Ernst Strüngmann Institute for Neuroscience
in Cooperation with Max Planck Society

ESI SyNC 2021 DataBlitz: Timetable

	August 30	August 31	September 1
DataBlitz Session 1	14:40 – 15:00 **Katja Reinhard** ➡ The neural basis of defensive behavior evolution in *Peromyscus* mice	15:10 – 15:30 **Felix Effenberger** ➡ Harmonic oscillator recurrent networks	15:10 – 15:30 **Katharine Shapcott** ➡ Experimental control of an immersive dome virtual environment for non-human and human behaviour created with Unreal Engine
	15:00 – 15:20 **Jennifer Hoy** ➡ Development of visually guided prey capture behavior in mouse	15:30 – 15:50 **Amr Farahat** ➡ Shape representation in Convolutional Neural Networks	15:30 – 15:50 **Owen Martin** ➡ Visual communication of synchronous firefly swarms in natural and virtual realities
DataBlitz Session 2	17:05 – 17:25 **Raghav Rajan** ➡ READY, STEADY, GO! Using songbirds to understand how the brain initiates natural, ethological relevant, motor sequences	17:45 – 18:05 **Francisco Garcia-Rosales** ➡ Echolocation reverses information flow in a cortical vocalization network	17:35 – 17:55 **Emily J. Dennis** ➡ Volumetric imaging and morphometry for comparative rodent neuroscience
	17:25 – 17:45 **Dejan Draschkow** ➡ The natural use of working memory	18:05 – 18:25 **Berkutay Mert** ➡ Discriminability of natural stimuli	17:55 – 18:15 **Peer Herholz** ➡ Combining open science & naturalistic imaging to investigate auditory perception: increasing replicability & generalizability through the Neuroscout platform

Ernst Strüngmann Institute for Neuroscience in Cooperation with Max Planck Society

ESI SyNC 2021 DataBlitz: Abstracts

Emily J. Dennis – Wednesday, September 1st, 17:35

Volumetric imaging and morphometry for comparative rodent neuroscience

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Introduction

Lab rats (*Rattus norvegicus*) and mice (*Mus musculus*) are frequently used model organisms in neuroscience. Researchers often perform similar behavioral and neural experiments across species and draw inspiration from each other, implicitly or explicitly comparing and building on data across species. Together with classic neuronal tracing techniques, recent developments in tissue clearing and lightsheet imaging allow for access to whole-brain connectivity in intact brains. This presents an opportunity to revisit how we compare data across species.

Methods and results

To take advantage of these techniques, we first adapted clearing procedures for mice to work with larger rat brains. We then use these cleared rat brains to create an open-source 3D rat atlas. Using these data, we validate our results by recapitulating known sexual dimorphisms in both rats and mice. We then created an average *Mus/Rattus* atlas, "Mattlas" and identified species dimorphisms at the gross anatomical level. Finally, we delve into two cortical areas of interest, where conflicting labels have made cross-species comparisons difficult.

Conclusion

Together, these methods, code, and data demonstrate the power of whole-brain neuroscience to facilitate cross-animal, -sex, -experimenter, -lab, and -species work and make may lab's future comparative work possible. At the datablitz, I will focus on the comparisons between rats and mice, and close by discussing how my lab, which opens at Janelia in January, will build on these results to create common coordinate frameworks for multiple *Mus musculus* subspecies. This will be an anatomical toolset allowing the Dennis Lab to use comparative neuroscience approaches at the behavioral, anatomical, and neural levels across *Mus musculus* subspecies in the wild, re-wild, and lab to better understand diet, especially hunting behavior, and its evolution.

Dejan Draschkow – Monday, August 30th, 17:25

The natural use of working memory

Dejan Draschkow & Anna C. Nobre

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Introduction

Working memory (WM) is a fundamental cognitive function which supports tasks that require bridging between perception and subsequent behavior. Highly controlled laboratory tasks have been used to investigate its properties, such as its capacity. We know much less about the utilization of WM in natural behavior, that is when reliance on working memory emerges as a natural consequence of interactions with the environment.

Methods

We tracked head, hand, and eye movements in virtual reality during an adapted object-copying task, during which participants copied a model display by selecting realistic objects from a resource pool and placing them into a workspace. Our task enabled us to derive an implicit measure of the tradeoff between reliance on working memory and gathering information from the external world during natural behavior. By further manipulating the locomotive demands required for task completion, we could investigate whether and how WM utilization changed as gathering information from the environment became more effortful.

Results

Reliance on WM was much lower than predicted based on WM capacity measures in typical laboratory tasks. As sampling information from the environment required increasing locomotion, participants relied more on their WM representations. This reliance on WM increased in a shallow, but linear fashion from ~1 to an average of ~2 features in memory. Encoding more features was associated with longer encoding durations, which made the individual copying sequences last longer. Nevertheless, using memory improved performance as it enabled more information to be copied in each sequence, which reduced the overall completion times of the to-be-copied displays.

Conclusion

Our results showcase a fundamental dependence on external information during natural behavior, even if the potentially storable information is well within the capacity of the cognitive system. These findings highlight the importance of investigating how the use of cognitive processes unfolds within natural tasks and extend our understanding of the interplay between memory and perception in the natural brain.

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Felix Effenberger – Tuesday, August 31st, 15:10

Harmonic oscillator recurrent networks

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Amr Farahat – Tuesday, August 31st, 15:30

Shape representation in Convolutional Neural Networks

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Introduction

Convolutional neural networks (CNNs) have achieved super human performance on object recognition tasks and are the best models in explaining neural data recorded from the ventral stream of primates visual pathway. However, recent studies have shown that they tend to be biased to surface regularities rather than object shapes in contrast to humans. This begs the question if CNNs can represent shape at all as humans do.

Methods

We used a sketch dataset to probe CNNs readiness to learn global shape. We trained several CNNs of variable effective receptive fields (RF) under different scrambling regimes. We quantified the effect of the spatial extent of evidence allowed to the networks on performance and tested how adaptive the learned features were to scrambling which reflected their sensitivity to global shape configuration.

Results

We observed that in contrast to CNNs trained on a natural image dataset, CNNs trained on the sketch dataset require an effective RF that covers the whole object and are very sensitive to scrambling during training and during testing. Surprisingly, however, when we analyzed the minimal configurations required by the networks to correctly classify the sketch images, we found that networks with big RFs required smaller patches to correctly classify the images in comparison to the networks with smaller RFs. Furthermore, the size of these patches differed significantly among classes.

Conclusion

According to these results, we conclude that shape-biased CNNs are still dominated by their simplicity bias and only attend to big enough patches that correctly classify the images without learning the global shape of the objects. This difference in shape representations between humans and CNNs could be due to the immense discrepancy in the environment from which natural and artificial brains learn i.e. interacting with the world versus learning from a static finite dataset.

Francisco Garcia-Rosales – Tuesday, August 31st, 17:45

Echolocation reverses information flow in a cortical vocalization network

Francisco García-Rosales[1], Luciana López-Jury[1], Eugenia Gonzalez-Palomares[1], Johannes Wetekam[1], Yuranny Cabral-Calderín[2], Ava Kiai[1], Manfred Kössl[1], Julio C. Hechavarría[1].

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Introduction

The mammalian frontal and auditory cortices are essential for vocal behaviour. The former is involved in vocal coordination, whereas the latter is crucial for vocal feedback mechanisms. Although extensive research has been devoted to both these structures separately, little is known about the interactions in the fronto-auditory circuit during vocalization. In this study we tackle this question, and unveil that frontal and auditory cortex engage in information transfer patterns that depend on vocal output.

Methods

To study the fronto-auditory network during vocal production, we used *Carollia perspicillata* bats as a model. Bats rely on vocalization for both navigation (echolocation) and communication, which makes them an excellent model organism to study vocal production. We compared neural activities recorded with laminar electrodes in frontal and auditory cortices, as bats freely vocalized echolocation or communication pulses. Directed phase-transfer entropy (dPTE) was used quantify information flow in the fronto-auditory network.

Results

We demonstrate for the first time that the timing and spatial pattern of oscillations in the fronto-auditory cortical network of freely-vocalizing bats predict the purpose of vocalization. Transfer entropy analyses of oscillatory activity revealed predominantly top-down (frontal-to-auditory cortex) information flow. The dynamics of information flow depended on the behavioural role of the vocalization and on the timing relative to vocal onset. Remarkably, we observed the emergence of bottom-up (auditory-to-frontal cortex) information transfer, but only when animals produced echolocation vocalizations leading to self-directed acoustic feedback.

Conclusion

These results reveal changes in information flow patterns across sensory and frontal (association) cortices driven by the purpose (echolocation vs. social communication) of the vocalization in a highly vocal mammalian model. In a broader frame, our data suggest that situations in which animals exchange information actively with the environment trigger dynamic switches of information flow in large-scale cortico-cortical networks.

Peer Herholz – Wednesday, September 1st, 17:55

Combining open science & naturalistic imaging to investigate auditory perception: increasing replicability & generalizability through the Neuroscout platform

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FMRI studies of naturalistic stimulation promise to increase our understanding of neural processes under more ecological conditions, importantly for auditory perception [1-5]. However, analysis of these rich stimuli requires time-intensive annotation, which is further exacerbated by the resource-intensive nature of fMRI analysis [6, 7] (Figure 1A). Neuroscout - a free, open source platform - aims to address these challenges by harnessing machine learning and open science to richly and automatically annotate stimuli and enabling researchers to create custom fMRI analyses across publicly available naturalistic neuroimaging datasets via a user-friendly web application (https://neuroscout.org, Figure 1B).

For each dataset, users can select predictors from a wide range of stimulus features and descriptors, pre-extracted by state-of-the-art algorithms (Figure 1B). A fully reproducible and replicable ready-to-run pipeline is generated with automated interactive outcome visualization which can then be deployed locally or through cloud-computing instances, as well as transferred to other datasets to investigate the generalizability of results.

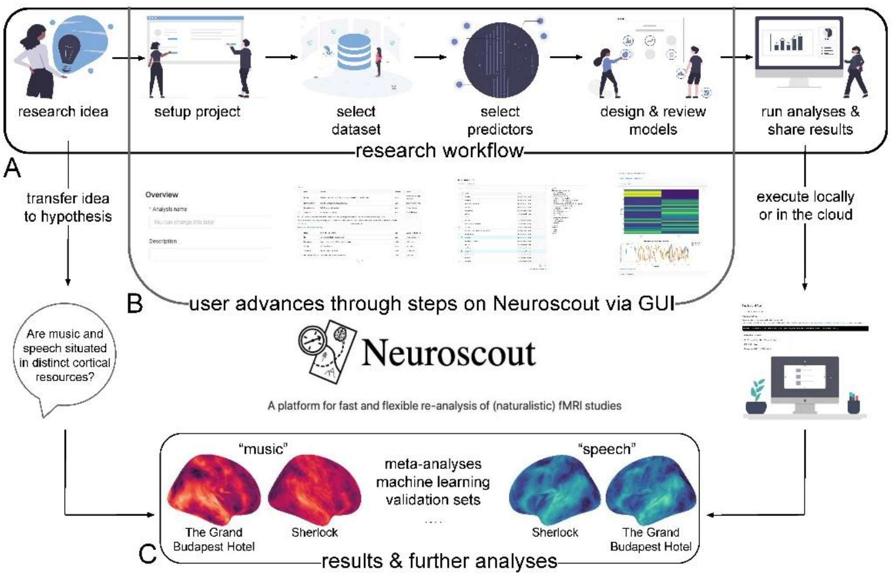

Figure 1: Neuroscout as a central part of the research workflow

With Neuroscout, creating, for example, speech and music encoding analyses across several datasets, each containing hours of data and a multitude of stimuli, is accomplished within minutes (Figure 1B). Upon deciding on datasets and predictors that specify which timepoints were labeled as either \music" or \speech", the respective analyses are automatically compiled and subsequently deployed. The obtained results indicate which voxels respond to these auditory categories (Figure 1C) and are in line with previous research indicating a broad involvement of the temporal lobe [8].

Neuroscout drastically reduces the barriers to entry of complex and large-scale investigations of auditory perception through naturalistic datasets by automating large parts of the processing. Through its utilization of publicly available datasets, it seamlessly allows investigators to evaluate the replicability and generalizability of results, both crucial aspects of fMRI research [9, 10]. Furthermore, it paves the ground for more advanced approaches like meta-analyses and machine learning [3, 4, 11] (Figure 1C).

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Jennifer Hoy – Monday, August 30th, 15:00

Development of visually guided prey capture behavior in mouse

Kelsey Allen, Rocio Olvera, Jennifer Hoy

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Understanding how the brain detects and responds to salient information in the environment is a central goal in neuroscience. To work towards this goal, we study the neural circuit basis of visually-guided prey capture behavior in mice where the behavioral goals of the animal and stimulus meaning are relatively clear even within complex and dynamic situations. We recently identified that mice will innately approach simple, computer generated visual stimuli if they are within a specific (preferred) range of sizes and speeds. Intriguingly, prey capture experience with crickets prior to exposure to these artificial stimuli changes the size and speed of stimuli that mice prefer to approach suggesting that the visual information that drives natural orienting responses in mice is flexible. To reveal whether these behaviors might be flexibly gated at specific developmental stages and possibly regulated by developmentally-regulated genetic programs we are also quantifying the behavior at specific stages of development. The results of this developmental investigation will be discussed.

Owen Martin – Wednesday, September 1st, 15:30

Visual communication of synchronous firefly swarms in natural and virtual realities

Owen Martin*, Raphael Sarfati*, Julie Hayes†, Orit Peleg*‡

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Introduction

Male P. carolinus fireflies perform synchronous mating displays as they swarm for several weeks every summer in the Great Smoky Mountains. These displays are wondrous and the source of much active study, but the mechanism for their discrete synchrony is not yet understood. Indeed, experimental data on the ash patterns produced by this species are very sparse. Here we present new field data from controlled experiments on small groups of P. carolinus fireflies that aim to inform computational modeling efforts of the emergent collective behavior of this species.

Methods

We performed experiments on fireflies caught in their natural environment and released in tents under controlled density conditions. First, we released fireflies into dark tents and observed their ash interactions. Second, we programmed artificial, adjustable firefly light signals into an Arduino-LED system and introduced these signals to groups of fireflies, also in tents. We varied the frequency of the artificial ash signal to imitate previously observed patterns from larger groups of fireflies. Both sets of experiments were recorded with 360° GoPro cameras, and we analyzed the resulting videos with computer vision and 3D reconstruction techniques to quantify the degree of synchrony at each density.

Results

We found a critical density of fireflies required for the emergence of the periodic synchronized response characteristic of this species. We also found fireflies in the presence of active artificial signals demonstrated a significantly higher degree of synchrony than fireflies interacting on their own. This suggests that firefly behavior is modulated by the frequency of the response of their neighbors, which supports previous experiments on higher densities of fireflies.

Conclusion

These results highlight an instance of distributed computing in nature. They will inform computational models of communication and synchronized oscillation on network topologies generated by randomly moving individuals, such as integrate-and-fire models commonly used to understand firing neurons.

Berkutay Mert – Tuesday, August 31st, 18:05

Discriminability of natural stimuli

Berkutay Mert, Katharine Shapcott, Iuliia Glukhova, Lea Kerçiku, Martha Havenith and Marieke Schölvinck

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Introduction

Classical visual discrimination tasks typically use simple, unrealistic sinusoidal or square wave gratings and gray backgrounds without texture, in order to increase control over the experiment and to minimize external factors. However, it is obvious that the human brain, especially the visual system, has evolved to respond to complex stimuli with multiple shapes, colors, and textures rather than such simple and 'backgroundless' stimuli. In this study, we investigated whether the sensitivity of human subjects in visual discrimination is enhanced by using natural stimuli and backgrounds as compared to classical gratings on a gray background.

Methods

We designed four stimulus types of increasing degree of naturalness: classical gratings, gratings with a leaf texture, leaf shapes with different textures, and morphed leaves, that were presented on two different backgrounds: a uniformly gray background and a natural landscape. All stimuli were shown within a 3D virtual reality environment. Psychometric curves were created using a two alternative forced choice (2AFC) discrimination task for the eight different conditions. The psychometric curves, response times, and eye tracking data were compared between the conditions to explore the effect of naturalistic stimulation on visual discrimination.

Results

Preliminary analyses show that presenting the stimuli on a naturalistic background sharpens the psychophysical curves in all stimulus types, compared to the gray background. Classical gratings and morphed leaves (the least and most natural stimuli) are better discriminated than the intermediate stimulus types. Generally, the threshold for visual discrimination in the virtual reality environment is lower than that reported in the literature.

Conclusion

Visual discrimination differs for different backgrounds and stimulus types, and it favors a naturalistic background compared to an unnatural background.

Raghav Rajan – Monday, August 30th, 17:05

READY, STEADY, GO! Using songbirds to understand how the brain initiates natural, ethological relevant, motor sequences

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2. Presenting author

Simple reaching movements are preceded by "preparatory" neural activity in many brain areas and this activity is thought to be important for initiating movements[1, 2]. Much of this knowledge comes from research on monkeys and rats, trained to memorize a sensory cue and then make the appropriate movement after a "GO" signal[1, 2]. How are more natural, ethologically relevant, movements initiated? Here, we address this question by examining the initiation of song in the adult, male zebra finch, a songbird3. The song of the zebra finch consists of a stereotyped sequence of sounds interleaved with silent gaps3. Song bouts begin with the repetition of a simple sound called an introductory note (IN) and we have shown that some aspects of INs may reflect "preparation" for song[4, 5, 6]. Using extracellular recordings from individual neurons in awake, singing, zebra finches, we show the presence of "preparatory" activity in premotor nucleus HVC, ~400ms before the first IN of a song bout[7]. The presence of this activity was correlated with successful progression to song. Neural activity during the INs showed strong differences in activity based on the identity of the upcoming syllable; some neurons were more active if the next syllable was an IN, while others were more active if the next syllable was the start of song. Overall, our results show the presence of "preparatory" neural activity in the songbird brain before song initiation and suggests that songbirds are an excellent model system to study how the brain initiates natural, ethologically relevant, movements.

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Katja Reinhard – Monday, August 30th, 14:40

The neural basis of defensive behavior evolution in *Peromyscus* mice

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Introduction

Evading threats is instinctive and critical for survival. In small mammals, the presence of overhead threats from predators is ubiquitous, and the two common strategies for evading capture are freezing and escape. Effective evasive strategies can depend on the proximity of shelter, lighting conditions and experience. These factors vary dramatically among different ecological niches and have led to a striking amount of behavioral diversity to have evolved, even among closely related species. Despite previous work on defensive behaviors in a variety of mammalian species, little is known about what components of the neural circuits that mediate these behaviors differ between species, or how each circuit is organized to trigger responses that are appropriately adapted to their particular ecological niche.

Methods & Results

Here, we find that two species of the rodent genus *Peromyscus* from very different ecological niches show distinct behavioral responses to the same looming stimulus mimicking an attacking predator: *P. maniculatus*, found in the densely foliated prairies of North America, predominantly darts quickly to safety, while *P. polionotus*, a species common to the open sandy areas of eastern Florida, pause their movement. Measurements of neuronal activity with cFOS and Neuropixels probes show that movement and escape is encoded by neurons in the dorsal periaqueductal gray (dPAG) of *P. maniculatus* but not *P. polionotus.* In addition, while weak optogenetics activation of neurons in the dPAG induces immobility in both species, strong dPAG activation triggers escape in *P. maniculatus*, but not *P. polionotus*.

Conclusions. These results reveal that the circuits through the dPAG are a node where evolution has acted to alter the preferential strategy and response of these two species of *Peromyscus* to the presence of looming overhead danger.

Katharine Shapcott – Wednesday, September 1st, 15:10

Experimental control of an immersive dome virtual environment for non-human and human behaviour created with Unreal Engine

Katharine Shapcott, Marvin Weigand, Iuliia Glukhova, Martha Havenith and Marieke Schölvinck

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Introduction

Virtual reality (VR) dome systems have become popular in neuroscience to present immersive behavioural tasks to non-human subjects. Unfortunately, these tasks are usually restricted to unnaturally simplistic environments due to limitations of the game system, whereas realistic 3D environments are necessary to mimic the visual environment that the brain evolved with and deals with in everyday life. Unreal Engine is a powerful game engine with photo-realistic graphics, able to display large naturalistic environments out of the box. Unreal additionally has a number of technical advantages, such as a visual scripting language which can be used by non-programmers but is compiled into fast C++ code. However, Unreal lacks the features needed to be used for controlled neuroscience experiments. We have therefore developed DOME for Unreal.

Methods

DOME contains features necessary to create immersive behavioural tasks for neuroscience research and control them during execution using Unreal: 1) A dome projection. 2) Control flow via state machines with blocks and trials. 3) Online inputs and outputs for e.g. eyetracking or eventmarkers. 4) An experiment GUI to control task parameters online and display behavioural performance. 5) A logging system to automatically record relevant information needed for offline analysis.

Results

To demonstrate these features we created a two-alternative forced choice task in a large naturalistic environment containing realistic objects. This task was performed successfully by three species (humans, macaque monkeys and mice). We show preliminary analysis of the task to illustrate the practical use of DOME as a research tool.

Conclusion

DOME provides the experimental features necessary to use the Unreal engine in a simple manner to create immersive and naturalistic 3D behavioural tasks for neuroscience research.