OIST OKINAWA INSTITUTE OF SCIENCE AND TECHNOLOGY GRADUATE UNIVERSITY

Computational Neuroethology Unit (Sam Reiter)

FY2023 Annual Report

Computational Neuroethology Unit
Assistant Professor Sam Reiter

(From left to right) Robert Ross, Tomo Mano,Yutaka Kojima, Makoto Hiroi, Olivier Fernandez, Van Dinh, Kostas Tsaridis, Aditi Pophale, Pedro Castelhanito, Sam Reiter

Abstract

The Computational Neuroethology Unit seeks to uncover the principles governing animal behavior and its neural basis. To achieve this goal, the unit combines novel methods for high-resolution behavioral recording with systems neuroscience and computational approaches. The unit currently focuses on coleoid cephalopods (cuttlefish, octopus, and squid), a group of marine invertebrates that evolved uniquely large brains and complex behaviors.

1. Staff

- Dr. Tomoyuki Mano, JSPS Postdoctoral Fellow

- Dr. Makoto Hiroi, Staff Scientist (with Stephens Unit)
- Dr. Robert Ross, Interdisciplinary Postdoctoral Fellow (with Pigolotti Unit)
- Dr. Alex Harston, JSPS Postdoctoral Fellow
- Dr. Nobuaki Mizumoto, Interdisciplinary Postdoctoral Fellow (with Bourguignon Unit)
- Ms.Chie Edwards, Research Unit Administrator
- Ms. Van Dinh, Laboratory Technician
- Mr. Keishu Asada, Fieldwork Technician
- Mr. Yutaka Kojima, Laboratory Technician
- Ms. Aditi Pophale, Graduate Student
- Mr. Kostas Tsaridis, Graduate Student
- Mr. Olivier Fernandez, Rotation Student

2. Collaborations

2.1 Squid collective behavior

- Description: Decoding the language of social cephalopods.
- Type of collaboration: Joint research
- Researchers:
  - Professor Greg Stephens, Vrije Universiteit Amsterdam/OIST
  - Dr. Makoto Hiroi, OIST

2.2 Cephalopod Physiology

- Description: Analysis of neural recordings from cephalopod brains
- Type of collaboration: Joint research
- Researchers:
  - Dr. Leenoy Meshulam, University of Washington

2.3 Cephalopod skin as growing active matter

- Description: Analysis of skin pattern growth and development
- Type of collaboration: Joint research
- Researchers:
  - Professor Simone Pigolotti, OIST
  - Dr. Robert Ross, OIST

2.4 Cuttlefish Camouflage Dynamics

- Description: Describing the space of cuttlefish camouflage, and how they move in this space
- Type of collaboration: Joint research
- Researchers:
  - Professor Gilles Laurent, MPI for Brain Research
  - Ms. Theodosia Woo, MPI for Brain Research
  - Dr. Xitong Liang, MPI for Brain Research
  - Dr. Dominic Evans, MPI for Brain Research

2.5 Clownfish behavior

- Description: Tracking clownfish social behavior in 4 dimensions
- Type of collaboration: Joint research

- Researchers:
  - Professor Vincent Laudet, OIST
  - Dr. Manon Mercader, OIST

2.6 Termite behavior

- Description: Tracking termite tandem running
- Type of collaboration: Joint research
- Researchers:
  - Professor Tom Bourguignon, OIST
  - Dr. Nobuaki Mizumoto, OIST

2.7 Cephalopod Genetics

- Description: genomics and transcriptomics
- Type of collaboration: Joint research
- Researchers:
  - Professor Dan Rokhsar, OIST
  - Dr. Gustavo Sanchez, OIST

2.8 Octopus chemosensation

- Description: from molecules to behavior
- Type of collaboration: Joint research
- Researchers:
  - Professor Nick Bellono, Harvard University
  - Dr. Rebecka Sepela, Harvard University
  - Dr. Pablo Villar del Rio, Harvard University

3. Activities and Findings

From OIST press release: https://www.oist.jp/news-center/news/2023/6/29/cuttlefish-camouflage-more-meets-eye

Cuttlefish, along with other cephalopods like octopus and squid, are masters of disguise, changing their skin color and texture to blend in with their underwater surroundings.

Now, in a study published 28 June in Nature, researchers at the Okinawa Institute of Science and Technology (OIST) and the Max Planck Institute for Brain Research have shown that the way cuttlefish generate their camouflage pattern is much more complex than previously believed.

Cuttlefish create their dazzling skin patterns by precisely controlling millions of tiny skin pigment cells, called chromatophores. Each chromatophore is surrounded by a set of muscles, which contract and relax under direct control of neurons in the brain. When the muscles contract, the pigment cell is expanded and when they relax, the pigment cell is hidden. Together, the chromatophores act like cellular pixels to generate the overall skin pattern.

Professor Sam Reiter, who leads the Computational Neuroethology Unit at OIST said: “Prior research suggested that cuttlefish only had a limited selection of pattern components that they would use to achieve the best match against the environment. But our latest research has shown that their camouflaging response is much more complicated and flexible – we just hadn’t been able to detect it as previous approaches were not as detailed or quantitative.”

To make their discovery, the team used an array of ultra high-resolution cameras to zoom into the skin of the common European cuttlefish, Sepia officinalis. The scientists presented the cuttlefish with a range of different backgrounds. As the cuttlefish transitioned between camouflage patterns, the cameras captured the real-time expansion and contraction of tens to hundreds of thousands of chromatophores.
Data from around 200,000 skin pattern images were then crunched by the supercomputer at OIST and analyzed by a type of artificial intelligence, known as a neural network. The neural network looked holistically at the different elements of the skin pattern images, including roughness, brightness, structure, shape, contrast, and more complex image features. Each pattern was then placed into a specific location in 'skin pattern space', a term the scientists coined to describe the full spectrum of skin patterns generated by the cuttlefish.

The researchers also used the same process to analyze images of the background environment, and looked at how well the skin patterns matched the environment.

Overall, the researchers found that the cuttlefish were able to display a rich variety of skin patterns and could sensitively and flexibly change their skin pattern to match both natural and artificial backgrounds. When the same animal was presented with the same background multiple times, the resulting skin patterns subtly differed in ways that were indistinguishable to the human eye.

The path that the cuttlefish took to reach each skin pattern was indirect. The cuttlefish transitioned through a range of different skin patterns, pausing in between, with each pattern change improving the camouflage until the cuttlefish stabilized on a pattern they seemed satisfied with. Such paths, even between the same two backgrounds, were never the same, emphasizing the complexity of the cuttlefish's behavior.

"The cuttlefish would often overshoot their target skin pattern, pause, and then come back," said Theodosia Woo, joint first author of the study and graduate student in the Max Planck Institute for Brain Research team. "In other words, cuttlefish don't simply detect the background and go straight to a set pattern, instead, it is likely that they continuously receive feedback about their skin pattern and use it to adjust their camouflage. Exactly how they receive that feedback – whether they use their eyes, or whether they have a sense of how contracted the muscles around each chromatophore are – we don't yet know."

The researchers also examined another skin pattern display, called blanching, which occurs when cuttlefish turn pale in response to a threat. "Unlike camouflaging, blanching was fast and direct, suggesting it uses a different and repeatable control system," said Dr. Dominic Evans, a postdoctoral fellow in the Max Planck Institute for Brain Research team.

When the researchers took high resolution images of the blanching display, they realized that some elements of the previous camouflage pattern remained, with the blanching pattern superimposed on top. Afterwards, the cuttlefish would slowly but reliably return to displaying its pre-blanching skin pattern.

"This suggests that information about the initial camouflage somehow remains. The blanching is more like a response that temporarily overrides the camouflage signals from the brain and might be controlled by a completely different neural circuit in the brain," explained Dr. Xitong Liang, joint first author of the study and former postdoctoral researcher in the Max Planck Institute for Brain Research team. "The next step is to capture neural recordings from cuttlefish brains, so we can further understand exactly how they control their unique and fascinating skin patterning abilities."

4. Publications

4.1 Journals

Pophale A, Shimizu K, Mano T, Iglesias T L., Martin K, Hiroi M, Asada K, Andaluz G P, Dinh T T V, Meshulam L, Reiter S (2023) Wake-like skin patterning and neural activity during octopus sleep, Nature, 619:129-134.

Woo T, Liang X, Evans D, Fernandez O, Kretschmer F, Reiter S, Laurent G (2023) The dynamics of pattern matching in camouflaging cuttlefish, Nature, 619:122-128.

Yamaguchi, ST.*, Hatori, S.*, Kotake, K., Zhou, Z., Kume, K., Reiter, S., Norimoto, H.† Circadian Control of Sleep-Related Neuronal Activity in Lizards. PNAS Nexus, in press

4.2 Books and other one-time publications

Nothing to report

4.3 Oral and Poster Presentations

1. Pophale A., Institute of Behavioural Neuroscience, UCL. Wake-like skin patterning and neural activity during octopus sleep, London UK.
2. Reiter S., OIST. Developmental Neural Circuits course. Octopus sleep, Okinawa, Japan.
3. Reiter S., OIST. OIST Computational Neuroscience course. Why do we sleep?, Okinawa, Japan.
4. Reiter S., Japanese Neuroscience Society Annual Meeting Symposium on REM sleep. Octopus sleep, Sendai Japan
5. Reiter S., OIST-Riken joint meeting. Exploring 2-stage sleep in octopus, Okinawa, Japan.
6. Reiter S., JSSR/JSC joint meeting, International Symposium on Invertebrate Sleep and Clock. Behavioral and Neural measurement of 2-stage sleep in an octopus, Yokohama Japan.
7. Reiter S., Max Planck Institute for Brain Research. Wake-like skin patterning and neural activity during octopus sleep, Frankfurt Germany.
8. Reiter S., Max Planck Institute for Animal Behavior. Cephalopod skin patterns as windows into brain dynamics, Constance Germany.
9. Reiter S., Max Planck Institute for Biological Intelligence. Wake-like skin patterning and neural activity during octopus sleep, Munich Germany.
10. Mano T., タコは夢を見るのか！？タコの二段階睡眠の謎に迫る, Online (Zoom).
11. Reiter S.,Vision Forum.Visual texture matching in camouflaging cuttlefish, Okinawa Japan.
12. Reiter S., UCSF. Wake-like skin patterning and neural activity during octopus sleep, California USA.
13. Reiter S., University of California. Wake-like skin patterning and neural activity during octopus sleep, Berkeley, California USA.
14. Reiter S., University of Washington. Wake-like skin patterning and neural activity during octopus sleep, Washington USA.
15. Hiroi M., The 42nd Annual Meeting of the Japanese Society of Animal Behavior. Potential and Application of Automatic Tracking Technology for the Behavioral Analysis of Cephalopods, Including Squids, Kyoto Japan.
16. Pophale A., National Centre for Biological Sciences. Wake-like skin patterning and neural activity during octopus sleep, Bangalore, India.
17. Reiter S., PRESTO meeting. Wake-like skin patterning and neural activity during octopus sleep, Okinawa Japan.
18. Reiter S., APS March Meeting. Cephalopod skin patterns as windows into brain dynamics, Minnesota USA.
19. Mano T., Pophale A., Shimizu K., Iglesias T., Martin K., Hiroi M., Asada K., Andaluz P. G., Dinh T.T.V.,

Meshulam L., Reiter S., Souhatsu Meeting. Wake-like Skin Patterning and Neural Activity During Octopus Sleep, Tokyo, Japan.

5. Intellectual Property Rights and Other Specific Achievements

Nothing to report

6. Meetings and Events

6.1 Thalamic Networks Coordinate Dynamic Updating of Cortical Representations to Enable Perceptual Inference

- Date: 2024-01-23
- Venue: OIST Campus, Seminar Room L4F01
- Speaker: Dr. Lukas Schmitt, RIKEN Center for Brain Science

6.2 Elucidating the structure of prefrontal cortical network transformation underlying flexible task-switching

- Date: 2024-01-23
- Venue: OIST Campus, Seminar Room L4E01
- Speaker: Dr. Miho Nakajima, RIKEN Center for Brain Science

6.3 Hibernation Research using Mice

- Date: 2023-10-25
- Venue: OIST Campus, B503 (Center Bldg)
- Speaker: Dr. Gensho Sunagawa, Laboratory for Hibernation Biology RIKEN Center for Biosystems Dynamics Research

6.4 Contribution of sleep to learning and memory in humans

- Date: 2023-10-19
- Venue: OIST Campus, Seminar Room L4F01
- Speaker: Dr. Masako Tamaki, RIKEN Cluster for Pioneering Research / Center for Brain Science

6.5 Kleptoprotein: sequestering functional protein from prey for bioluminescence

- Date: 2023-09-04
- Venue: OIST Campus, Seminar Room L4F01
- Speaker: Designated Assistant Professor Manabu Bessho-Uehara , Institute for Advanced Research, Nagoya University

6.6 Molecular mechanisms of odorant receptor-instructed neural map formation

- Date: 2023-08-31
- Venue: OIST Campus, Seminar Room L4F01
- Speaker: Dr. Ai Nakashima, Graduate School of Pharmaceutical Science, University of Tokyo

6.7 OIST Developing Neural Circuits Course (DNC) 2023

- Date: 2023-07-11 to 2023-07-23
- Venue: OIST Conference Center - Meeting Rooms

6.8 Light-intensity coding in the human prefrontal cortex

- Date: 2023-07-03
- Venue: OIST Campus, Seminar Room L4F01
- Speaker: Prof. Jerome Sanes, Department of Neuroscience, Carney Institute for Brain Research, Brown University

6.9 Thalamocortical circuits for the formation of hierarchical pathways in the mammalian visual cortex

- Date: 2023-05-22
- Venue: OIST Campus, Seminar Room L4E01
- Speaker: Dr. Tomonari Murakami, Department of Physiology, Graduate School of Medicine, The University of Tokyo

6.10 The dragonfly's superpowers: from predictive visual guidance and wing aerodynamics sensing to bio-inspired robotics

- Date: 2023-05-01
- Venue: OIST Campus, Seminar Room L4F01
- Speaker: Dr. Huai-Ti Lin, Imperial College London, Department of Bioengineering

6.11 Multidimensionality of leadership and emergent feedback mechanisms revealed by interspecific groups

- Date: 2023-04-06
- Venue: OIST Campus, Seminar Room L4F01
- Speaker: Dr. Eduardo Sampaio, Max Planck Institute of Animal Behavior, Department of Collective Behavior