory navigation in blind cavefish

Animals navigate their environment using multimodal sensory cues. How do they adapt to a drastic environmental change that deprive them of one of these major sensory modalities? We ask this question in an evolutionary context, deciphering behavioral evolution in the cave-dwelling and dark-adapted blind cavefish, *Astyanax mexicanus*. By comparing swimming behaviors in blind cavefish and their river-dwelling sighted conspecifics, we have discovered major differences in locomotor patterns and strategies, both to navigate their environment and to respond to olfactory cues in the dark. To explore the genetic basis of this behavioral shift, we have used quantitative genetics and second-generation F2 hybrids resulting from crosses between surface fish and cavefish. We find a complex architecture of the navigation and olfactory-driven navigation trait in cavefish. After expression studies and functional validation, candidate genes will reveal some neural bases of the adaptive evolution in cavefish behaviors and further, some general mechanisms for sensory navigation in vertebrates.

Active sensing & sensorimotor gating | Thursday, July 30 **|** 15:45 – 16:00

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Neural computations and behavioral strategies for active sensing and whole-body movement

In natural behavior, we coordinate the movement of our heads, eyes, hands, and bodies to collect sensory information. Our understanding of whole-body sensorimotor integration is limited because many laboratory tasks profoundly restrict the subject's movement. To address this gap, we have developed a new naturalistic sound-seeking task for mice that is amenable to detailed video tracking and high-density neural recordings of multiple brain regions. In the sound-seeking task, mice use continuous head and body movement to localize an ongoing and complex sound. Mice with single-sided hearing loss initially lose their ability to perform sound-seeking, but their performance recovers over about a week. We are now asking how both healthy performance and recovery from hearing loss are mediated by interactions between the auditory cortex and inferior colliculus. Using new wireless technologies to record large populations of neurons, we found that encoding of sound location in the auditory cortex is distorted by hearing loss. We hypothesize that restoration of healthy spatial tuning relies on the descending projection from cortex to colliculus. Finally, in the course of these behavioral experiments, we noted that mice in our multi-chambered and complex environment voluntarily engage in balancing, climbing, and leaping, leading us to ask how the motor cortex coordinates whole-body movement during natural behaviors. We use multiple camera views to track the position of the entire body in 3D. Using unsupervised machine learning, we discovered that certain whole-body behaviors, such as rearing, emerge with learning and disappear after dopaminergic neurodegeneration. We are presently determining how the motor cortex encodes these whole-body movements. Our long-term goal is to understand how sensory and motor areas interact to enable free and natural behavior.

S2.3 **|** 11:40 – 12:00 **|** Tuesday, July 28

Principles of communication in social groups: from behavior to neuron

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Social dynamics modulate call patterning in a South American treefrog

Communication systems shape behavioral interactions that are crucial for recognition, territoriality, and reproduction across animals. Temporal patterns within vocalization systems often provide key signals that individuals use to modify their behavior, varying in rhythmicity and predictability both between and within individuals over time. Understanding how signalers modulate features of their vocalizations provides crucial insight into the physiological mechanisms that regulate call patterning and communication. In chorus settings, males must navigate acoustically complex environments where competing signals overlap, making vocal flexibility a critical component of successful communication. Here, we use a rhythm-analysis and probability transition framework to examine how males of the South American treefrog Boana pulchella modulate their vocal timing in response to acoustic playbacks of varying complexity. We systematically varied the inter-call intervals and call types of playback stimuli to assess how focal males adjust the call rhythms and temporal sequencing in response to changes in signal complexity. Our results suggest that males modulate their vocalizations to match their acoustic environment, with evidence for both synchrony and call alternation depending on the playback stimulus. These findings highlight the vocal flexibility of this species in dyadic interactions and lay the groundwork for understanding how chorus-level dynamics emerge from individual-level responses to socially complex acoustic environments.

S11.4 | 12:00 – 12:15 | Thursday, July 30

The neuroethology of water stress: thirst, desiccation risk and water-seeking behavior

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Body fluid perturbations in the rat and the comings/goings of phasic dopamine signals

Maintaining blood osmolality is critical for survival and yet there are near constant deviations from ideal levels due to fluid loss or challenges from ingested food. Autonomic and endocrine processes can conserve water and solutes (e.g. sodium) and change blood pressure, but eventually behavior must be motivated to seek out water and salt. Indeed, the value of water and salt as targets for behavior are dependent on the physiological state of the animal. The mesolimbic dopamine system is critical for assigning value to environmental stimuli and actions and in motivated behavior. We have previously shown that sodium depletion recruits phasic dopamine responses to the taste of hypertonic sodium solutions and that water deprivation (and central circuits engaged by dehydration) similarly recruit phasic dopamine signaling for water and water-predictive cues. As animals replete themselves, the value of fluid decreases and eventually water and hypertonic sodium solutions are rejected. Here, we use intraoral delivery of fluid to determine the time course by which dopamine evoked by oral fluid changes as rats replete themselves. This approach permits the response to the exact same solution and volume regardless of the motivational state of the animal. Using in vivo fiber photometry and pose estimation models to assay detailed behavioral responses to fluid, we show that the magnitude of dopamine responses to intraoral fluid decays based on the amount of repletion. Moreover, changes in dopamine closely precede changes in behavior. Together, the data support a rapid updating of motivated behavior by phasic dopamine responses to oral fluid.

Chemosensory encoding | Thursday, July 30 **|** 15:15 – 15:30

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Antennal lobe coding of olfactory cues in the Bogong moths

The Bogong moth *Agrotis infusais* a long-distance nocturnal migrant who travel up to a thousand kilometres to the Australian Alps where they seek out the shelter of isolated cool alpine caves, thereby escaping the approaching summer heat of their breeding grounds. Olfactory cues are thought to guide moths to these caves. Once there they enter a state of dormancy for three months over the coming summer, known as aestivation. When autumn comes, they migrate back again to the breeding grounds mate, lay their eggs and then the adults die. Throughout their life cycle olfaction plays a crucial role, from locating nectar sources and host plants to finding mates via sex pheromones. Analysis of cave odours identified one compound, (Z,E)-9,12-tetradecadienyl acetate, to which Bogong moths respond strongly. During the spring migration towards the caves, they are significantly attracted to this compound, whereas during their autumn retorn migration, they are no such attraction. The main sex pheromone component, (Z)-9-tetradecenyl acetate, is chemically similar but distinct from the cave compound. Using immunohistochemistry, 3D reconstructions and calcium imaging, we investigated the physiology and function of the Bogong moth antennal lobe across life stages. We found that the cave compound activates regions of the antennal lobe overlapping those responsive to the main sex pheromone, the cumulus, as well as regions associated with potential minor pheromone components within the macroglomerular complex (MGC). Although females lack an MGC the glomeruli responsive to both the cave compound and the sex pheromone occur in somewhat corresponding regions of the antennal lobe.

S2.2 **|** 11:20 – 11:40 **|** Tuesday, July 28

Principles of communication in social groups: from behavior to neuron

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Neural circuits for social communication in bats

Social context shapes how animals perceive and respond to communication signals, yet the neural and physiological mechanisms underlying context-dependent processing of affective vocalizations remain poorly understood. The Egyptian fruit bat, Rousettus aegyptiacus, is a highly social species that uses echolocation clicks for navigation and a diverse repertoire of social calls to communicate internal states. We combined behavioral assays, extracellular electrophysiology, and heart rate monitoring to investigate how the bat brain processes these vocalizations. Behaviorally, bats showed differential responses to playbacks of distress calls, aggression calls, and echolocation clicks. To examine the neural substrates of these responses, we recorded from the auditory cortex (A1) of awake, passively listening bats. Our results show that A1 neurons exhibit distinct selectivity for different call categories. Additionally, heart rate responses varied with call type, suggesting autonomic modulation during social sound processing. Importantly, we found that social context influences action selection, pointing to an integration of sensory and contextual

information during vocal communication. This work advances our understanding of how mammalian auditory circuits encode socially relevant sounds and contributes to a comparative framework for studying communication across species.

Computational sensorimotor control | Wednesday, July 29 **|** 15:15 – 15:30

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Experience-dependent sensory representations in the amphibian brain

Animals must integrate sensory stimuli with contextual cues to select an appropriate behavioral output. In mammals, this integration is carried out in the cerebral cortex, where sensory inputs are processed hierarchically in molecularly distinct regions before being integrated with other modalities and contextual cues in multimodal areas. While this cortical architecture has been extensively studied, its evolutionary origins remain unclear. To better understand the evolution of sensory integration in vertebrates, we sought to determine how experience-dependent sensory information of different modalities is represented in the amphibian brain. The salamander brain is a relatively simple structure in which the cortical pallium, as in mammals, receives thalamic input and contains distinct molecularly heterogeneous regions, making it a well-suited system for studying the ancestral organization of sensory integration. We first show that salamanders exhibit context-dependent behavioral responses to sensory cues, depending on feeding state. When fed, salamanders will snap at moving objects that do not elicit behavioral responses in unfed animals, indicating that context and internal state can modulate sensory-driven behavior. To examine experience-dependent sensory responses in the brain, we developed a transgenic salamander line with pan-neuronal GCaMP expression and a wide field calcium imaging approach that allows us to image simultaneously the entire pallium, thalamus and midbrain. We presented visual, olfactory, auditory, and somatosensory stimuli to awake, behaving animals and recorded brain wide responses and behavior. This sensory mapping revealed spatially and temporally distinct responses across molecularly defined brain regions. Our data suggest a hierarchical processing of sensory information in which the midbrain encodes stimuli in a modality-dependent manner whereas the pallium contains multimodal sensory regions that respond in a context-dependent manner. We propose that the amphibian pallium may serve as an integration hub upon which multimodal sensory inputs and contextual cues converge. Moving forward, we will manipulate behavioral state by feeding animals prior to sensory stimulation during imaging to determine how internal state shapes brain wide sensory responses.

Developmental plasticity & evolution | Tuesday, July 28 **|** 15:00 – 15:15

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Alternative androgen-signaling pathways underly mating behavior across five male morphs

Alternative male phenotypes are often thought to reflect quantitative differences in androgen signaling, with more aggressive morphs having stronger androgenic effects and sneaker morphs having weaker ones. We tested this model in *Poecilia parae*, a vertebrate with five discrete male morphs that differ dramatically in reproductive behavior, body form, and coloration. By selectively blocking androgen receptor (AR) signaling in the brain versus the periphery, we found that the central and peripheral control of mating behavior differs fundamentally among morphs. Sexual behavior in the aggressive *parae* morph required central AR signaling, whereas sexual behavior in the melanzona morphs depended primarily on peripheral AR signaling. In contrast, sexual behavior in the sneaker immaculata morph was largely insensitive to AR inhibition. These morph-specific behavioral responses did not correspond to differences in circulating androgen levels or AR expression, both of which were broadly similar across male morphs. However, RNA-seq after AR inhibition revealed that the transcriptional consequences of androgen signaling were dramatically different among morphs, with distinct sets of androgen-responsive genes and co-expression modules in brain and muscle. Our results suggest that the genomic targets of endocrine signaling can differ within a species, thereby generating stable alternative reproductive phenotypes despite equal hormone abundance. This identifies divergence in steroid-responsive gene regulation as a powerful mechanism underlying intrasexual diversity.

S15.1 | 11:00 – 11:20 | Friday, July 31

Animal architecture

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Collective, coordinated construction in mound-building termites

Termites collectively construct a wide variety of complex structures through the coordination of their activities. Mound-building termites, in particular, represent an especially compelling system, as they build massive above-ground mounds that emerge from the coordinated efforts of thousands of workers. These mounds house the entire colony, including the queen and king, as well as soldiers, major and minor workers, and alate reproductives. In many species, the colony also cultivates a symbiotic Termitomyces fungus, which aids in the digestion of plant material. The mound architecture is thought to play critical roles in thermoregulation and in maintaining the high humidity levels required for sustaining this fungal culture. In most mound-building species, both the workers responsible for construction and the soldiers that defend the colony lack image-forming eyes. As a result, communication during construction is primarily mediated through pheromonal cues deposited in the soil, a process referred to as stigmergy. Because maintaining mound integrity is essential for colony survival, termites have evolved mechanisms to detect and repair structural breaches. What sensory and behavioral mechanisms underlie these processes remains a central question. To address this, we have developed a series of behavioral assays in *Odontotermes obesus*, a mound-building species abundant in peninsular India. Using this system, we investigated how termites detect and repair breaches in their mounds and how they communicate chemically during these processes. Our results show that termites can reliably identify soil that has been previously processed by conspecifics and can further discriminate between their own mound and those constructed by other colonies of the same species. Together, these findings reveal a layered chemical coding system that underlies communication during stigmergic construction.

Modulation of social behavior | Friday, July 31 **|** 16:00 – 16:15

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Conserved and sex-variable circuits modulating aggression in *Drosophila*

Aggression is conserved across species, but the sensory contexts driving it can differ across sexes, suggesting both shared and sex-variable circuit logic. In *Drosophila melanogaster*, prior work using the two female connectomic datasets has implicated several isomorphic and sexually dimorphic cell types in guiding the approach, engagement, and continuation of female aggression (Palavicino-Maggio et al., 2019; Schretter et al., 2020; Deutsch et al., 2020; Chiu et al., 2021; Chiu et al., 2025; Schretter et al., 2025). However, relatively little is known about the circuitry that downregulates aggression, and whether aspects of this aggression promoting and suppressing circuitry is shared or divergent across sexes. The recent completion of the male CNS dataset now makes both questions directly tractable.

Using the female connectomes alongside the recently completed male dataset, we mapped a sexually dimorphic aggression-promoting cell type, aIPg, across sexes. We first uncovered a novel glutamatergic cell type that downregulates aggression across sexes. While we identified remarkable conserved function for select neurons in females and males, additional connectomic analysis has identified divergent sensory inputs across sexes that mirror known variability in environmental contributions. Our results reveal how conserved circuit architecture may generate sex-variable behavior through divergent inputs.

3D navigation & spatial cognition | Friday, July 31 **|** 15:15 – 15:30

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How three-dimensional position and head-directions are encoded in the goldfish brain?

Fish, like many other animals, navigate to ensure survival. The ability to navigate is based, in part, on the encoding of spatial information regarding the environment and the position and orientation of the animal in space. Previous studies have identified the fish telencephalon's involvement in navigation, while findings from goldfish electrophysiology demonstrate the existence of spatial encoding cells in this region. These studies utilized quasi-2-dimensional experimental environments and found several cell types that represent aspects of space and kinematics. However, fish in nature explore 3-dimensional environments, hence there is a gap between environments used in the lab and the natural habitat. We address this gap by exploring and characterizing how 3-dimensional position and head directions are encoded in the goldfish brain. We used wireless electrophysiology system to record neural activity from single cells in the goldfish telencephalon, while tracking the fish' position and orientation during free exploration of a three-dimensional cubic water tank. We have identified various patterns of place encoding and head directions cells. These cells exhibit complex patterns unlike the patterns discovered in other vertebrates. These results expand our current understanding of how fish navigate in three-dimensional environments and the neurobiology of navigation across vertebrates.

Chemosensory-guided behavior | Friday, July 31 **|** 15:00 – 15:15

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Adaptive behavioral modulation mechanism for pheromone source localization with antennal loss in adult male silkmoth, *Bombyx mori*

Odor-source localization is a fundamental behavioral capability essential for survival-related activities such as mate searching and foraging. Insects, despite possessing compact neural systems, exhibit remarkably robust olfactory navigation even in turbulent environments and under physical impairment. Notably, many species retain localization performance following damage to their antennae--the primary olfactory organs--by exploiting remaining sensory resources. However, the adaptive behavioral mechanisms enabling such resilience remain insufficiently understood. This study investigates behavioral modulation induced by antennal loss during pheromone-source localization in adult male silkmoths, *Bombyx mori*, and functionally validates the identified mechanisms through a constructive approach. Free-walking experiments compared intact individuals with moths subjected to unilateral antennal ablation. Although impaired individuals showed a slight reduction in success rate, overall localization capability was largely preserved. Trajectory analyses revealed systematic alterations in navigational strategies rather than simple performance degradation. Using a tethered behavioral measurement system, we quantified stimulus-response relationships under controlled odor presentation. Results demonstrated that behavioral selection probabilities were dynamically modulated by interactions between odor reception along the remaining antenna and locomotor direction. Antennally impaired moths exhibited more bilaterally balanced turning responses, suggesting compensatory enlargement of whole-body movements to reconstruct spatial odor information. Based on these findings, an insect-inspired computational model that switches navigation strategies according to sensory states was implemented on a quadrupedal robotic platform. Robotic experiments confirmed that adaptive behavioral modulation maintained localization efficiency under simulated sensor deficiency, outperforming conventional symmetric-sensing frameworks. This suggests that this is a behavioral compensation function that is exerted when sensory information cannot be acquired properly.

Computational sensorimotor control | Wednesday, July 29 **|** 15:45 – 16:00

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Representing cuttlefish camouflage patterns

Dwarf cuttlefish are masters of camouflage. To camouflage, the cuttlefish brain must solve a hard computational problem: it must encode the visual environment, compute an appropriate body pattern, and orchestrate the expansion and contraction of roughly half a million pigment-filled sacs, known as chromatophores, to produce that pattern. How the brain accomplishes this remains unknown. We hypothesize that cuttlefish camouflage relies on a low-dimensional representation of the visual world from which appropriate skin patterns are generated. A central open question is what is this representation. We observe that both cuttlefish skin patterns and the backgrounds they match are often visual textures. Visual textures are images that are spatially homogeneous with repeated structure and

typically some random variation. Textures are notable because they can be represented compactly by a relatively small set of summary statistics (Portilla & Simoncelli, 2000). Here, we test the hypothesis that the cuttlefish brain encodes the visual world through these texture statistics and uses this representation to generate camouflage. First, using texture synthesis methods, we show that many cuttlefish skin patterns can be well captured by these statistics. We then develop a behavioral paradigm that reliably elicits camouflage in freely behaving dwarf cuttlefish and present a broad range of visual stimuli in the lab. We find that camouflage can be quantified using a metric based on texture statistics, and that these statistics capture changes in cuttlefish body patterns better than several alternative large-scale image representations. Finally, we show that these same statistics can be used to generate images that effectively camouflage a simulated cuttlefish. Together, these results support the idea that texture statistics may link visual input to camouflage output. This work is a first step toward identifying the neural algorithm underlying cuttlefish camouflage by constraining both how the visual world is encoded and how skin patterns are generated.

S14.2 **|** 11:20 – 11:40 **|** Friday, July 31

Periphery is key: adaptations to natural scenes in the visual periphery of arthropods & vertebrates

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Natural stimuli drive functional temporal diversity in the fly optic lobe

Visual systems extract increasingly complex features from their input. Visual circuits initially process luminance, ON and OFF contrast, and become increasingly more specialized to respond to motion in certain directions, or specific types of objects. This sequential feature extraction is organized across visual hierarchies, and at each level of hierarchy, distinct cell types again respond to distinct stimulus features. The principles underlying the (developmental and evolutionary) emergence of cell type diversity at each level of hierarchy as well as across network hierarchies remains poorly understood. Focusing on the early visual pathways of *Drosophila melanogaster*, we will discuss how feature extraction is shaped by distinct molecular programs. While a single transcription factor establishes early feature specialization in the visual system, contrast vs. luminance sensitivity, the downstream molecular components are degenerate. We will next examine the evolutionary principles that shape temporal diversity, which is key for motion detection, at both the single-neuron and network levels. We first describe temporal responses of visual system neurons within a common feature space and use a statistical description of natural motion to construct an efficient coding framework for peripheral visual hierarchies. Overall, our work shows that splitting the visual pathway into parallel temporal channels, defined by different molecular programs, specifically enhances the encoding of naturalistic dynamic inputs. Remarkably, predictions at both neuronal and circuit levels align with experimental observations in the peripheral fly eye, highlighting the central role of natural motion statistics in driving the emergence and fine-tuning of temporal properties within the motion detection pathway. Together, the work presented here will highlight how developmental and evolutionary processes shape neural processing strategies that are tuned natural stimulus statistics.

Urban stressors & adaptation | Monday, July 27 | 16:00 – 16:15

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The great frog hunt: how urban noise shapes host-seeking in a frog-biting mosquito

A major challenge animals face arises when background noise exceeds biologically relevant signals, a problem that is becoming increasingly common with the rise of anthropogenic sources such as road traffic. Many animals with tympanic ears have evolved strategies to detect important signals under noisy conditions. In contrast, the extent to which insects with flagellar ears are affected by elevated background noise remains largely unknown. In this study, we focused on *Uranotaenia lowii*, a unique species of mosquito that relies on auditory cues to locate anuran hosts, to examine how they are impacted by traffic noise and the strategies they use to overcome it. One mechanism that could allow *U. lowii* to overcome noise is Spatial Release from Masking (SRM), a phenomenon where listeners can detect sounds when they originate from different spatial locations than competing background noise. We hypothesized that these frog-biting mosquitoes are affected by noise and use SRM to improve their ability to detect frog calls. To test this, we performed electrophysiological and behavioral experiments using road traffic noise and frog calls to determine how *U. lowii* females respond. We used speakers broadcasting frog calls and traffic noise from spatially distinct directions. In the behavioral experiment, a live barking treefrog (*Dryophytes gratiosus*) was paired with the speaker broadcasting frog calls to examine mosquito responses under noisy conditions. We quantified mosquito behavioral responses and latency to respond to assess their ability to locate frog hosts when background noise originates from the same or different location as the frog call. Equivalent experiments varying the relative position of noise and target signal were performed to examine the electrophysiological response at the antennal nerve. Investigating how *U. lowii* responds to noise and identifying the mechanisms that support auditory function using flagellar ears under noisy conditions deepens our knowledge of hearing systems and can enhance our understanding of how urbanization influences species interactions.

S9.5 | 12:15 – 12:30 | Thursday, July 30

Peripheral circuits that shape descending commands to modulate motor programs

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Modulating a precisely timed, spiking motor program for flight

Agile animals must parse complex sensory environments to extract actionable features relevant to behavior. The central nervous system must also translate this perception into the animal's motor program—a set of temporally coordinated spike patterns across multiple muscles that mediate movement. In the hawkmoth *Manduca sexta*, we can record a nearly complete, spike-resolved motor program, capturing almost every action potential from all muscles that control wing movement. Using this combination of completeness, resolution, and rich behavior, we have shown that most control is achieved with precisely coordinated spike timing patterns. Neural circuits must orchestrate millisecond scale shifts in spikes across almost all muscles to achieve even simple turns. We next combine our comprehensive motor program recordings with simultaneous multi-electrode array recordings from the neck connective to ask how spike precision and representations of

sensory cures are integrated into motor action. The descending connective of invertebrates is often hypothesized to carry task-level representations of essential visual features tuned to an animal's behavior and ecology. In *Manduca*, neck connective neurons demonstrate rate encoding of flower-like visual objects and some are selective for narrow vertical objects like those present in floral guides on flowers. However, individual neurons' rate codes are unlikely resolved enough to mediate rapid flight maneuvers. Using neural-network based estimators of mutual information, we show that spike timing precision is typically about 2 to 15 ms in all recorded descending and ascending units in the neck connective. A few units approach the 0.5 to 2 ms precision of peripheral motor units, but spike timing precision is greater in the periphery. This suggests that motor commands may be distributed across many neck connective neurons and mapped through thoracic circuits into a more precise spike timing code.

Vision-guided behavior camouflage | Wednesday, July 29 **|** 15:45 – 16:00

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Insight into harbor seals (*Phoca vitulina*) sensory processing using electroencephalography

Harbor seals are confronted with various challenges when leaving haul out places to navigate the open sea during foraging trips. These challenges include the transition from the terrestrial to the aquatic environment, the rather featureless environment above and underwater as well as low ambient light. During evolution, harbor seals have adapted to these challenges by developing specialized sensory organs and probably also specific corresponding brain structures. While many aspects of sensory perception of harbor seals have already been described in behavioral experiments or through analyses of the sensory organs, little is known about the neuronal correlates of sensory perception. To understand these neuronal correlates, it is necessary to investigate the neural activity - alongside with neuroanatomy, while the harbor seal is perceiving sensory stimuli. To measure brain activity in real time, we established non-invasive electroencephalography (EEG) measurements with three trained harbor seals. We acquired the cortical visual responses with the g.USBamp biosignal amplifier and six active gold-pin scalp electrodes positioned in the area of the visual cortex as deduced from neuroanatomical findings. We recorded steady-state visual evoked potentials (SSVEPs) using full field visual stimuli flickering at 5-20 Hz with 5 Hz increments. We reliably measured frequency specific SSVEPs in all harbor seals, with strongest responses at flicker frequencies of 5 and 10 Hz. The response strength decreased at 15 Hz and 20 Hz, likely because temporal sensitivity decreases as the flicker rate approaches the critical flicker fusion frequency. We demonstrate, for the first time, that non-invasive EEG can be successfully used to measure brain activity in an awake, cooperating pinniped. In the future, EEG has the potential for advancing marine mammal neuroscience. It could be used to measure event-related potentials, i.e. voltage changes that coincide with presentation of a visual cue, to evaluate cognitive functions during decision-making processes.

Urban stressors & adaptation | Monday, July 27 **|** 15:30 – 15:45

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Sense and scentability: a perceptual model indicates air pollution-induced shifts in honeybee floral-scent recognition

Air pollution threatens pollination by degrading floral odors essential for attracting pollinators. This study explores the utility of the Compounds Without Borders method, which quantifies odor changes using molecular features, as a tool for understanding how pollutants like ozone affect scent perception. We identified a pollution-degradation threshold as quantified by Compounds Without Borders by analyzing published datasets on honeybee proboscis extension responses to pollution-modified *Brassica* odors: odors degraded beyond 10 degrees show decreased response rates. Application of Compounds Without Borders analysis to different plant scent profiles indicates the scents of some species (canola) are vulnerable to air pollution, while others (apple) are resilient. Our results support the utility of Compounds Without Borders to assess the effects of air pollution on honeybee olfaction, offering a predictive tool and establishing a foundation to build a model that could be used to safeguard pollination services against the growing threat of air pollution and other environmental stressors.

Vision-guided behavior camouflage | Wednesday, July 29 **|** 15:15 – 15:30

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From night stalkers to day walkers: diurnal foraging in a nocturnal predator, the ogre-faced spider

Animals benefit from possessing sensory systems well-suited to their environmental niche. However, the enhancement of a sensory system to perform well in a specific niche may come at the cost of performance in other niches. For example, nocturnal animals with visual systems adapted for dim light environments may struggle to perform well in bright day light. A textbook example of this is the ogre-faced spider (*Asianopis subrufa*). Pioneering work by Blest, Land, and colleagues first illustrated the supreme sensitivity of ogre-faced spider eyes, while also documenting a daily cycle in retinal morphology and physiology, where photoreceptors degrade at sunrise and resynthesize at sunset. These circadian sensory alterations match activity patterns of predatory behavior, where *A. subrufa* transform into motionless stick-mimics during daylight hours, only becoming active hunters following sunset. Unsurprisingly, the ogre-faced spider has been a posterchild for visually mediated nocturnal behavior. Here, contrary to foundational work, I show present-day *A. subrufua* are facultatively diurnal in foraging behavior. First, I report the frequency and ecological correlates of diurnal foraging in natural populations. I then show the effects of diet and lighting environment on the propensity for *A. subrufa* to forage during the day. Next, I compare physiological and behavioral thresholds of predatory behavior between diurnally and nocturnally active spiders. Taken together, I present a foundational understanding of the causes and consequences of this shift away from strict nocturnality to facultatively diurnal behavior and sensory ecology.

S10.5 | 12:15 – 12:30 | Thursday, July 30

Brains in the wild B

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How weakly electric fish sense musical intervals

Weakly electric fish are a powerful model organism for studying principles of sensory processing on a cellular level in the lab. Recent hardware and software developments allow us to observe natural social interactions by tracking these nocturnal fish in their neotropical habitats solely based on their continuous electric organ discharges (EOD). In some of these field recordings we found that courting pairs of *Apteronotus rostratus* synchronize the frequencies of their sinusoidal EODs to form ratios at or near musical intervals, such as the "perfect fifth" (f1/f0 = 3/2). Although electrosensory afferents share many properties with mammalian auditory nerve fibers, fish do not resolve frequencies in distinct frequency bands as the mammalian cochlea does. How are these fish able to distinguish musical intervals from other frequency ratios?

A threshold-nonlinearity, like the transfer function of the electroreceptor/hair cell synapse onto its afferent, is required to extract amplitude modulations (AMs) from superimposed sinusoidal EODs/tones. Near musical intervals, this nonlinearity also generates additional low-frequency components that modulate the strong beating AM. This is perceived as "roughness" by humans. We propose that these low-frequency components are exploited by the electrosensory system to efficiently represent complex periodic stimuli. Simulations of modified LIF models and electrophysiological recordings demonstrate that these low-frequency components are well represented. We also find behavioral responses close to musical intervals that further support the relevance of these low frequencies in electrosensory processing. By integrating electrophysiology with further field work, we aim to elucidate the behavioral relevance of musical intervals in weakly electric fish. This work may reveal fundamental neural mechanisms by which periodic signals are transformed and represented, providing insight into musical interval perception in both fish and humans.

S14.4 | 12:00 – 12:15 | Friday, July 31

Periphery is key: adaptations to natural scenes in the visual periphery of arthropods & vertebrates

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Information processing beyond the retina of mantis shrimp

Stomatopods have the most complex retina described, with over 20 different types of photoreceptors between the different eye regions. These photoreceptors project to the lamina, the first optic neuropil, and connect to multiple first-order interneurons to begin processing the large amount of retinal information. Using serial block-face scanning electron microscopy, we reconstructed photoreceptor terminals and lamina interneurons in two major superfamilies with different visual ecologies. The overall connectivity pattern in all lamina cartridges across species and eye regions is consistent in the photoreceptor termination pattern as well as the relative location and branching of the major lamina monopolar cells, which create two layers corresponding to opposing visual input. These layers may represent the beginning of an opponency circuit in this neuropil. This separation is seen in other crustaceans but not in insects, where color opponent processing likely begins in the medulla. Interneurons that extend beyond their parent cartridge in the midband show a tendency to branch between rows within the same visual column of cells, as well as some connections within the same row. The inter-row connectivity supports the hypothesis that these animals use the specialized midband during scanning behavior, which is unique to these animals.

S12.3 | 11:40 – 12:00 | Thursday, July 30

The neuroscience of emotion

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Limbic circuits regulating cultural behaviours in songbirds

Songbirds have the ability to imitate complex vocal sequences called songs from other individuals and transmit these unique songs across generations, similar to cultural transmission in humans. Emotion is often involved in appreciating, performing, and transmitting cultural behaviors, yet the precise mechanisms linking emotion and cultural behaviors remain to be elucidated. We are exploring how avian limbic circuits, specifically the amygdala and nucleus accumbens of a songbird species, the zebra finch, may play roles in cultural behaviors. Results suggest that the amygdala regulates social motivation toward potential tutors, facilitating selective imitation of a specific tutor's song. The amygdala projects to the nucleus accumbens, which receives dopaminergic projection preferentially from the ventral tegmental area. Disrupting the dopaminergic signaling in the nucleus accumbens appears to diminish preferences to certain songs. These results begin to elucidate how cultural transmission and preferences are regulated by limbic circuits, which are known to play important roles in emotional processing in mammals.

Principles of communication in social groups: from behavior to neuron

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Social and cognitive evolution of individual face recognition in wasps

In many taxa, social interactions rely, in part, on individual face recognition. This ability is not only socially beneficial, it is also considered cognitively challenging. This has led some to theorize that the ability to recognize individuals and track individual social relationships has played a key role in the evolution of enhanced cognitive abilities. *Polistes fuscatus* wasps have sophisticated individual face recognition abilities and also use specialized, configural mechanisms to identify individuals. I will describe experiments that take advantage of natural variation in individual face recognition within and among *Polistes* wasp species to test how social interactions influence the evolution and development of individual face recognition. I will also discuss recent experiments using microCT imaging to assess how intraspecific variation in cognitive performance is linked with *Polistes* neuroanatomy.

S8.3 | 11:40 – 12:00 | Wednesday, July 29

Neurosustainability: how brain science is revolutionizing environmental design and policy

Tresguerres, Martin, University of California San Diego, USA

A roadmap to integrate neurobiology in changing oceans into environmental science

Marine animals face unprecedented environmental change, yet the neurobiological mechanisms underlying their responses remain poorly understood. Many species evolved in naturally fluctuating environments, making it essential to understand how nervous systems function under these conditions when interpreting responses to anthropogenic warming, hypoxia, acidification, and other stressors. Because nervous systems integrate sensory inputs with physiology and behavior, uncovering how they operate across environmental variability is critical for predicting resilience and vulnerability. We outline a transdisciplinary framework integrating genomics, neurophysiology, behavior, and environmental monitoring across laboratory and field settings. To promote research on neurobiology in changing environments worldwide, we are developing transdisciplinary training activities that integrate neuroscience, physiology, ecology, engineering, and AI through collaborative research, workshops, and cross-disciplinary mentorship. We are also creating a public exhibit at Birch Aquarium that will communicate how changing environments shape animal nervous systems and why this knowledge matters for ocean conservation. Generating high-quality mechanistic data from diverse organisms is essential to constrain and inform emerging artificial intelligence approaches, enabling environmental research to move beyond documenting impacts toward predicting biological responses. This vision requires deploying high-resolution molecular and cellular approaches directly in natural environments, where experimental control, sample integrity, and environmental complexity demand integrative solutions across disciplines.

Developmental plasticity & evolution | Tuesday, July 28 | 15:15 – 15:30

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Early life predation stress leads to long term changes in behavioral and neural trajectories

Undergoing stressful stimuli during early life can lead to long term changes in brain development and behavior, and a key goal is to understand the mechanisms generating such durable change. However, separating the impact of an individual's environment from their genetic makeup can be challenging in sexually reproducing organisms. The Amazon molly (*Poecilia formosa*), a naturally clonal fish, provides a useful system for analyzing how an individual's phenotype develops, as it allows for the standardization of both environment and genetics. We divided newborn fish into two groups: a control group which received no predator cues, and a treatment group which received chronic olfactory predator cues for the first month of their lives. Nine months later, in adulthood, we measured behavior under a neutral context and after individuals were (re)exposed to predator chemical cues coupled with a model predator. We then used pS6 neural activation to identify which brain regions were differentially activated between groups. We found that early life predation stress leads

to inducible behavioral differences; fish reared with predation exposure do not behave differently under a neutral context, but when exposed to the acute predator threat, they show a more active antipredator strategy. These behavioral differences are reflected in neural activation patterns: predator cue reared fish show decreased activation in brain regions associated with the integration of early life stress, sensory processing, and memory when compared to fish reared under control conditions. Further, predator cue reared fish show increased activation of the hypothalamic-pituitary-interrenal axis (HPI), seen through a coordinated increase in activation of brain regions associated with the stress response as well as positive correlations between these brain regions and more active antipredator behaviors. Our results show that early life predation stress can have strong, organizational effects on behavioral and neural trajectories, leading to different perceptions of an acute threat in adulthood.

Active sensing & sensorimotor gating | Thursday, July 30 **|** 15:30 – 15:45

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Neural control of respiration in *Drosophila*

Breathing is one of the most fundamental motor behaviors of terrestrial animals, yet the neural mechanisms that dynamically match respiration to metabolic demand remain poorly understood. Insects regulate gas exchange through spiracles: valve-like openings in the cuticle that open during flight to supply oxygen while minimizing water loss. Using high-speed video in *Drosophila*, we show that spiracle aperture is dynamically regulated by flight power and desiccation state. Optogenetic activation of spiracle motor neurons closes spiracles and rapidly reduces flight power, while silencing opens them. Extracellular recordings reveal that spiracle closure impairs flight through both reduced neural drive and oxygen deprivation in the flight muscles. We identify a class of GABAergic interneurons that are downstream of flight-correlated descending neurons and required to match spiracle aperture to metabolic demand. We also identify a parallel interoceptive pathway that is positioned to close spiracles based on hydration state. Our results reveal a circuit in which feedforward descending commands couple flight power to spiracle opening, while an interoceptive pathway constrains opening to balance oxygen supply against water loss. This compact circuit architecture - feedforward coupling of locomotor commands to respiratory output, modulated by interoceptive feedback - may reflect a general solution to the problem of matching breathing to movement across species.

S6.1 **|** 11:00 – 11:20 **|** Wednesday, July 29

Brains in the wild A

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Neuroethology of navigation in the wild: place cells and head-direction cells in bats navigating outdoors on a remote oceanic island

Place cells and head-direction cells in the hippocampus and surrounding brain structures are thought to provide map and compass information for navigation. These neurons were studied for many years in animals navigating in small laboratory environments – but never in the wild. Here we provide the first report, in any species, on neural recordings of place cells and head-direction cells in the real world, outdoors. We wirelessly recorded the activity of these neurons in Egyptian fruit bats navigating outdoors on a remote oceanic island near Zanzibar. These experiments revealed head-direction cells and place cells outdoors. The head-direction cells were stable across the geographical extent of the island, and were stable despite the movement of celestial cues such as moon and stars – suggesting that these neurons can indeed serve as reliable neural compasses for navigation. Place cells exhibited clear spatial tuning, with some neurons showing a single place-field and others showing multiple fields. We recorded large ensembles of 100-200 hippocampal neurons simultaneously in the bats as they were navigating outdoors on the island, and these ensemble recordings allowed us to characterize neural population manifolds – which showed surprising differences between outdoors and indoors navigation. Overall, these experiments highlight the importance of taking neural recordings out to the real world.

S3.5 | 12:15 – 12:30 | Tuesday, July 28

Evolution of sleep: a comparative perspective to unravel the biological function of sleep?

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Rapid iris movements during REM sleep in pigeons: a new window into the sleeping brain

Birds, like mammals, express two major types of sleep, rapid-eye-movement (REM) and non-REM sleep, distinguished from one another by behavior and brain activity. Although several features of avian sleep are remarkably similar to their mammalian counterparts, the avian pupil behaves in an opposite manner to that of mammals across wakefulness and sleep. Birds' pupils constrict during aroused states such as courtship, remain dilated during non-REM sleep, and rapidly constrict during REM sleep.

What accounts for the opposite avian pupillary behavior and what might it reveal about the functions of sleep? A key anatomical difference lies in the iris: in birds it is composed of striated muscle, whereas in mammals it consists of smooth muscle. Nevertheless, both avian and mammalian pupils receive parasympathetic input and respond to acetylcholine, though through different receptor types—nicotinic in birds and muscarinic in mammals. While the presence of striated muscle may explain the rapid dynamics of avian pupil constrictions, it cannot account for their opposite behavioral pattern.

Instead, I propose that downstream parasympathetic pathways have been recruited by pallial circuits, enabling birds to exert voluntary control over their striated iris muscles for social signaling during courtship and aggressive interactions. Within this framework, the rapid pupil constrictions observed during REM sleep represent a form of motor twitching analogous to that seen in other striated skeletal muscles. These events could also reflect moments of neural reactivation and memory processing.

Using whole-brain imaging in pigeons, I aim to identify the neural networks associated with these REM-linked pupil constrictions, providing a novel window into the dynamics of the sleeping avian brain.

Sensory learning & decision-making | Monday, July 27 | 15:15 – 15:30

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Olfactory gating of wavelength-dependent visual memory in *Aedes aegypti*

Mosquitoes rely on multisensory integration to navigate their environment, using both olfactory and visual stimuli to locate hosts, nectar, and oviposition sites. While *Aedes aegypti* display innate wavelength preferences and can learn to avoid host-associated odors, their capacity for visual and multimodal learning remains poorly understood. Here, using a forward-paired aversive classical conditioning paradigm, we establish that visual memory in *A. aegypti* shows 24-hour retention and is olfactory-gated and wavelength dependent, providing the first behavioral and genetic evidence for wavelength-dependent visual learning in mosquitoes. Specifically, mosquitoes do not form visual memories in the absence of olfactory cues, identifying odor input as a requirement for visual learning. Congruent bimodal training and testing significantly enhance learning, but this effect depends on the wavelength of the visual stimulus. We further examined how the intensity of visual stimuli interacts with wavelength to influence learning, finding that while intensity plays a role, wavelength remains a key determinant of learning outcomes. Consistent with these behavioral dependencies, learning is strongly reduced in Orco (olfactory) and opsin (op1/op2 and op9) knockout mutant lines, suggesting that olfactory input and opsin-dependent wavelength sensitivity are necessary for visual memory formation. Furthermore, while bimodal training strengthens visual memory, this effect does not extend to olfactory memory, revealing an asymmetry in how these modalities interact during learning. Together, these findings provide novel evidence that olfactory input gates visual memory formation in mosquitoes and that wavelength shapes the effectiveness of bimodal learning.

Urban stressors & adaptation | Monday, July 27 **|** 15:45 – 16:00

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Do behavioral and physiological hearing thresholds vary among urban and rural soundscapes?

Population growth, urban expansion, and mounting transportation networks continuously contribute to increases in levels of anthropogenic noise, altering natural soundscapes and affecting species that communicate acoustically. Several studies have shown how vocal signals change in response to increasing levels of anthropogenic noise. Recent reviews propose that the major gap in the field is our lack of understanding of how sensory-processing mechanisms, particularly the ability to extract signals from noise, are changing in urban soundscapes. In this study of Cope's gray treefrogs (*Hyla chrysoscelis*), we asked whether the ability to detect and respond to communication signals varies among populations exposed to different levels of natural and anthropogenic noise. In the absence and presence of broadband noise broadcast at two levels, we (i) measured behavioral signal recognition thresholds (SRTs) using female phonotactic response to male calls, and (ii) recorded auditory brainstem responses (ABRs) to obtain thresholds for elements of male calls. Our results suggest that, in quiet conditions, SRTs and ABR thresholds are higher in subjects from noisier, urban sites, than in subjects from quieter, rural sites. Differences in SRTs and ABRs across sites, however, are reduced when obtained in the presence of background noise. Together, our results suggest that hearing differences associated with ambient noise levels improve the signal-to-noise ratio by filtering out noise in frequencies important for communication. Future research should focus on the underlying mechanisms of these differences in peripheral auditory sensitivity.

Acoustics & sensory mechanics | Monday, July 27 **|** 15:15 – 15:30

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Seeking dances in darkness: vibro-acoustic communication of the dance signal in honeybees

Honeybees communicate resource location through waggle dances, which are primarily vibroacoustic, olfactory and gustatory signals. Despite being a well-studied behavior, some aspects of dance communication are still a mystery. Dance communication appears to be a two-step process: a dancer first attracts nestmates to her, and then, transmits the spatial information encoded as wing-beat sounds. While we have some understanding of the latter half, the first step, i.e. attraction, is not understood. Are bees attracted by the dance sound, or are substrate vibrations the key to long-distance communication? We first looked at the efficacy of sound in long-range detection of dances. Bees 'hear' when rapidly moving air particles deflect their antennae. Air particle velocity, however, decays to noise-equivalent levels at very short distances (~10-3 m). Indeed, we measured the sound field around a vibrating honeybee wing and found that the particle velocity emanating from the wings decays rapidly over 10-20 mm (approximately one body length). In silico models of the wing-air-antenna interaction further showed that the force experienced by the antenna shows a similar distance-dependent decay. Some insects possess actively amplified hearing to perceive low-amplitude signals. However, our measurements show no evidence of active amplification in honeybee antennae. Since we found acoustic long-distance communication improbable, we explored vibration transmission along the honeycomb. We measured vibration transmission from combs to the legs of live honeybees, and found that legs move in response to naturalistic vibration levels on the comb. We find that comb vibrations remain perceptible for greater distances than the sound field. Thus, vibrations appear to act as the primary long-distance cue of the dance signal. Our findings present strong evidence that long-distance dance detection by honeybees occurs through substrate vibrations and not through the dance sound.

S6.4 | 12:00 – 12:15 | Wednesday, July 29

Brains in the wild A

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Mice navigate using sparse sets of repeated path motifs

Navigation is a central aspect of behavior, but how rodents navigate complex natural environments is unknown. Here, we investigate mouse navigation without explicit rewards in an outdoor environment, and in an artificial self-similar arena that is too complex to easily memorize. After initially surveying the arena, mice converged on a sparse set of paths that they then slowly modified over several days. Stable path repetitions suggest that mice maintain a working memory of which path they are executing over seconds. The set of paths used by mice is maintained across days and changes globally after local modifications of the arena, suggesting that paths act as extended mental objects, independent of immediate sensory cues. These results show that mice navigate complex environments by iteratively building and refining sparse sets of navigation motifs.

S16.2 | 11:20 – 11:40 | Friday, July 31

Orientation across modalities

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Exploration dynamics enable path integration in predictive electrosensory learning

Many animals navigate environments to find resources, avoid predators, and locate shelter. To do so, they integrate sensory information to construct internal representations that guide spatial orientation and goal-directed movement. Theoretical work has shown that such spatial representations can emerge in recurrent networks performing sensorimotor prediction.

In many contexts, however, navigation occurs under conditions in which sensory information is sparse, ambiguous, or restricted in range, such as darkness, turbid water, or the open ocean. Under these conditions, animals must rely heavily on path integration, updating their position by integrating self-motion cues to estimate location relative to places where reliable sensory information was last encountered. How path integration emerges from neural circuit dynamics remains poorly understood.

Weakly electric fish provide a useful model for studying navigation under such constraints, as they rely on a short-range active electrosense to detect objects and landmarks while moving through complex environments.

To investigate this, we implemented a predictive sensorimotor learning model in which sensing was constrained to mimic short-range electrosensory input. We show that such models fail to track the animal's position when reliable sensory input is absent. However, spatial representations reemerge when such models are trained using a variable-lag exploration strategy. This suggests that exploration dynamics may play a key role in the emergence and maintenance of path integration in neural networks. Consistent with this hypothesis, we show that the exploratory behavior of electric fish navigating in a large arena varies systematically under different sensory constraints. Together, these results suggest that exploration strategies may enable path integration when sensory information is limited and highlight how interactions between sensing and behavior shape the emergence of spatial representations in neural systems.

Arthropod locomotion & motor programs | Tuesday, July 28 | 16:00 – 16:15

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Watch your tongue: lateralized visuo-motor control guides hawkmoth proboscis probing

Lateralization of behaviour, including motor control and sensory processing, is widespread across bilaterians. A well-studied example is visual appendage control, which often aligns appendage and target in a shared reference frame, forming a lateralized visuo-motor axis. However, it remains unresolved whether visual or motor asymmetries independently drive such control, or if they reflect an integrated sensory-motor strategy. Moreover, evidence for this control axis is currently limited to vertebrates, as in primates and birds, leaving unclear whether such sensory-motor organization extends to invertebrates. While insects serve as ideal models for investigating the mechanisms of sensory-motor lateralization, few species display continuous visual guidance of appendages. Using the hummingbird hawkmoth *Macroglossum stellatarum* as a unique model to address this (Walsh et al. 2026, bioRxiv: 10.64898/2026.01.27.702022), we present evidence of lateralization of an unpaired appendage in an invertebrate. High-speed behavioural tracking revealed stable lateralization from first proboscis use, with an experience-dependent refinement. Using gaze estimation to quantify visual input in freely-flying hawkmoths, we found that proboscis position tightly covaried with pattern viewing angle, showing that probing behaviour is organized along a time-resolved eye-proboscis-target control axis. Surprisingly, this was not reversed by monocular occlusion - hawkmoths instead adjusted body posture to preserve preferred visuo-motor geometry, strengthening eye-appendage coupling under sensory perturbation. We further showed that lateralization direction and strength differentiate probing strategies and targeting precision, emphasizing functional consequences of such organization. Together, our results demonstrate lateralization of an integrated visuo-motor system in an animal with a compact brain, sharing similar control principles to those seen in primate, elephant, and avian appendage guidance.

Computational sensorimotor control | Wednesday, July 29 **|** 16:00 – 16:15

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Emergent behaviors in an embodied whole-brain simulation of larval *Drosophila*

To what extent can connectome structure, independent of synaptic plasticity, produce emergent behavior? To address this question, we constructed an embodied whole-brain simulation of the *Drosophila melanogaster* first-instar larva from electron microscopy (EM) connectome data (3,013 neurons, 111,243 connections, 353,859 synapses). Neurotransmitter identities were assigned via five confidence tiers based on availability of data-published literature, hemilineage propagation, EM morphology, random forest, and neighbor voting-signing 98.5% of connections. The signed connectome drove a leaky integrate-and-fire network with primarily Poisson sensory input (gustatory 30 Hz, mechanosensory 15 Hz, chordotonal 120 Hz, bilateral olfactory 5-205 Hz). Photoreceptors use graded potentials with saturating light-side drive (24 pA) versus near-zero dark-side (0.2 pA), releasing histamine to inhibit visual projection neurons through connectome synapses. Descending neurons drive a ventral nerve cord (VNC) premotor-motor circuit (17 interneuron types and 60 motor neurons) through a unified stimulus-agnostic pipeline with no test-specific routing between brain and muscles. The neural model was coupled to a 12-segment articulated MuJoCo body (44 joints covering slide, pitch, yaw, and roll movements; 60 muscles driving dorsal, ventral, left lateral, right lateral, and slide actuator forces) with anisotropic denticle band friction, graded joint compliance (flexible head, stiff body), and heading-only thrust. Four of eight tested behaviors emerged: forward peristaltic crawling with posterior-to-anterior muscle waves from tonic gustatory/mechanosensory input, hunching with bilateral body shortening from 120 Hz chordotonal vibration, phototaxis from graded photoreceptor drive via connectome-derived histaminergic inhibition of visual projection neurons, and chemotaxis from a bilateral olfactory gradient. Head sweeps, backward crawling, rolling, and head raises do not yet emerge; ongoing work extends body physics (soft-body deformation for rolling, dorsal-ventral asymmetry for head raises) and involves VNC model refinements to enable emergent wave reversal for backward crawling and peristaltic pause gating for head sweeps.

S15.5 **|** 12:15 – 12:30 **|** Friday, July 31

Animal architecture

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How do mice know how to build a nest?

The animal kingdom is full of elaborate structures that animals build instinctively or learn to build from limited practice. Creating these structures usually requires multiple steps that are organized hierarchically in time. Rodent nest building is a striking example in which mice gather suitable material, transport it to a nest site, shred it, and then sculpt it into the final nest shape. Mice can build a functional nest on their first attempt — without ever having seen or built one before — but they also get more efficient with practice. How is this program encoded in the brain, and how is it modified by experience? Here I discuss the sensory pathways, motivational circuits and reward signals that shape this fascinating behavior. To understand the role of learning, we recorded dopamine release in nucleus accumbens during nest construction and found transient signals time-locked to building subgoals such as discovering material and delivering it to the nest site. These innate reward responses suggest that mice are hardwired to recognize nesting material. We are therefore investigating the peripheral sensory pathways that underlie this recognition, such as orofacial light touch. Finally, we have begun to identify the hypothalamic cell types that drive nest construction as a coherent behavioral program.

Evolution of sensory & motor systems | Wednesday, July 29 **|** 15:15 – 15:30

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Rapid evolution of olfactory circuits underlying human host preference in *Aedes aegypti*

Recent years have seen a surge of interest in understanding the mechanisms through which neural circuits evolve. This is typically studied by comparing the behavior and brains of species that have been diverging for hundreds of thousands to hundreds of millions of years - timescales over which new mutations can accumulate and become fixed, leading to marked changes in neural cell types, tuning, and connectivity. However, robust changes in behavior can sometimes arise much more quickly. Here, we examine two subspecies of the mosquito *Aedes aegypti* that separated only 3-5 thousand years ago yet differ strikingly in host odor preference: one strongly prefers human odor while the other is attracted to a range of animal odors. To understand how preference for humans evolved in such a short period of time, we surveyed the antennal lobes of the two subspecies for differences in both anatomy and functional response. Our functional studies leveraged newly developed genetic tools for volumetric two-photon calcium imaging and naturalistic odor delivery from human and animal hair, as well as live human hosts, in real time. We found that divergence was highly distributed. Anatomically, human preference was associated with modest shifts in the size of many olfactory glomeruli rather than a few more marked changes. Functionally, the neural representation of host odors was broadly similar across subspecies. However, while human and animal odors could not be reliably separated by population neural activity in the ancestral generalist form, the two types of stimuli were clearly discriminable in the human-preferring form, mirroring behavior. This discrimination arose through incremental reweighting across many channels rather than large changes in individual units. Together, these results show how small, distributed changes in peripheral sensory coding can reshape behavior over rapid evolutionary timescales.

S2.4 | 12:00 – 12:15 | Tuesday, July 28

Principles of communication in social groups: from behavior to neuron

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Tracking the social lives of electric eels in their natural habitat

Electric eels (*Electrophorus voltai*) are Neotropical apex predators, often assumed solitary hunters. Field observations, however, report groups of multiple individuals persisting throughout the day, with close-range interactions and coordinated hunting. Their social organization and electrical signaling in the wild remain poorly described, largely because electric eels are difficult to observe directly. We developed autonomous electrode loggers and a pipeline that uses electric organ discharges (EODs) as intrinsic "tags" to estimate pulse-wise positions and putative identities. Deployed at 16 sites along two rivers of the southern Guyana Shield, our loggers recorded continuously for six days and nights, capturing foraging, conspecific encounters, and interactions with sympatric weakly electric fishes. We calibrate a localization model on physics-based electric-field simulations spanning electrode geometries and candidate eel poses, and then infer pulse source locations (with uncertainty) from recorded voltages. Waveform and discharge-timing features separate overlapping emitters and link pulses into tracks. Initial analyses quantify diel activity, co-occurrence and group-size structure, and high-voltage discharge bouts associated with predation. These methods lay the groundwork for a quantitative ethogram of wild electric eels and provide a transferable blueprint for passive electric monitoring across electrogenic fishes.

Mechano- & thermosensation | Wednesday, July 29 | 15:45 – 16:00

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Neurobiological responses to thermal pressure in natural threespine stickleback populations

Nervous systems allow animals to interact with their environments, ensuring appropriate sensory responses in dynamic diel, seasonal, and anthropogenic conditions. What neurobiological activity confers adaptation to changing environments and how could this provide resilience to anthropogenic pressure? I am adapting neuroscience tools, including whole-brain imaging and quantitative behavior paradigms, from the zebrafish model system to study natural populations of threespine stickleback fish in an ecologically relevant context. I am currently using these tools to explore the neural activity and gene expression changes underlying behavioral responses to an altered thermal environment. I will discuss

recent work to record free-moving and head-tethered behavior at distinct temperatures and report the corresponding neural activity patterns. I will also discuss future efforts to probe sensory systems and establish genetic tools in stickleback.

Arthropod locomotion & motor programs | Tuesday, July 28 **|** 15:30 – 15:45

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How the structure of the motor program is set by the frequency of locomotion

Animals locomote at a variety of frequencies. To accommodate different gait frequencies, the motor program (the set of all action potentials sent to muscles) could simply play faster or slower, scaling to preserve relative phase and duty factor. Yet the neuromuscular and mechanical physiology that generates this motor program is constrained by physical timescales which may not scale with frequency. How do animals balance these competing constraints to locomote at higher or lower frequency? To investigate this, we recorded >400,000 wingstrokes of comprehensive, spike-resolution motor programs from the flight muscles of 19 species of bombycoid moths. Bombycoid moths have a conserved set of ~10 muscles which control all wing motion, yet contain tremendous diversity in morphology, flight style, life history, and, crucially, an order of magnitude of wingbeat frequency variation (8-80 Hz). Utilizing this, we found that the number of spikes and interspike intervals for all muscles decrease such that the relative duration (duty factor) of spike bursts is constant across species. Information-theoretic analyses showed that due to this phase scaling of burst duration, the encoding strategy of the motor system is frequency-dependent. In slow species rate coding dominates, but in fast-flapping species spike timing becomes progressively more important. This scaling eventually leads to sub-millisecond-scale precision in the fastest moths. Using measurements of muscle physiology, we further show that this motor program scaling is partially compensated for by adaptations of faster muscle kinetics in faster-flapping species. However, these muscle adaptations don’t match the pace of wingbeat frequency increase. To compensate, different species utilize the same flight muscles with different coordination patterns and activation phases. Together, our results demonstrate that different frequencies of locomotion are accomplished through a combination of mechanical adaptations and neural compensation.

Vision-guided behavior camouflage | Wednesday, July 29 **|** 15:30 – 15:45

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A distributed gain-control of cephalopod chromatophore via skin light-sensing

Cephalopods achieve rapid, adaptive camouflage by modulating millions of chromatophores distributed across their skin. This process is controlled by brain which translates environmental visual statistics from eyes into coordinated skin patterns. However, the skin itself can also possess intrinsic light sensitivity. The integration of these top-down motor commands with peripheral sensory modulation is a fundamental challenge in biological motor control. To resolve this, we asked three fundamental questions: (i) how the skin senses light, (ii) how skin light sensing is integrated with descending motor commands, and (iii) what functions skin light sensing serves during natural behavior. Using single-nuclei sequencing and two-photon calcium imaging, we identified a dense array of rhodopsin-expressing dermal photoreceptors. We then mapped the complete neural pathway from these photoreceptors to motor neuron terminals. Our findings reveal that skin photoreceptors release glycine to inhibit serotonergic terminals, which otherwise tonically suppress glutamatergic motor neurons. Notably, both serotonergic and glutamatergic projections are originated from the brain but are modulated locally within the skin, revealing an unconventional circuit architecture where both modulatory steps occur presynaptically, forming a disinhibitory pathway that regulates motorneuron terminal release. Therefore, rather than directly driving chromatophores, skin photoreceptors act locally to fine-tune the gain of descending motor commands with single-chromatophore resolution. This local gain-tuning selectively enhances chromatophore expansion in brighter regions when the skin is under nonuniform illumination. We demonstrated that the skin light-sensing functions as a previously unrecognized form of active countershading that dynamically mitigated depth perception by concealing shading. This evolutionarily conserved mechanism allows camouflage patterns to be adaptively adjusted to ever-changing environmental lighting, likely representing an intermediate step in the evolution of the elaborate camouflage system in cephalopods.

S1.4 | 12:00 – 12:15 | Tuesday, July 28

Principles of sensory navigation across species & habitats

Wyart, Claire, Paris Brain Institute, France

Unraveling motor strategies during navigation

During navigation, animals coordinate sequences of motor patterns over long time scales to adapt to their internal needs and the environmental conditions. The unbiased identification of motor sequences and states remains challenging. To tackle this question, we developed a maximally-predictive modeling approach and demonstrate how it can reveal the dynamic adaptation of fish to the kinematics of their prey, or uncover motor states of hunting, exploration and quiescence. Because our approach simply relies on continuous detection of center of mass and measurement of velocity over long period of time, it can generalize to virtually any animals walking, swimming, flying and recorded during navigation.

S1.5 | 12:15 – 12:30 | Tuesday, July 28

Principles of sensory navigation across species & habitats

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Visual navigation in ants

Visual navigation is best understood from the animal's point of view. In the spirit of von Uexküll, we will consider how ants—expert navigators—solve the challenge of moving through complex environments via a 'function circle', in which vision and movement act in synergy; and brain, body, and environment are tightly coupled.

S9.3 | 11:40 – 12:00 | Thursday, July 30

Peripheral circuits that shape descending commands to modulate motor programs

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Multimodal motion detection in flying insects

Performing demanding behaviours requires precise integration of multiple sensory modalities to detect task-relevant inputs. For rapid behaviours like flight, vision is often complemented by fast mechanosensory signals that enable immediate body adjustments. Strategically placed mechanosensors allow efficient encoding, and a simple force-activation interface provides fast, reliable feedback. Different insect species exhibit diverse flight strategies, which are reflected in their specialized sensory adaptations. Flies, for example, use halteres (modified hindwings) to detect inertial forces resulting from body rotations, whereas hawkmoths use their antennae. However, many insects show no evidence of requiring a specialized structure for sensing inertia to maintain stable flight. Dragonflies rely on mechanosensory feedback from their wings, which—unlike halteres or antennae—both generate and sense the forces acting on them during flight. Wing sensory signals thus contain a mixture of both self-generated and externally induced motion. Visual inputs can help disambiguate these signals and often interact with mechanosensory pathways. Proprioceptive feedback and wide-field visual motion detection are key contributors to the multimodal integration that underlies reflexive flight stability. Structural, functional, and ecological constraints shape how self-motion is sensed and translated into motor output. By comparing evolved specializations across diverse flight strategies, we can begin to reveal fundamental principles that underlie adaptive sensorimotor control.

S4.4 | 12:00 – 12:15 | Tuesday, July 28

Adaptive responses to changing internal and external environments: weathering the storm

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Hibernation uncouples neural activity from oxygen consumption in the American bullfrog.

Aerobic metabolism supplies most of the ATP for neural activity, making oxygen consumption indispensable for brain function. The American bullfrog (*Aquarana catesbeiana*) offers a striking exception where brainstem motor circuits that generate breathing can sustain activity for hours during anoxia after emergence from hibernation, a period when circuits must restart on the background of blood and brain hypoxia set by constraints of the hibernation environment. We hypothesized that hibernation triggers a global reduction in the aerobic cost of neural activity. Using isolated brainstem preparations from control and hibernated bullfrogs, we present four lines of evidence supporting this. First, pharmacological blockade of ATP-consuming pathways revealed that hibernators consume less oxygen for network activity, without altering activity-independent ion regulation costs. Second, hibernator network output remained stable from normoxia through anoxia, while controls exhibited a critical pO_2 below which activity failed. Third, accelerating physiological activity did not increase oxygen consumption in hibernators as in controls, though seizure-like hyperexcitability let to large O_2 consumption in both groups. Finally, extending this work to brainstem slices, we measured oxygen consumption at the hypoglossal motor neuron pool in response to axon tract stimulation confirmed to evoke action potentials. Hibernator slices consumed less oxygen than controls across a range of stimulation intensities. Ongoing experiments are dissecting the pre- and postsynaptic processes that account for cheaper synapses after hibernation. Together, these results demonstrate that hibernation reduces the aerobic cost of neural activity, a reduction

resolvable at the level of identified neuronal population, revealing previously unrecognized flexibility in the relationship between neural activity and aerobic metabolism.

Sensory learning & decision-making | Monday, July 27 **|** 15:30 – 15:45

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The development of active vision strategies in bumblebees

Bees have miniature brains compared to mammals yet manage to perform impressive feats of visual behaviour. How can they perform complex tasks such as learning concepts, discriminating complex patterns and assessing quantities? Recent research points towards active vision: by using stereotypical flight movements and assessing the visual input, bees in effect convert complex visual problems into simpler ones. However, we do not know how they develop these flight movements as they learn a visual task. To investigate this, we used a visual discrimination paradigm where bumblebees had to learn to distinguish plus and cross patterns. We reinforced the patterns using 50% sucrose and quinine to train bees to visit one pattern and avoid the other respectively. Bees performed the task in a free flight arena and were allowed to freely choose patterns mounted on the rear wall. Flight trajectories of the bees were recorded by two cameras during each trial, and video analysis was performed to investigate scanning behaviours. We found that the bees learnt the discrimination task in 5 trials, with steadily increasing accuracy at choosing the correct pattern. Analysis of the flight paths revealed that bees refine their search area across training trials, focusing their search on unique visual features of the plus or cross. This suggests that bees learn to identify the most informative regions of the pattern to inspect before making their decisions. Further work will investigate if bees display individual differences when approaching and inspecting patterns, and whether scanning strategies are correlated with discrimination performance.

S10.3 **|** 11:40 – 12:00 **|** Thursday, July 30

Brains in the wild B

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From sensory perception to acoustic cognitive maps, studying bats in the real world

With ~1500 species, bats are considered the most diverse taxa of mammals. Many bats are amazing navigators. Some species nightly commute dozens of kilometres in search of food, and some species annually migrate over thousands of kilometres. Studying bats in their natural environment has always been extremely challenging because of their small size (mostly <50 gr) and agile nature. To overcome this challenge, we have developed miniature sensors allowing us to GPS-tag small bats, while also recording their echolocation sound signals, thus opening a new window to document their behaviour in the wild. We have used this technology to track blind-folded bats, showing that they can create acoustic cognitive maps. Using sequence-learning neural networks, we model this behavior showing how acoustic-based maps could be generated by self-learning. We moreover used the approach to demonstrate how mother bats facilitate the acquisition of navigation by young pups and to show that bats track the time since their last visit to a foraging site. Altogether, this approach enables us to study bats' sensorimotor decision making in the real world.

S13.1 | 11:00 – 11:20 | Friday, July 31

Neural basis of acoustic communication across vertebrates

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Neural circuits for the production of different mouse vocalization types

To communicate successfully, animals produce different vocalization types, which differ in their acoustic features and are produced in different behavioral contexts (e.g., contact calls, mating calls, etc.). How vocalization-related brain circuits are organized to enable the production of different vocalization types remains poorly understood. In this talk, I will describe ongoing research to understand how midbrain-to-hindbrain circuits are organized to enable the production of ultrasonic vocalizations and distress calls (squeaks) in the laboratory mouse.

S3.2 | 11:20 – 11:40 | Tuesday, July 28

Evolution of sleep: A comparative perspective to unravel the biological function of sleep?

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Do not disturb: sleep and memory in honeybees

Honeybees provide a powerful model to investigate how sleep contributes to memory consolidation—even in a brain with fewer neurons. My research shows that bees reactivate learned information during sleep, actively strengthening their memories. When this process is disrupted, their memory performance declines. Our research provides compelling evidence for a deeply conserved function of sleep in strengthening memories, from insects to mammals.