



CIN ANNUAL REPORT

2022-2024



CIN

Werner Reichardt

Centrum für Integrative
Neurowissenschaften

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WELCOME ADDRESS

Dear colleagues,

At the Werner Reichardt Centre for Integrative Neuroscience (CIN), the University's cross-faculty hub, we take pride in our collaborative, interdisciplinary mission. From its origins as an Excellence Cluster, the CIN has matured into a vibrant and productive research center uniting 28 research groups across the life sciences, medicine, and the humanities, working closely with partners across the Tübingen Neuro Campus.

Our broad base of expertise – together with strong partnerships – enables rigorous, multi-level neuroscience and strengthens the CIN's role as a fertile ground for interdisciplinary collaboration, launching joint initiatives. We remain committed to the highest scientific standards, responsible animal research, and comprehensive support for our researchers.

Guided by our mission to understand how the brain generates intelligent behaviour, this 2022–2024 report highlights the CIN's research achievements, institutional developments, and its collaborative spirit. It also features initiatives that strengthen collaboration, including shared facilities, training programs, and interdisciplinary workshops and symposia.

We are excited to build on this momentum – deepening our integrative science, empowering early-career researchers, and turning bold ideas into discoveries that advance neuroscience and benefit society.

The CIN Board

CIN AT A GLANCE



CROSS-FACULTY RESEARCH HUB

The Werner Reichardt Center for Integrative Neuroscience (CIN) is a cross-faculty research hub at the University of Tübingen, uniting the Faculties of Science, Medicine, and Humanities. The CIN brings together 28 research groups and collaborates closely with partners across the Tübingen Neuro Campus – including the Max Planck Institutes, the Bernstein Center for Computational Neuroscience, and the Hertie Institutes for Clinical Brain Research and AI in Brain Health. As a central hub within the Tübingen Neuro Campus, the CIN brings together an exceptional breadth of expertise in experimental, computational, and translational neuroscience.

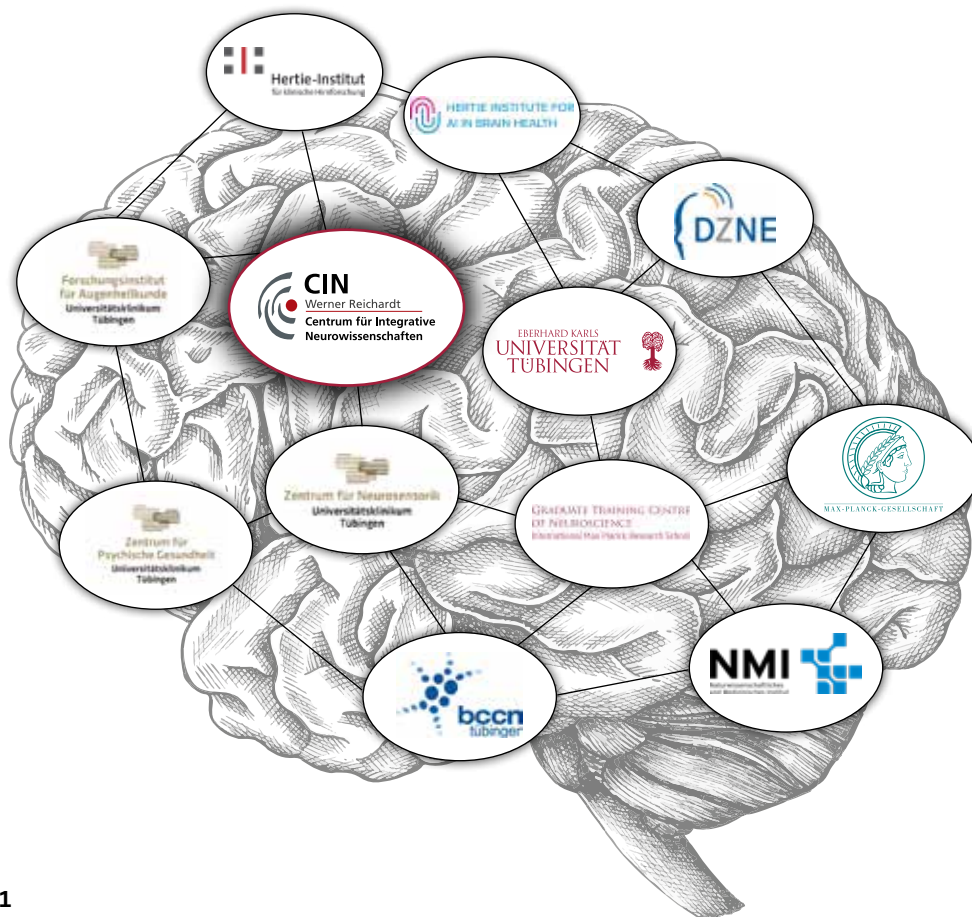


Fig. 1

Tübinger NeuroCampus (TNC) Members

The CIN's mission is to understand the principles of brain function from synapses to large-scale circuits and how these mechanisms give rise to intelligent behavior. To achieve this, the CIN pursues an integrative, systems-oriented approach that connects basic research and computational modeling and spans

methods from the molecular and cellular levels to whole-brain circuits and behavior. This integrative structure directly links to cutting-edge developments in machine intelligence, opening synergies between biological and technological systems and fueling innovation in translational and clinical research.



From 2022 to 2024, the CIN has strengthened its role as a vibrant catalyst for interdisciplinary research, fostering collaboration and launching joint initiatives. Highlights include consortium-scale projects led by CIN PIs, such as the Collaborative Research Center “Robust Vision” (SFB 1233), DFG Research Units (FOR 1847, FOR 5434), and several national and European training networks. In total, five ERC grants (Advanced, Consolidator, Starting, and Synergy) awarded to CIN investigators underscore the excellence and impact of our research.

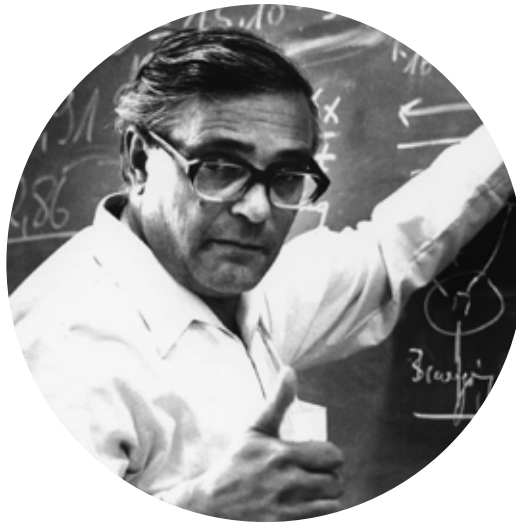


Supporting early-career researchers and training the next generation of neuroscientists lie at the heart of the CIN’s mission. We provide high-quality training at

all levels of the academic career and foster exchange through summer schools, workshops, and international conferences – including the “CIN Exchanges”, the annual “Systems Neuroscience Symposium”, and the “Dialogues between the Neurosciences and the Arts and Humanities.”

Looking ahead, the CIN will deepen its integrative strategy, expand shared research platforms, and strengthen partnerships across the Neuro Campus and beyond. By integrating rigorous experimentation, computational approaches, and responsible translation, we aim

to accelerate discovery, empower young scientists, and turn bold ideas into tangible advances for neuroscience and society.



Werner Reichardt

The Werner Reichardt Centre for Integrative Neuroscience (CIN) is named after Werner Reichardt (1924–1992), a physicist who became one of the pioneers of modern neurobiology. Trained in physics, Reichardt applied the rigor of quantitative methods and theoretical modeling to biological systems, helping to establish the field of biological cybernetics. His research was guided by a central question: how do nervous systems extract and process information from the environment?

Reichardt's most influential work focused on visual motion detection in the fruit fly. Together with his colleagues, he combined precise behavioral experiments with mathematical theory to show how neural circuits can compute motion from spatial and temporal changes in light. The resulting "Reichardt detector" became a cornerstone of visual neuroscience and remains a widely used framework for understanding motion perception. Its influence extends beyond biology, shaping approaches in robotics, computer vision, and artificial intelligence.

Equally significant was Reichardt's vision of science as an interdisciplinary endeavor. He recognized that progress in neuroscience required the combined perspectives of physics, biology, psychology, and engineering. To realize this vision, he co-founded the Max Planck Institute for Biological Cybernetics in Tübingen. Under his leadership, the institute became an international hub where researchers from different fields worked together on shared questions about perception, computation, and behavior.

Reichardt is remembered not only for his scientific contributions but also for his intellectual openness and support of younger colleagues. He fostered an environment where bold ideas could thrive and where theoretical and experimental approaches complemented each other.

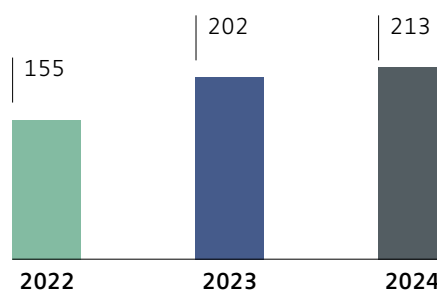
At the CIN, we are proud to carry forward Werner Reichardt's legacy. His integrative approach – uniting theory, experiment, and technology – continues to guide our mission to uncover the principles of brain function across levels, from neural circuits to cognition.

FACTS & FIGURES

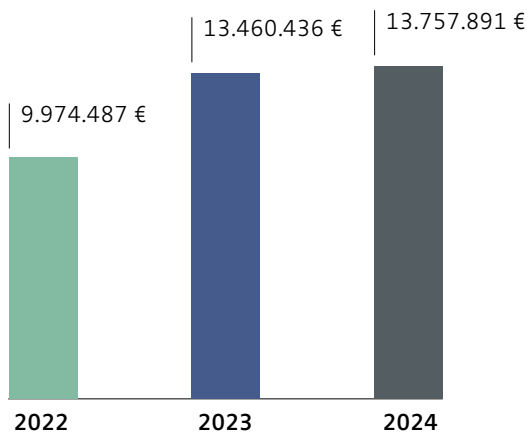
Number of Staff in 2024



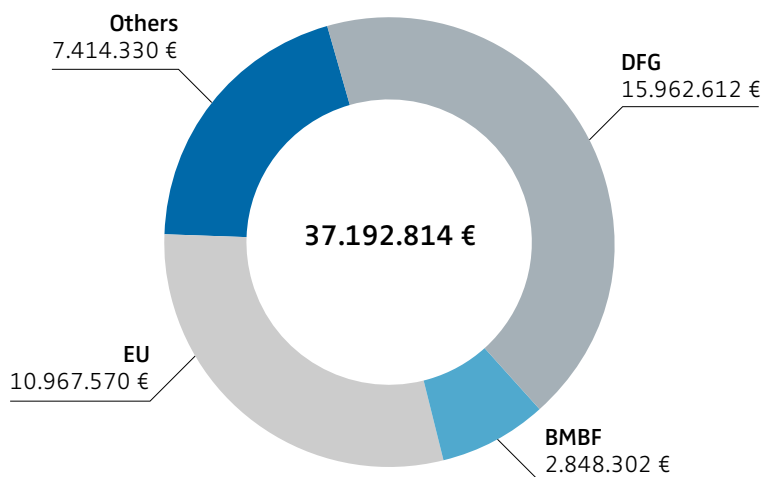
Total number of papers



Third Party Funding



Third Party Funding 2022-2024





DIVERSITY

Excellence thrives on diversity. At the CIN, our strength lies not only in groundbreaking research but in the range of perspectives, experiences, and backgrounds that each member brings. By embracing diversity, we create an environment where innovation flourishes, collaboration deepens, and everyone is empowered to contribute their unique voice.

Our community currently unites scientists from 27 nations, reflecting the international spirit that drives our work and enriches daily collaboration. By welcoming differences in culture, gender, discipline, career stage, and thought, we cultivate a setting where creativity prospers and complex challenges in neuroscience are approached from multiple angles.

We are proud of initiatives that underscore our commitment to inclusion. Mentoring programs such as TüWIN - Tübingen Women in Neuroscience provide guidance, support, and networking for early-career scientists. Complementary workshops and training equip researchers with skills in career planning,

communication, and mentorship, ensuring that everyone has the tools to succeed. Beyond individual development, our collaborative networks - including the Tübingen Neuro Campus, the Graduate Training Centre of Neuroscience, and various collaborative research units - bring together expertise across institutions and disciplines, strengthening our shared pursuit of discovery.

We extend our sincere thanks to all members of our community for their contributions. By continuing to embrace and celebrate our diversity, we not only advance our science - we enrich the shared journey that connects us as a research community.



BOARD AND CENTRAL OFFICE

The CIN maintains by a collaborative and transparent governance structure. The CIN Board manages the Centre's ongoing activities, while major strategic decisions are taken collectively by the congregation of all Principal Investigators.

CIN Board

Elected by all Principal Investigators, the Board consists of five members – a Chairperson, a Deputy Chairperson, and three additional CIN scientists. Together, they translate strategic decisions into action, address

operational matters and represent CIN's interests across institutional, national, and international forums. Meetings of the CIN Board are generally open to all CIN members, promoting transparency and fostering shared responsibility.

Current Members



Prof. Dr. Markus Siegel
Chairperson



Prof. Dr. Thomas Euler
Deputy Chairperson



Prof. Dr. Olga Garaschuk



Jun. Prof. Dr. Anna Levina



Prof. Dr. Steffen Hage

CIN Central Office

The Central Office is the administrative backbone of the CIN, enabling scientists to focus on their core mission: cutting-edge neuroscience. It manages critical research infrastructure – human resources, financial management, and internal grant administration and budgeting – ensures compliance for external funding,

supports public relations and scientific outreach, and provides IT systems administration as well as technical support. The Central Office is supported by the University of Tübingen and the University Hospital, ensuring institutional alignment and resource sharing.

Members of the Central Office



Dr. Katherina Goris
Chief Executive



Lea Grauer
Executive Assistant



Oana Parepa
Administrative Assistant



Susanne Werner-Hansen
System Administrator



Elisabeth Gustafsson
Technical Assistant



Adam von Daranyi
System Administrator

Daniel Semmler
Research Assistant

Frederek Reinecke
Research Assistant

CIN IT

The CIN operates an independent data centre housing a high-performance computing cluster with over 70 nodes, 1,000+ cores, 10TB RAM, and 70+ GPUs optimized for HPC and AI applications. Our energy-efficient infrastructure supports distributed computing and complex deep learning models requiring substantial computing power and scalability.

Cluster Storage and Backup

Our highly available parallel cluster file system provides 1.2 petabytes of storage with individual quotas for 20+ research groups. Nodes connect via 10+ gigabit links to storage heads, which connect through fibre channel to 250+ SAS drives (6TB each), enabling parallel read/write speeds exceeding 1,000 MB/s. Redundancy, load balancing, and fault tolerance ensure reliable operation and uninterrupted access for hundreds of simultaneous users.



Fig. 1

Hot air duct for optimum heat flow



Fig. 2

Export node for highly available cluster storage

To safeguard research data, a dedicated 1-petabyte backup system protects all active cluster storage and supports long-term archiving requirements, including those defined by the FAIR principles for research data management. In addition, two tape libraries equipped

with three drives each and more than 100 tape slots (45 TB per tape) provide secondary backup and project archiving at speeds of up to 1,000 MB/s. This multi-layered backup strategy ensures the long-term security, integrity, and availability of valuable scientific data.

Network Infrastructure

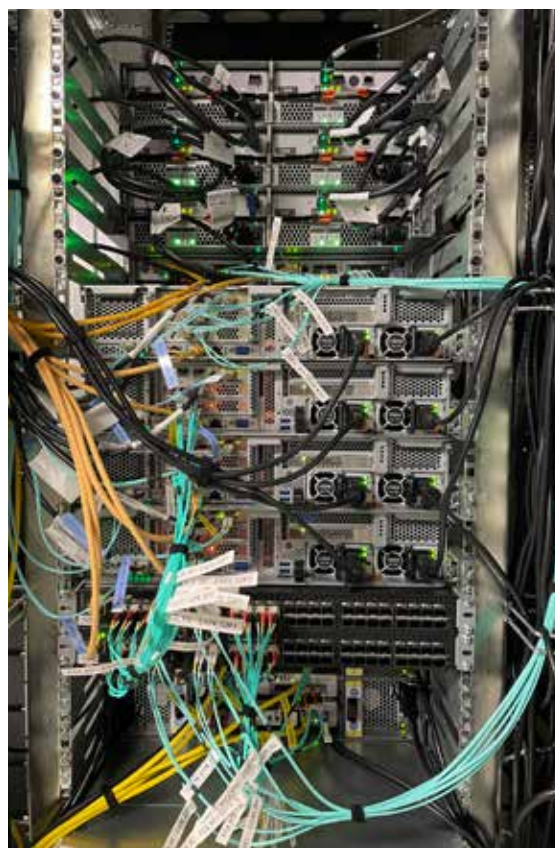
The CIN operates an autonomous and robust network infrastructure with redundant firewalls and clearly separated virtual local area networks (VLANs) to address different security and performance requirements. These include a demilitarized zone (DMZ) for publicly accessible web services, a secure VPN for remote access, and a dedicated 100 GB high-speed backbone network optimized for internal cluster communication. This setup ensures high availability, strong security, and low-latency data transfer across all services.

Additional Services

In addition to the HPC environment, CIN operates a range of supporting services, including database, license, web, cloud storage, and remote login servers, deployed on both dedicated hardware and virtualized platforms. The IT team provides comprehensive support for researchers, covering hardware selection, system configuration, installation, and maintenance, as well as first- and second-level user support. These services ensure reliable day-to-day operation and enable researchers to focus on their scientific work without technical barriers.

**Fig. 3**

Numerous GPU nodes for modern AI applications

**Fig. 4**

HPC cluster for a variety of parallel computing tasks

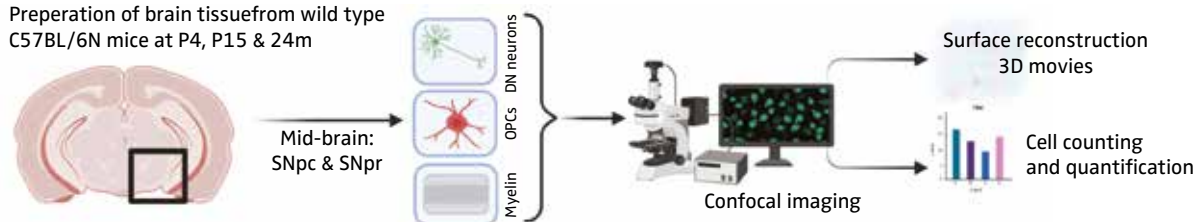
HIH-CIN IMAGING CLUSTER

The HIH–CIN Imaging Cluster (HCIC) was established 2022 within the virtual Microscopy Core Facility of the University of Tübingen and provides comprehensive support for confocal and wide-field light microscopy. Its services span the full imaging workflow—from microscope selection and sample preparation to image acquisition, processing, analysis, and preparation of publication-ready figures. The facility serves researchers from the CIN, HIH, and external groups, offering daily technical assistance, user training, and open workshops. Microscopes are accessible through a shared booking system.

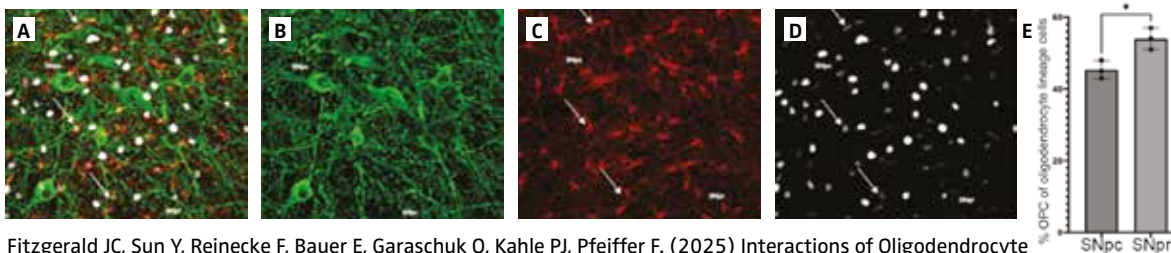
As part of the Microscopy Core Facility, the CIN–HIH Imaging Cluster (HCIC) supports light-microscopy-based research by providing advanced imaging infrastructure, expert guidance, and training. The facility promotes collaborative and interdisciplinary work by ensuring researchers have access to high-quality optical imaging tools and technical expertise.

Optical imaging is essential for studying the nervous system and its disorders. Modern neurobiological models, including mouse and human brain slice cultures and organoids, enable three-dimensional and real-time investigation of complex molecular and cellular processes. Brain slice cultures allow the analysis of synaptic connectivity, calcium dynamics, protein distribution,

Preparation of brain tissue from wild type C57BL/6N mice at P4, P15 & 24m

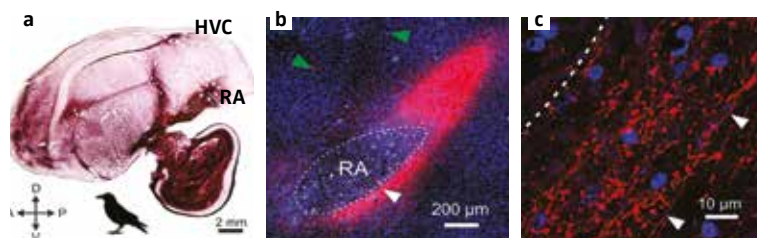


Interactions of Oligodendrocyte Precursor Cells and Dopaminergic Neurons



Fitzgerald JC, Sun Y, Reinecke F, Bauer E, Garaschuk O, Kahle PJ, Pfeiffer F. (2025) Interactions of Oligodendrocyte Precursor Cells and Dopaminergic Neurons in the Mouse Substantia Nigra. *J Neurochem.* 169(1): e16298.

Exploring Anatomical Links Between the Crow's Nidopallium Caudolaterale and Its Song System



(a) Histological slice of the crow brain at ML 5.0 mm (side view) stained against myelin. **(b)** Low magnification image of the arcopallium around the lateral RA (dashed outline) and **(c)** Individual anterogradely labeled NCL fibers (red) at the ventral boundary of RA (dashed line).

Moll FW, Kersten Y, Erdle S, Nieder A. Exploring Anatomical Links Between the Crow's Nidopallium Caudolaterale and Its Song System. (2025) *J Comp Neurol.* 533(2):e70028.

and disease-related cellular events, providing an experimental platform for studying epilepsy and neurodegeneration. These preparations reduce fixation-related artifacts and can be combined with classical cell culture systems to validate pharmacological interventions.

Live imaging approaches can be integrated with morphological analysis of fixed tissue sections, requiring high-performance optical systems with stable environmental control. Confocal microscopy, when correlated with intravital two-photon imaging, links functional activity with structural information. The HCIC supports these workflows by providing high-speed laser-scanning confocal and wide-field microscopes in multiple configurations. These shared systems deliver high-resolution imaging for routine and advanced applications and promote resource-efficient collaboration across research groups.

The facility currently includes four shared microscopes and two analysis workstations. A digital booking system (PPMS) alongside detailed user guidelines, manuals, and standardized training procedures ensure accessibility. Training and community-building activities include a practical workshop on image processing and analysis that is integrated into the "Optical Imaging" course for PhD and MD students as well as instrument demonstrations with industry partners on campus and at external institutions such as EMBL Heidelberg. Public workshops on microscopy software further strengthened the local imaging community and promote best practices.

Looking ahead, The HCIC will broaden its advanced imaging capabilities by establishing fluorescence lifetime imaging microscopy (FLIM) workflows on a newly acquired confocal microscope, enabling detailed analysis of molecular interactions in living systems. A dedicated light-sheet microscope will also be introduced for imaging large, optically cleared samples and generating high-resolution volumetric datasets. These developments will enhance the local imaging infrastructure and reinforce the HCIC's role as a regional center for cutting-edge optical imaging in neuroscience.



SELECTED PUBLICATIONS

Fitzgerald JC, Sun Y, Reinecke F, Bauer E, Garaschuk O, Kahle PJ, Pfeiffer F. (2025) Interactions of Oligodendrocyte Precursor Cells and Dopaminergic Neurons in the Mouse Substantia Nigra. *J Neurochem.* 169(1): e16298.

Kiesel A., Laugwitz L., ... Oleksiuk O, Synofzik M., Haack TB, Peralta S (2024) Elevated cholesterol is a common cellular phenotype for autosomal dominant and recessive ATAD3-associated disorders resulting in membrane cholesterol aggregation. *Brain* awae402.

Kersten Y, Moll FW, Erdle S, Nieder A. Input and Output Connections of the Crow Nidopallium Caudolaterale. (2024) *eNeuro.* 11(4): ENEURO.0098-24.2024.

Shan X, Contreras MP, Sawangjit A, Dimitrov S, Born J, Inostroza M. (2023) Rearing is critical for forming spatial representations in pre-weanling rats. *Behav Brain Res.* 452:114545.

Stajković N, Liu Y, Arsić A, Meng N, Lyu H, Zhang N, Grimm D, Lerche H, Nikić-Spiegel I. (2023) Direct fluorescent labeling of NF186 and NaV1.6 in living primary neurons using bioorthogonal click chemistry. *J Cell Sci.* 136(12): jcs260600.

GROUP LEADER



Olga Oleksiuk
Instrumental manager for Light Microscopy, HCIC

ORGANIGRAM

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A. Nieder
(Inst. Neurobiology)

H.-U. Schnitzler⁽²⁾
(Inst. Neurobiology)

J. Benda
(Inst. Neurobiology)

L. Veit
(Inst. Neurobiology)

H.-Y. Wong
(Philosophy of
Neuroscience)

**Inst.
Neurobiology**

F. Wichmann
(Dep. Computational
Science)

A. Levina
(Dep. Computational
Science)

Z. Li
(Dep. Computational Science;
MPI Biol. Cyb.)

**Dep.
Computational
Science**

A. Bartels
(Dep. Psychology)

M. Bethge
(Inst. Theoretical Physics)

⁽¹⁾ CIN JRGs, contract at UKT

⁽²⁾ Senior professor member

⁽³⁾ Research unit, tentative

Italic: External affiliations

CIN board: Siegel, Euler, Garaschuk,
Hage, Levina

EDUCATION AND TRAINING



INTERNATIONAL EXCELLENCE IN NEUROSCIENCE EDUCATION

The Graduate Training Centre of Neuroscience (GTC) is the central hub for educating young researchers in the neurosciences at the University of Tübingen. In close cooperation with the Werner Reichardt Centre for Integrative Neuroscience (CIN) and numerous partner institutions, the GTC forms an internationally visible, interdisciplinary platform for master's and doctoral programs.

A key strength of the GTC is the integration of its master's and doctoral programs. Many students transition from the master's into the structured doctoral program, joining one of many internationally competitive research groups involved in GTC teaching. This continuity supports a coherent academic pathway from coursework to independent research and helps retain top international talent in Tübingen.

Development of the master's programs

Between 2022 and 2024, all three master's programs were revised and re-accredited with new curricula that adopted the wish of our students for more individual flexibility, at the same time offering opportunities to come together as an interdisciplinary group of young neuroscientists. We continued the basic structure of a mostly theoretical 1st year of studies in lecture and seminars and a 2nd year that is entirely spent in labs for two lab rotations and the master's thesis project. We introduced three newly designed elective modules that allow the students to choose their favorite courses to develop an individual profile. As a result of this revision, each student can decide on about 75% of the individual neuroscience curriculum, an unprecedented level of flexibility and freedom. In this freedom the students are not left alone because of an open-door policy at the GTC, offering individual feedback and counselling on request. A few strategic elements of common teaching, e.g. introductory courses in neuroanatomy and neurophysiology, joint lab rotation seminars, and the TNC Neurocolloquium provide a common, interdisciplinary space to join and share diverse backgrounds and expertise, reflecting the very nature of the Centre for Integrative Neuroscience. With the CIN as a backbone of the GTC faculty and teaching, researchers from all Tübingen neuroscience institutions contribute to the GTC's curricula.

Training and Support for Doctoral Researchers

The doctoral program currently supports over 250 candidates through courses, methods training, and individual counselling. While approximately 40% of our master's graduates continue their academic career in Tübingen by joining the GTC's doctoral program, most doctoral candidates come from other universities and educational backgrounds. To ensure a shared foundation and foster interdisciplinary expertise, external doctoral candidates in particular benefit from GTC's broad portfolio of high-level master's courses. These offerings allow for personalized and structured academic training that complements and extends the candidates' prior education beyond the scope of their respective labs and disciplines. Additionally, the GTC offers specific courses for the doctoral candidates ranging from general science-related



// **The GTC empowers young neuroscientists to grow through freedom and structure.**



skills (e.g. Arduino workshop, coding courses) to typical transdisciplinary skills (e.g. project management, career planning, presentations). The GTC cooperates with centers at the University, which offer digital and transdisciplinary skills courses for young researchers, i.e. the Dr. Eberle Centre for Digital Competences and the University's Graduate Academy, helping the doctoral candidates to navigate through the various offers. Beginning early 2023, the GTC offers bimonthly Zoom Info Sessions for all doctoral students with an average attendance of about 35 doctoral students. The topics of these sessions range from an introduction to the GTC's doctoral program to in-depth discussions of the appropriate use of AI tools in daily research work and writing. This low threshold format often leads to fruitful subsequent Q&A rounds, followed by individual counselling, taking up critical questions from the Info Session.

An outstanding annual event, among others, is organized by the doctoral students themselves and continuously supported by the GTC, the Neurowissenschaftliche Nachwuchskonferenz (NeNa). It provides early-career neuroscientists from Tübingen and beyond with a platform to present their work, exchange ideas, and build interdisciplinary networks. After a successful post-pandemic return as a three-days event, NeNa has continued to grow in reach and relevance. Recent editions featured keynote lectures by leading researchers such as Rosanne Rademaker and Ben Scott and attracted about 60 participants from Tübingen and beyond. The conference's student-led format and informal atmosphere make it a valuable and distinctive element of doctoral training at the GTC.



KEY FIGURES SUMMARY

1999 Initial doctoral regulations

2015 Last revision of doctoral regulations

2022–2024 Master's program revision period

2022 Alumni network via LinkedIn started

2025 Start of new alumni meeting series

2025 First graduating cohort under revised master's curriculum

75% Individual choice within the master's curriculum

40% Master's graduates continuing to PhD at GTC

250+ Current doctoral candidates in the program

3 days Duration of the NeNa conference

60 Participants at recent NeNa conferences

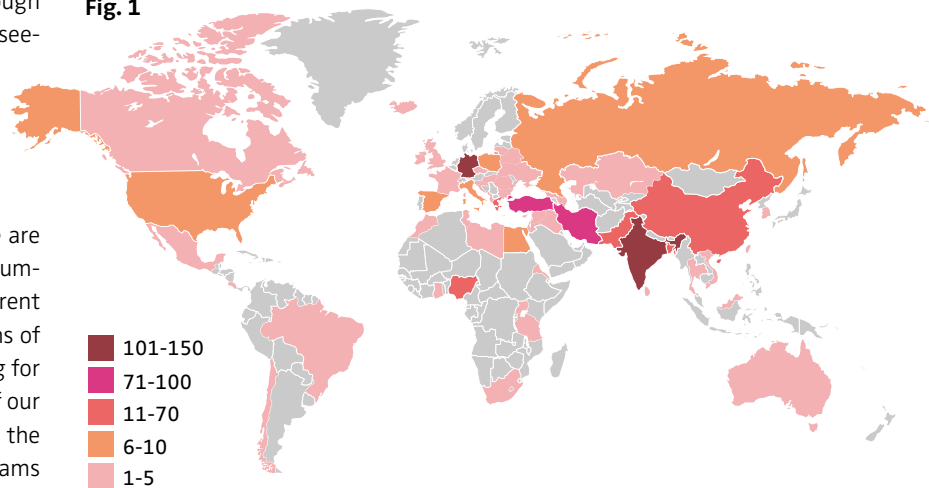
Outlook and Perspective

The revision of the GTC master's programs dramatically changed the way of each student through the master's curriculum. In 2025, the first cohort of students that enjoyed this much freedom will conclude their studies. A second cohort is currently going through the 1st year, and we are foreseeing a thorough evaluation of our changes and revisions for further adjustments, if needed. Further improving our outreach through social media and alumni contacts, we are expecting further increasing numbers of applications. The current numbers call for crucial revisions of our selection procedures aiming for higher efficiency and validity of our decisions. While we focused on the revisions of the master's programs in 2022-2024, it is about time to evaluate and revise the GTC's doctoral program. We made first steps towards a thorough revision of the GTC's interfaculty doctoral regulations, which date back to their original formulation in 1999 and the first revision in 2015. We'll have to incorporate more recent changes in modern research environments and institutes. Beginning in 2022, we established a network with our Alumni through LinkedIn that we would like to build on in the next years. 2025 will see the beginning of a new Alumni meeting series, offering master's and doctoral students direct contacts with their predecessors.



Global Reach of GTC Applicants

Fig. 1



GTC master's programs applications 2022-2024

Fig. 2

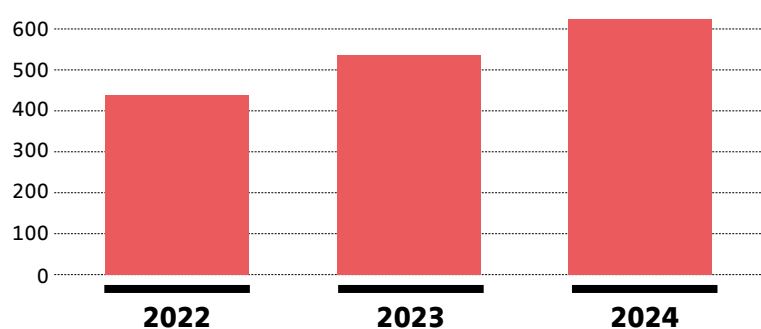


Fig. 1 + Fig. 2

Development of application

Figure 1 shows the geographic distribution of the applicants' citizenships in 2024. Figure 2 shows numbers for the three international master's programs at the Graduate Training Centre of Neuroscience (GTC) from 2022 to 2024.

PUPIL LAB

In 2024, the activities of the Neuroscience Pupil Lab continued to focus on the visits of the biology courses of high-schools. Overall, more than 70 of these courses visited to the Pupil Lab, approximately 1.000 high-school students, and performed experiments which are related to actual neurobiological research topics (such as eye-tracking, brain-computer interface, or behavioral studies). The students are supervised by specially trained teaching assistants who are funded among others by the CIN. In addition to perform the experiments, the students also analyze the obtained data, prepare presentations and present it in the concluding seminar in plenary. The unique selling point of the Pupil Lab is the possibility to perform mind-on experiments, in contrast to hands-on experiments of many other out-of-school learning facilities.

In addition to the activities for the entire school classes, the Pupil Lab also offers special project for highly motivated individual pupils. In 2024, 13 pupils performed a weekly practical called BOGY in order to orient themselves with respect of later profession. Three pupils performed experiments for individual term paper in Biology. And finally, 17 pupils participated at the Summer Academy of Neuroscience, which lasted for one week (July, 29th to August, 2nd). The participants of the academy came from Istanbul, Athens or Luxemburg to Tübingen.

In order to promote especially girls, the Pupil Lab participated at the Girls' Day initiative on April, 25th. 16 girls were fascinated by the mysteries of the brain, optical illusion as well as the particularities of the human senses. The Pupil Lab also offers young children the access to Neuroscience. Approximately 200 pupils from different elementary schools examined their abilities to see, hear, and feel as well as illusions of their senses.

The teacher education on February 22nd aimed towards the introduction of the Institute of Neurobiology. The lectures ranged from counting crows to oculomotor control in zebrafish and provided new input for close to 100 biology teachers for their classes in high-schools.

Finally, the Pupil Lab also contributes to the education of future high-school teachers (Bachelor and Master of Education in Biology).



Fig. 1

The Pupil Lab is accommodated in the building formerly known as Medical-Life-Science Center of the University of Tübingen.

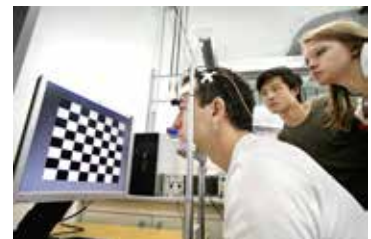


Fig. 2

In order to address higher cognitive functions, pupils record visual-evoked potentials (VEP). The take home message here is the observation that it takes approximately 100 ms to measure the first activity in the visual cortex known as p100. The pupils recognize that this slowness of the visual response is able to explain misperceptions as the Flash-Lag effect or the representational momentum.

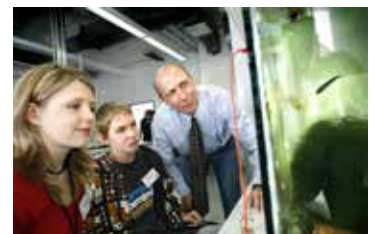


Fig. 3

Weakly electric fishes are subject for behavioral experiments in the Pupil Lab. Here, the Head of Pupil Lab, Prof. Uwe Ilg (right) explains the behavior together with the voltages generated by knife-fishes in the aquarium

OUR GLOBAL COLLABORATORS





COLLABORATOR MAP

North America

- Canada – Google DeepMind, Toronto (Robert Geirhos)
- Canada – McGill University, Montreal (Michael Petrides)
- Canada – University of Toronto Scarborough, Toronto (Tod Thiele)
- USA – Baylor University, Waco (Katrin Franke)
- USA – Columbia University, Nathan Kline Institute, New York (Charlie Schroeder)
- USA – Duke University, Durham (Richard Mooney)
- USA – Georgia Institute of Technology, Atlanta (Prof. Dr. Garrett Stanley)
- USA – Johns Hopkins University, Baltimore (Leyla Isik)
- USA – Johns Hopkins University, Baltimore (Prof. Cindy Moss)
- USA – Massachusetts Institute of Technology, Cambridge (Earl Miller)
- USA – Massachusetts Institute of Technology, Cambridge (Jonathan Polimeni)
- USA – National Eye Institute, Bethesda (Prof. Wei Li)
- USA – Northwestern University, Chicago (Emma Alexander)
- USA – Princeton University, Princeton (Prof. Tatiana Engel)
- USA – Princeton University, Princeton (Sebastian Seung)
- USA – Rockefeller University, New York (David Hildebrand)

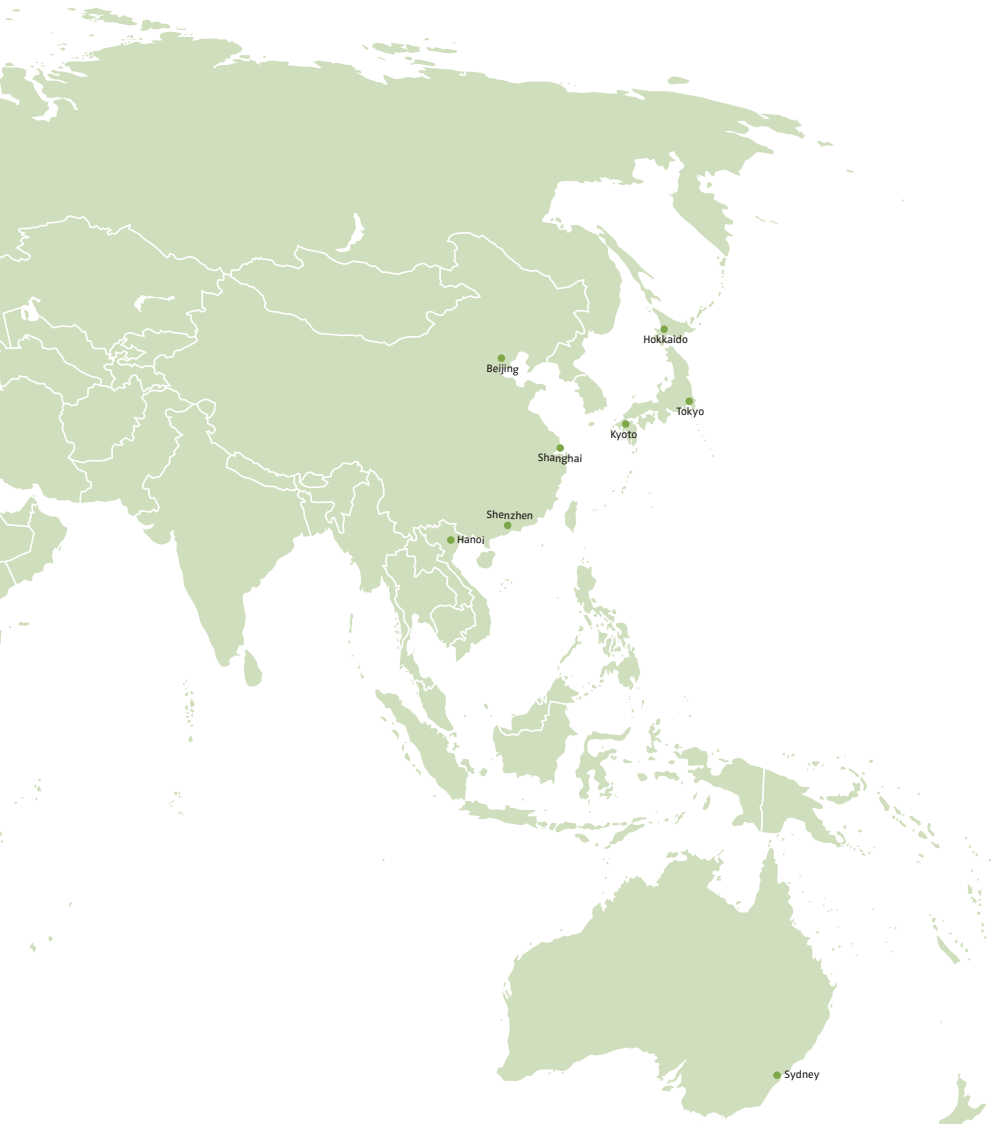
- USA – Stanford University, Stanford (Andreas Tolias)
- USA – University of Alabama, Tuscaloosa (Dr. Kristina Visscher)
- USA – University of California, Berkeley (Emily Cooper)
- USA – University of California, Berkeley (Prof. Dr. Gasper Begus)
- USA – University of California, San Francisco (Michael Brainard)
- USA – University of California, San Francisco (Prof. Dr. Marilu Gorno-Tempini)
- USA – University of Maryland, College Park (Scott Juntti)
- USA – University of Rochester, Rochester (Jessica Cantlon)
- USA – University of Wisconsin, Madison (Chiara Cirelli)
- USA – Vanderbilt University, Nashville (Prof. Dr. Reyna Gordon)

South America

- Colombia – Universidad de los Andes, Bogotá (Jorge Molina)
- Brazil – Federal University of Rio Grande do Norte, Natal (Daniel Takahashi)
- Chile – Pontificia Universidad Católica de Chile, Santiago (Pablo Fuentealba)
- Argentina – Instituto Tecnológico de Buenos Aires, Buenos Aires (Cecilia Forcato)
- Uruguay – University of the Republic, Montevideo (Ana Silva)

Europe

- Austria – University of Graz, Graz (Dr. Natalia Zaretskaya)
- Belgium – KU Leuven, Leuven (Rufin Vogels)
- Belgium – KU Leuven, Leuven (Tinne Tuytelaars)
- Belgium – KU Leuven, Leuven (Wim Vanduffel)
- France – Centre national de la recherche scientifique, Marseille (Prof. Dr. Rochelle Ackerley)
- France – Centre national de la recherche scientifique, Paris (Prof. Dr. Frederique de Vignemont)
- France – European Research Biology Center, Baugy (Pascal Champeroux)
- France – INSERM-CEA Cognitive Neuroimaging Unit, Gif-sur-Yvette Cedex (Stanislas Dehaene)
- France – Institut de la Vision, Paris (Olivier Marre)
- France – Institut Imagine, Paris (Michela Deleidi)
- Germany – Carl von Ossietzky University of Oldenburg, Oldenburg (Jan Clemens)
- Germany – Charité Berlin, Berlin (Dr. Matthias Guggenmoos)
- Germany – Charité Berlin, Berlin (Prof. Dr. Martin Holtkamp)
- Germany – Federal Institute of Physics and Metrology, Berlin (Thomas Middelmann)



- Germany – Helmholtz center Munich, Munich (Eric Schulz)
- Germany – Humboldt University of Berlin, Berlin (Benjamin Lindner)
- Germany – Humboldt University of Berlin, Berlin (Manuela Friedrich)
- Germany – Humboldt University of Berlin, Berlin (Ruediger Krahe)
- Germany – Ludwig-Maximilians-University Munich, Munich (Laura Busse)
- Germany – Max Planck Institute for Intelligent Systems, Stuttgart (Christoph Keplinger)
- Germany – Saarland University, Saarbrücken (Prof. Dr. Roland Bennewitz)
- Germany – Technical University of Berlin, Berlin (Marianne Maertens)
- Germany – University and Max Planck Institute, Göttingen (Prof. Viola Priesemann)
- Germany – University Bayreuth, Bayreuth (Roy Müller)
- Germany – University Cologne (Matthias Hammerschmidt)
- Germany – University Giessen, Giessen (Stefan Hebart)
- Germany – University Medical Center Hamburg-Eppendorf, Hamburg (Boris Fehse)
- Germany – University Medical Center, Kiel (Prof. Thorsten Bartsch)
- Germany – University Münster, Münster (Prof. Michael Ziller)
- Germany – University of Heidelberg, Heidelberg (Dr. Kevin Allen)

- Germany – University of Heidelberg, Heidelberg (Frank Winkler)
- Germany – University of Heidelberg, Heidelberg (Lorenzo Masia)
- Germany – University of Heidelberg, Heidelberg (Prof. Andreas Draguhn)
- Germany – University of Heidelberg, Heidelberg (Prof. Dr. Christoph W. Korn)
- Germany – University of Stuttgart, Stuttgart (Jens Anders)
- Germany – University of Stuttgart, Stuttgart (Syn Schmitt)
- Germany – University of Stuttgart, Stuttgart (Tobias Siebert)
- Hungary – Eötvös Loránd University, Budapest (Eszter Kozma)
- Hungary – Hungarian Academy of Sciences, Budapest (Istvan Winkler)
- Hungary – Hungarian Academy of Sciences, Budapest (Péter Kele)
- Italy – Suor Orsola Benincasa University, Naples (Antimo Buonocore)
- Italy – University of Parma, Parma (Prof. Dr. Vittorio Gallese)
- Netherlands – Leiden University, Leiden (Andrew Webb)
- Netherlands – Maastricht University, Maastricht (Beatrice de Gelder)
- Netherlands – University of Amsterdam, Amsterdam (Efstratios Gavves)
- Scotland – University of Glasgow, Glasgow (Alessio Fracasso)
- Spain – Spanish National Research Council, Madrid (Marcelo Bertalmio)

- Spain – University of Barcelona, Barcelona (Prof. Jordi Soriano Fradera)
- Spain – University of Valencia, Valencia (Jesús Malo)
- Sweden – Lund University, Lund (Johan Jakobsson)
- Switzerland – Federal Institute of Technology, Zürich (Mackenzie Mathis)
- Switzerland – University of Lausanne, Lausanne (Prof. Manuel Mameli)
- United Kingdom – Cambridge University (Nicola S. Clayton)
- United Kingdom – King's College London, London (Dr. Adrian Alsmith)
- United Kingdom – University College London, London (Matthew Whelan)
- United Kingdom – University of Bristol, Bristol (Prof. Dr. Alan Champneys)
- United Kingdom – University of Essex, Colchester (Hong-Viet Ngo)
- United Kingdom – University of London, London (Prof. Dr. Matthew Longo)
- United Kingdom – University of Manchester, Manchester (Axel Verkhatsky)
- United Kingdom – University of Southampton, Southampton (Diego Gomez-Nicola)
- United Kingdom – University of Sussex, Brighton (Tom Baden)
- United Kingdom – University of Warwick, Coventry (Prof. Dr. Stephen Butterfill)

Asia

- China – Beijing Normal University, Beijing (Prof. Wu Li)
- China – Inst. of Advanced Technology, Shenzhen (Dr. Robert Naumann)
- China – Institute of Neuroscience, Shanghai (Dr. Zhiming Shen)
- China – International Center for Primate Brain Research, Shanghai (Nikos Logothetis)
- China – University of Science and Technology of China & Center for Brain Information, Shenzhen (Prof. Guoqiang Bi)
- Israel – Bar-Ilan University, Ramat Gan (Shahar Alon)
- Israel – Tel Aviv University, Tel Aviv (Prof. Yossi Yovel)
- Israel – Weizmann Institute of Science, Rehovot (Prof. Elisha Moses)
- Israel – Weizmann Institute of Science, Rehovot (Tamar Flash)
- Israel – Weizmann Institute of Science, Rehovot (Yarden Cohen)
- Japan – Doshia University, Kyoto (Prof. Shizuko Hiryu)
- Japan – Hokkaido University, Sapporo (Masatoshi Yoshida)
- Japan – Kyoto University, Kyoto (Tadashi Isa)
- Japan – University of Tokyo, Tokyo (Mayu Takahashi)
- Japan – University of Tokyo, Tokyo (Prof. Dr. Isao Shimoyama)
- Japan – University of Tokyo, Tokyo (Prof. Dr. Masatake Watanabe)
- Vietnam – Insitute of Ecology and Biological Resources, Hanoi (Prof. Vu Dinh Thong)

Afrika

- The Gambia – Medical Research Council Unit, Serekunda (Bubacarr Bah)

Australia

- Australia – Neuroscience Research Australia, Sydney (George Paxinos)

RESEARCH GROUPS

SYSTEMS NEUROBIOLOGY

As an animal actively navigates, or is passively carried through its environment, its eyes receive continuous visual motion signals generated by its movement relative to the surroundings. How does the vertebrate brain process such visual information and prepare appropriate locomotor and eye movement behavior?

Our group investigates the underlying neural circuits in zebrafish larvae. We study visual brain areas, (pre-) motor brain areas and their interaction and aim to understand how optic flow is filtered by the optic tectum and the pretectum to mediate behavioral responses. Recently, we began to characterize the identified circuits also in the context of natural zebrafish habitats and behavioral needs, in an effort to better understand the specific adaptations of the zebrafish brain. To improve animal welfare, we allocate twenty percent of the lab's research activity to welfare-related projects. In the near future, we plan to establish holographic photostimulation of optogenetic fish lines in our laboratory to identify causal relationships in neural circuits, e.g. those underlying eye position stability.

VISION / EYE MOVEMENTS / RECEPTIVE FIELD / OCULOMOTOR / EGO-MOTION

Zebrafish larvae are well-suited for exploring vertebrate brain functions because their brain is relatively simple and translucent, so one can see and manipulate activity directly. We use a combination of optogenetics, two-photon microscopy, genetics, behavioral assays, as well as other physiological approaches and computation to investigate the architecture and mechanisms of the larval neural circuitry.

Encoding of self-motion in the diencephalon

To mechanistically predict behavior and understand the emergence of self-motion perception in vertebrate brains, it is essential to systematically characterize the motion receptive fields of optic-flow-processing neurons. We developed a receptive field mapping method that depends on Contiguous Motion Noise and reverse correlation. In combination with calcium imaging, we

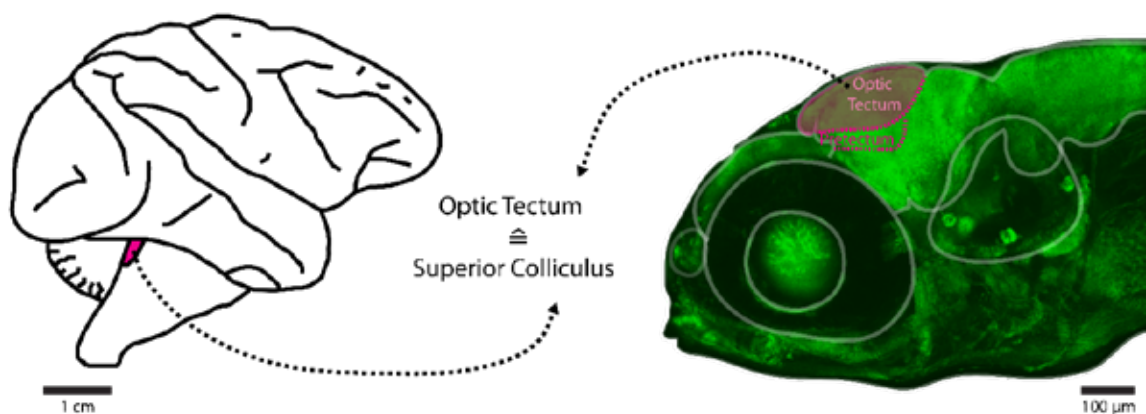


Fig. 1

Comparison of two homologous brain structures of zebrafish and monkeys, which are investigated in a project on active vision together with Ziad Hafed. Right: side view of a 6 day old fluorophore-transgenic zebrafish larva.

recently demonstrated the fine-scale receptive fields of thousands of motion-sensitive neurons in the diencephalon and the midbrain of zebrafish. We found neurons that serve as linear filters and robustly encode directional and speed information of translation-induced optic flow. These neurons are topographically arranged in pretectum according to translation direction. The unambiguous encoding of translation enables the decomposition of translational and rotational self-motion information from mixed optic flow. In behavioral experiments, we successfully demonstrated the predicted decomposition in the optokinetic and optomotor responses. Together, this study revealed the algorithm and the neural implementation for self-motion estimation in a vertebrate visual system.

Visual circuit adaptations to natural environments

In a collaboration with UC Berkeley and the University of Toronto Scarborough, we studied efficient encoding of ego-motion from natural underwater motion videos that we had recorded in India in 2019. Together with our collaborators we showed computationally that noisy natural environments favor visual systems that extract spatially biased samples of optic flow when estimating self-motion. The identified optimal strategy is consistent with our recent neurophysiological and behavioral findings on the optomotor response and can explain the organization of neural representations and behavior in the context of evolutionary adaptation to the habitat. We are planning to continue this line of research on efficient encoding and the adaptations of the vertebrate brain.

Saccadic suppression: from zebrafish to primates

Next to adaptations to the environment, sensory systems are prepared to operate during behavior which can alter the sensory stimuli themselves, such as visual stimuli during eye movements. In a collaboration with Ziad Hafed's research group at the CIN we study saccadic suppression across species (from zebrafish to primates). We already showed that saccadic suppression exists in zebrafish. Our goal is to understand potential convergent evolutionary principles that might explain both the qualitative similarities and quantitative differences between species and might be related to the vast difference in brain size. Our investigation of the evolutionarily more ancient zebrafish brain might help to clarify long-lasting debates about the involvement of homologous brain structures in mammalian saccadic suppression.

Our basic research program aims to reveal and understand information processing of the sub-cortical vertebrate brain. Our focus is on vision research, and we have further projects on oculomotor circuits, methods development, and animal welfare.



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GROUP LEADER



Aristides Arrenberg
Head of Research Group
Systems Neurobiology

VISION AND COGNITION LAB

We study high-level visual perception in the human brain, focusing on real-life problems: how does the brain represent space around me, my movement, that of objects around me? What differentiates conscious from non-conscious perception? How do we segment scenes? How do we robustly identify objects under variable viewing conditions? How are dynamics in faces or bodies encoded? Our studies include links to attention, memory, emotions, and social interactions. We use illusions, magic tricks, and natural stimuli to probe the brain. We work with clinicians to gain insights on disorders such as autism, schizophrenia, and ADHD.

Methodologically we use non-invasive brain imaging (3T and 9.4T fMRI), and we perturb neural processing using transcranial magnetic stimulation (TMS), also simultaneously during fMRI. Deep neural networks (DNNs) are central for data analyses, model-building, and stimulus generation.

VISUAL PERCEPTION / fMRI / TMS / DEEP NEURAL NETWORKS

We seek to understand the neural mechanisms that allow the brain to make sense of our surrounding world. Some of our key research questions are the following. Illusions, Magic tricks, and Eye movements

Illusions open experimental windows into questions of consciousness, scene segmentation, perceptual grouping, Gestalt perception, and prior knowledge.

For example, we identified parietal regions, using fMRI and video-navigated TMS, as causal contributors to Gestalt perception. We also found that early cortex, down to V1, is a drawing board for predictive feedback of illusory content (work with Pablo Grassi, Natalia Zaretskaya). It encodes illusory boundaries, fore- and background of illusory objects, and even the colours of objects presented in grayscale.

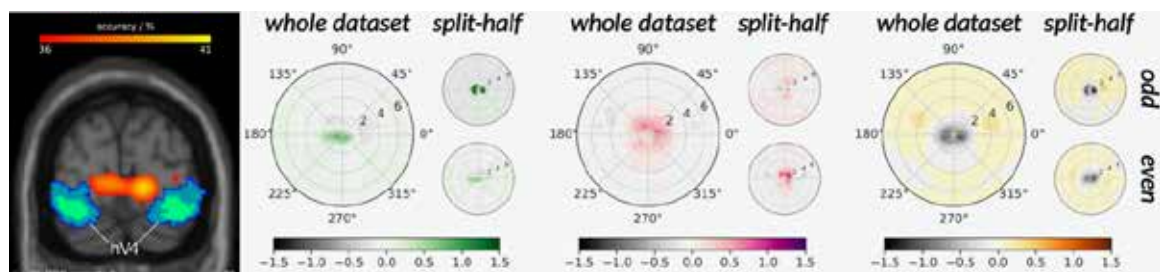


Fig. 1

What are the commonalities across individuals' brains when seeing different colours? The brain on the left shows regions (in red) that allowed "brain reading" which colour a person saw based on a classifier that was trained on colour responses in other people's brains. Across-brain colour prediction was in part possible due to biases across the visual field that are unique for each colour and brain area: the circular plots show visual fields and their preference for yellow, purple and green (fovea in the middle). From: Bannert and Bartels 2025, Journal of Neuroscience, in press.

Magic tricks allow us to explore expectation violations and predictive processing, as well as philosophical implications of magic and the brain (with Pablo Grassi, Vincent Plikat, and Hong Yu Wong). It turns out that even mid- and early visual areas encode visual real-world expectation violations. Prior knowledge – i.e. trick-explanation, modulates visual and higher-level cortex.

Eye movements tell us about saliency: what is important to us? We try to figure this out using deep learning models, behaviour, and by identifying neural substrates encoding saliency in human fMRI. We ask: do visual motion, high-level content, or scene segmentation contribute to saliency (work with Michael Bannert, Peter El-Jiz, Hardik Bhatnagar, and the Bethge-Group)?

Objects, human bodies, and working memory

Human body and **face** perception are central for high-level cognition, social and emotional skills. We use them also to study invariances and compositionality – the idea that individual features combine into and define objects or their viewing conditions – of neural representations. We found human brain regions encoding identities of people regardless of whether bodies or faces were viewed. A subset of regions also encoded gender or weight, or the orientation of bodies and faces (work with Celia Foster, Isabelle Bühlhoff, Mintao Zhao and Michael Black). Our interests extend to dynamics in facial motion, in body posture, and people interactions. We will soon endeavour studies of **human attachment** (with Agustín Sainz Ballesteros).

Working memory is a key to cognition, allowing us to keep objects and their properties in mind, allowing for adaptive behaviour that can be studied using serial dependence paradigms. We use TMS and combined TMS-fMRI to probe causal contributors to working memory in both, early visual cortex and in parietal regions (work with Pablo Grassi, and Raymundo Azevedo de Neto).

Natural scenes, motion, and space

Natural scenes (such as feature movies) are fascinating: they contain most visual input our brain evolved in. Alongside controlled paradigms, we use natural and ground-truth stimuli to examine how the brain encodes physical properties of the visual world, such as depth fields, velocities, objects, colours and illumination (work with Michael Bannert, Peter El-Jiz, Michael Black). Finally we examine cross-modal integration of visual with body-related signals (efference copies of muscle-movements, proprioceptive and vestibular signals) that provide perceptual stability.



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GROUP LEADER



Andreas Bartels
Head of Research Group
Vision and Cognition Lab

NEUROETHOLOGY

We aim to understand general principles of neural information processing. In our *in vivo* and *in vitro* electrophysiology experiments we measure cellular properties of single neurons in response to sensory stimuli and/or injected currents. With methods from computational neuroscience we analyze the recordings and create, simulate, and analyze models in order to generalize our experimental results. We quantify animal behavior, communication signals and natural sensory stimuli in the lab as well as in natural habitats to better understand the design and operating regimes of neural systems. Consequently, we are also interested in the evolution and ecology of our favorite model animals, neotropical electric fish.

COMPUTATIONAL NEUROSCIENCE / NEUROPHYSIOLOGY / SENSORY SYSTEMS / ANIMAL COMMUNICATION / ELECTRIC FISH

During the last five years we have made progress in three research directions: (i) electric fish behavior, (ii) non-linear aspects of sensory encoding, (iii) simulations of ion channel variants in the context of epilepsy.

Observing electrocommunication in the wild

For a better understanding of the function of sensory systems a quantification of natural sensory scenes and the behavioral relevance of specific signals is important. We are developing hardware and software

that allows to track electric fishes and their electrocommunication signals in the lab and in the wild without tagging by recording their self-generated electric fields (Henninger et al. 2020, Migliaro et al. 2025). With these techniques we explore how various types of electrocommunication signals are used in the context of aggression, social dominance, and courtship (Raab et al. 2021). This behavioral data pointed us to difficult but behaviorally relevant regimes of sensory stimuli.

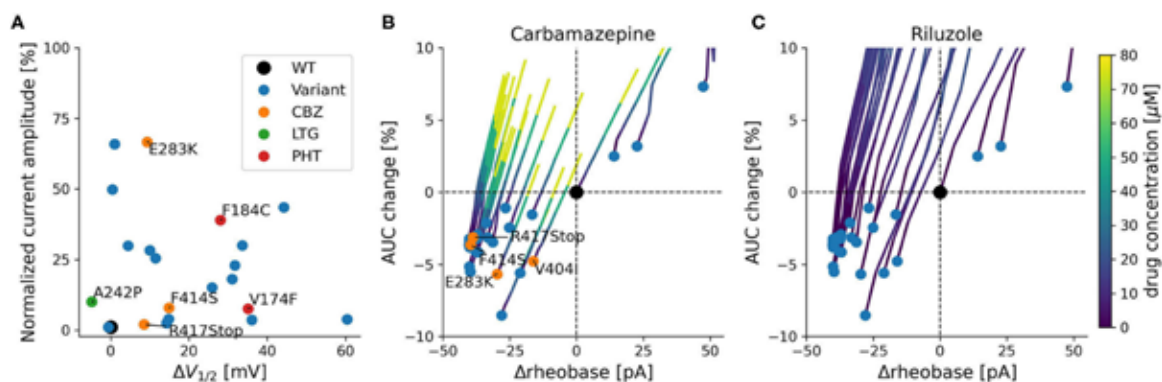
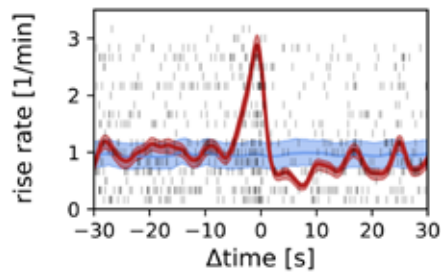


Fig. 1

Simulating the effects of drugs in restoring neuronal function (Lauxman et al. 2021, Fig 3). A) Variants of KCNA1 currents differ in their activation curve and current amplitude. B & C) Simulations showing how different concentrations of Carbamazepine and Riluzole, sodium channel blockers, might restore two properties of neuronal firing towards the wild type (black dot in the origin).

**Fig.2**

The emission of rises, a specific type of electrocommunication signals, is significantly enhanced right before the onset of ritualized chasing events in staged competitions between pairs of the brown ghost knifefish, *Apteronotus leptorhynchus* (Raab et al. 2021, Fig 6A).

Non-linear encoding in sensory systems

In electrophysiological experiments we explore how these are encoded and processed in the electrosensory system. Together with simulations and mathematical derivations we demonstrated how multiple stimulus frequencies are simultaneously encoded in sensory cells (Sinz et al. 2020) and how amplitude modulations arising by stimulation with very high frequencies are extracted by specific non-linearities that are known from synaptic transmission (Barayeu et al. 2023). The latter might explain the physiological basis of the perception of beats also at mistuned octaves that have been studied by Ohm and Helmholtz in the 19th century. We are now investigating how non-linearities introduced by the spike-generator itself are potentially boosting the detectability of weak stimuli in the presence of distractors (Schlungbaum et al., 2024).

Predicting neuronal firing in the context of genetic epilepsies

With our expertise in simulating models of neuronal activity we contribute to a better understanding of the effects of ion channel variants on neuronal excitability in the context of genetic epilepsies. We demonstrated that non-affected ionic currents influence the phenotype of ion channel variants. Consequently, the effects of variants on neuronal firing depend on the specific neuron type in which these variants are expressed (Koch et al. 2023).

Outlook

In the coming years we are going to expand our field studies in collaboration with various colleges in South America for a comparative approach on electrocommunication in gymnotiform weakly electric fish and the electric eel. This will be further accompanied by electrophysiological experiments, with a focus on efficient coding in sensory systems in general. In our research on ion channel variants we are going to tackle the still missing gap between the various potentially powerful models for simulating neuronal activity (see Figure) and the still missing precise experimental techniques needed for specifying these models. Closing this gap would pave the way for predictions and suggesting personalized treatment options.



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Henninger J, Krahe R, Sinz F, Benda J. Tracking activity patterns of a multi-species community of gymnotiform weakly electric fish in their neotropical habitat without tagging. *J. Exp. Biol.* 2020;223:jeb206342.



GROUP LEADER

**Jan Benda**

Head of Research Group
Neuroethology

DATA SCIENCE

We analyze large and complex data sets in neuroscience and ophthalmology to advance our understanding of the healthy eye and brain and how they are affected by degenerative diseases. To this end, we pursue a data science approach, using machine learning, mechanistic modeling and visualization to generate knowledge from data. We believe that data holds the key to answering many questions about how the healthy eye and brain works and how diseases impact its function, how they can be detected early and how their time course can be predicted. We are the interface that brings together data with domain knowledge and the most suitable algorithm to distill insight into scientific or clinical questions.

COMPUTATIONAL NEUROSCIENCE / MACHINE LEARNING / MEDICAL AI

Mission

With our clinical partners in the Department of Ophthalmology, we develop interpretable algorithms for improving clinical decision-making, detecting degenerative diseases of the eye or the brain early and modelling their time course. We analyse fundus images as well as optical coherence tomography (OCT) data, and focus on major causes of vision impairment such as diabetic retinopathy and age-related macular degeneration. We focus on algorithms that enable clinicians to do their work more effectively or that further our understanding of the disease.

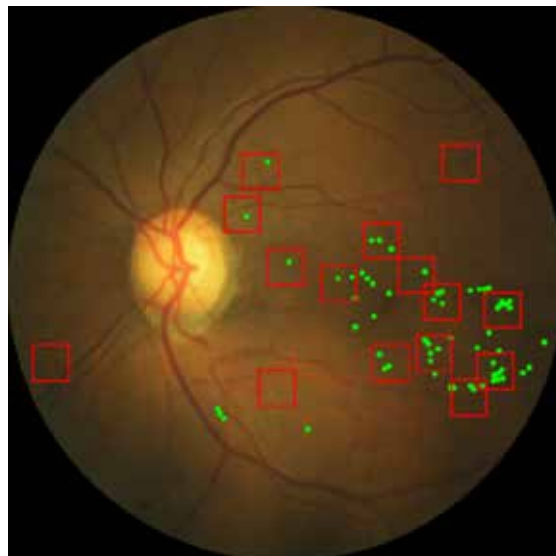
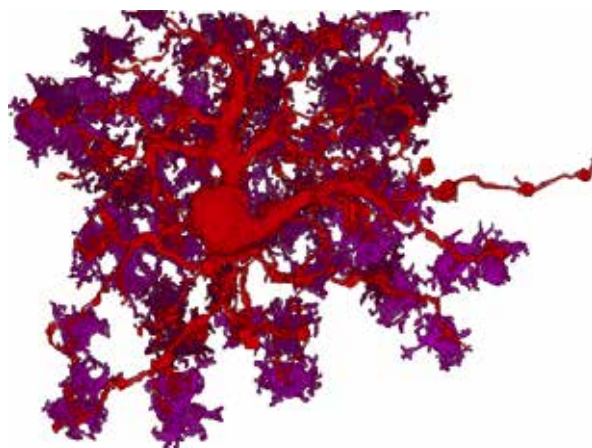


Fig. 1

A fundus image of the eye background including AI-based annotations

**Fig. 2**

Electron microscopy image of retinal cones (purple) and a horizontal cell (red)

Methods

In basic research, we work in close collaboration with our experimental partners to integrate diverse data sources such as electrophysiological and functional recordings, single cell transcriptomics and high-resolution anatomical data to link the computations performed by individual cell types to their genetics and anatomy and we strive to understand how these neural computations are affected in degenerative diseases. To this end, we develop novel techniques for visual exploration of high-dimensional data and work on new hybrid models incorporating mechanistic and statistical components.

Recent achievements

We have received approximately 900,000 € of third-party funding in 2023 and collaborated with numerous national and international partners. The research highlights in the reporting period include publication of an early version of an inherently interpretable deep learning model which was presented as an Oral Presentation at the MIDL Conference. In addition, we published a multitask learning framework for activity detection in neovascular AMD in TVST.

Future direction

Looking ahead, we focus on further research on interpretable machine learning for medical imaging time series data in ophthalmology, mechanistic model frameworks for retinal circuits and representation learning for scientific datasets including images and text.



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GROUP LEADER



Philipp Berens
Head of Research Group
Data Science

COMPUTATIONAL NEUROSCIENCE & MACHINE LEARNING

We aim to bridge neuroscience and artificial intelligence (AI), transforming fundamental questions about the mind into empirical research. While AI originated with inspiration from neuroscience, it is now advancing toward general intelligence largely independently focusing on foundation models, infrastructure and tools. Yet, there are innumerable untapped opportunities to use AI for reverse-engineering the neural algorithms of the brain.

A key puzzle in cognitive neuroscience is how the brain selectively updates its compressed, holistic representation of lifelong incoming data. This integrative, experiential learning is essential to understanding subjective reality, and deciphering the brain's algorithms for constructing reality offers a profound computational approach to integrative cognition.

Our research focuses on developing and benchmarking algorithms that unify self-logging, compositional representation learning, and planning to achieve human-like integrative learning. By utilizing lifelong learning tasks - such as open-ended navigation and skill improvement in games - we aim to benchmark machines' ability to mimic human learning behavior.

COMPUTATIONAL NEUROSCIENCE / NEURO AI / DEEP LEARNING / ROBUST VISION / MACHINE LEARNING

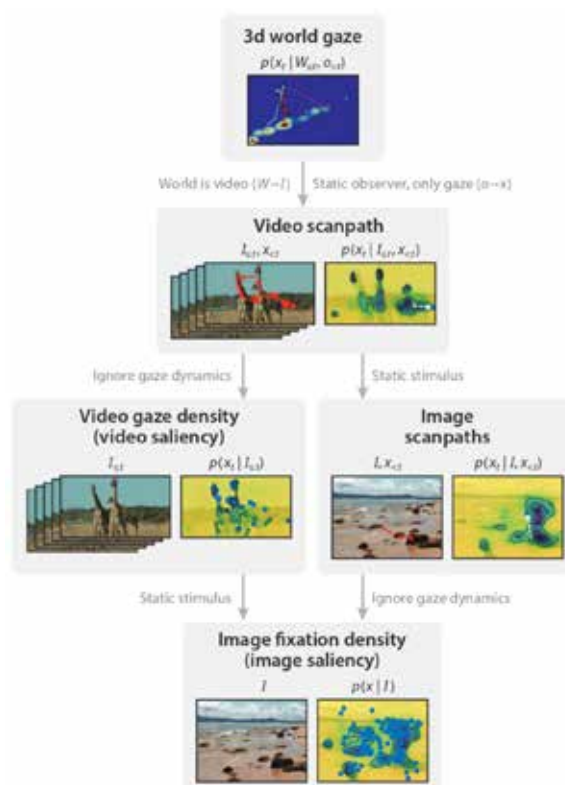


Fig. 1

Predicting where we look. A three-dimensional world gaze saliency illustration.

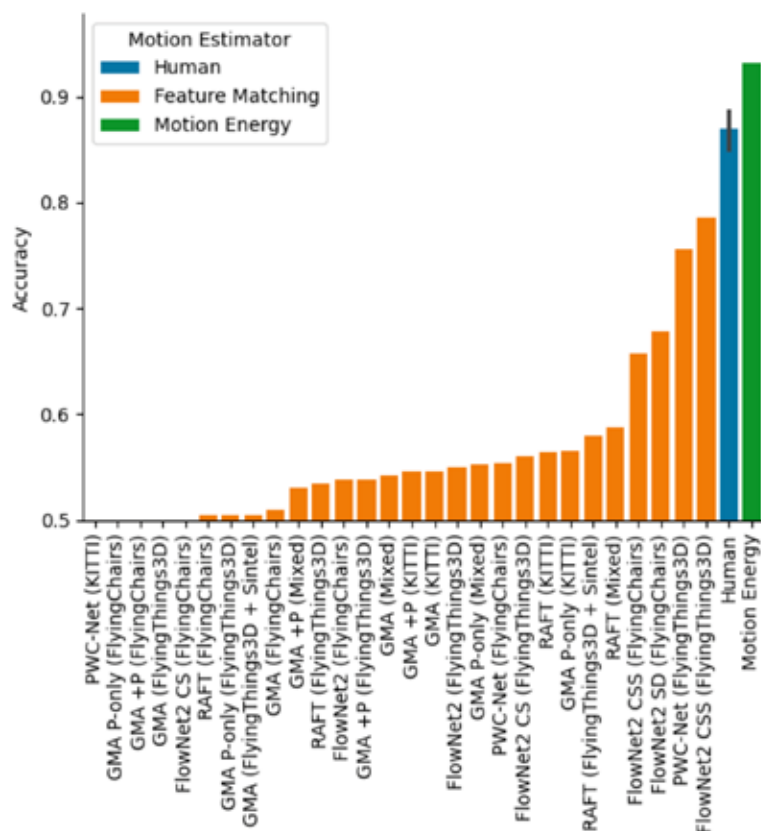


Fig. 2

Comparison of human and model performances for a random dot shape matching task as a proxy to measure segmentation in humans.

Neuro AI at Bethge Lab

Our lab works on “Neuro AI” – the interface between machine learning and computational neuroscience. We both develop ML tools for neural data analysis and take inspiration from the brain about what key problems to solve in ML and also how to tackle them. The brain excels in autonomous learning from unlabeled data streams. While machine learning is rapidly advancing toward learning with unlabeled or weakly labeled datasets, autonomous knowledge accumulation through continuous data collection is largely missing. To address this discrepancy, we develop mathematical concepts, build machine learning systems, and compare machines to brains in terms of their representational structure and learning algorithms.



SELECTED PUBLICATIONS

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GROUP LEADER



Matthias Bethge
Head of Research Group
Computational Neuroscience

MEMORY AND SLEEP

Our research is focused on learning and memory, i.e., how brain and behavior change as a function of experience. Of particular interest is how specific experiences are consolidated into long-term memory, and how such long-term memories are formed while the brain is asleep and while the brain is awake. A special focus of our research pertains to the parallel development of the episodic memory system and the architecture of sleep during early life. We examine these questions in healthy adult participants, children and infants, as well as in selected patient groups. We use rodent models (rats, mice) to uncover the neurobiological mechanisms mediating memory consolidation during sleep and wakefulness. Beyond behavioral methods, we use for our studies in humans methods such as electroencephalography (EEG), magnetoencephalography (MEG), and magnetic resonance imaging (MRI), and for our studies in rodents electrophysiological recordings and 2-photon calcium imaging of the activity of neuron networks and single neurons.

EPISODIC MEMORY / SLEEP / SYSTEMS CONSOLIDATION / EARLY DEVELOPMENT /
RODENTS / HUMANS

Sleep – a brain state serving long-term memory formation

We aim to understand how the brain transforms everyday experiences into long-lasting memories. Our research is based on the “active systems consolidation concept” that assumes that conscious (episodic) experience during wakefulness is encoded into neocortical and hippocampal neuronal networks, with the hippocampus primarily encoding the spatial-temporal context of the experience. During slow wave sleep periods following the wake experience, newly encoded contextual information is repeatedly replayed in the hippocampal neuron ensembles which drives the formation and shaping of long-term memory representations in neocortical networks serving as the long term-store. The emerging neocortical long-term representations contain only an abstracted schema-like version of the original experience. One focus of our research addresses the questions which kind of information is abstracted during sleep from the originally experienced episode to be integrated into

schema-like long-term memory representations, and how this abstraction process during sleep is mediated by oscillatory activity, i.e., the neocortical sleep slow oscillations, thalamic spindles and hippocampal sharp-wave ripples.

Starving for memory – consolidation independent of sleep

Two of our recent research lines are of particular interest as they have the potential to challenge the active systems consolidation concept. Building on our preliminary studies indicating that long-term memories can be formed not only during sleep but also during wakefulness, we aim at dissociating the neurobiological characteristics of such wake-consolidation processes. Ongoing studies in rats and humans provide novel evidence that such wake consolidation processes are greatly enhanced by hypothalamic need states, like starvation, and strengthen newly encoded representations independently of hippocampal memory replay.

Long-term memory formation in the infant brain

The second research line concerns the sleep-dependent formation of long-term memory during early development. Our behavioral studies show that human infants as well as rat pups use sleep to form long-term memory, although the underlying structures, like the hippocampus and the medial prefrontal cortex, are still very immature. Our recent findings indicate that the sleep-oscillatory phenomena thought to mediate long-term memory consolidation in the mature brain, specifically the phase-coupling of hippocampal ripples to thalamic spindles during slow wave sleep, do not emerge until late childhood. These findings suggest that, rather than on a fine-tuned dialogue between hippocampal and thalamocortical networks, sleep-dependent memory consolidation during infancy relies on distinct other mechanisms that remain to be characterized.

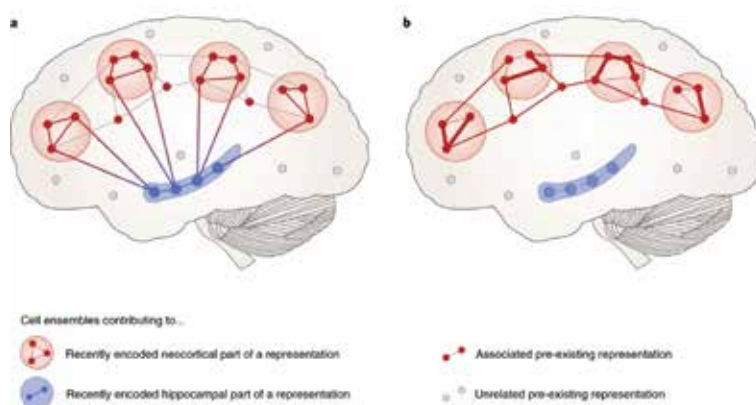


Fig. 1

Memory reactivations during sleep strengthen representations in the neocortical long-term store.

(a) A newly encoded representation of an experience (engram) is distributed across neocortical brain regions (red-shaded networks of nodes) and the hippocampus (blue-shaded network), the latter of which carries the episodic features of the experience (blue nodes). When patterns of neuronal ensemble activity in the hippocampus are reactivated during sleep, this simultaneously triggers the reactivation of their neocortical projection targets. **(b)** Repeated reactivations result in a systems-level reorganization of the representation, which comprises with regard to its neocortical parts: (i) the strengthening of some of the synaptic connections (thickest lines), (ii) the weakening of others (thinnest lines), and (iii) the formation of some new synaptic connections with cells outside the recently encoded representation. Fully consolidated memories are mainly supported by neocortical networks and may completely lose their dependency on the hippocampus. (from Klinzing et al. 2019)



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GROUP LEADER



Jan Born
Head of Research Group
Memory and Sleep

NEURAL CIRCUITS AND BEHAVIOR

How are memories formed and encoded? How are memory representations dynamically modified to enable flexible behavior? These are some of the central questions we address in our lab. We use the rodent spatial memory system as a model to investigate how memory representations are formed, stored, and used by the brain to guide behavior. To address these questions, we employ a multidisciplinary approach that includes single-cell electrophysiology, calcium imaging, behavioral analysis, and optogenetic tools for neural circuit dissection.

MEMORY / HIPPOCAMPUS / SPATIAL NAVIGATION / BEHAVIOR

Our current research is focusing on the cellular basis of sensory-, memory- and reward-guided behaviors. Particular emphasis is devoted to cortico-hippocampal circuits, and on the role of head-direction neurons (the 'internal compass') and place cells (the 'cognitive map'). In our recent work, we have begun dissecting the microcircuits underlying the head-direction and place representations in the mouse brain. We have also begun exploring whether and how these cortico-hippocampal codes are modulated by brain state and sensory stimuli in the context of memory formation and ethological behavior. With these research lines, we aim at understanding how purely naviga-

tional signals (like head-direction and place codes) are more broadly integrated into the mechanisms of episodic memory formation, and how they contribute to ethologically-relevant behaviors.

Cellular mechanisms of memory formation

How do spatial representations emerge, and what are the underlying in-vivo induction and plasticity rules? How do morphologically and molecularly distinct neurons contribute to neural coding? To address these questions, we use a combination of optogenetics, juxtacellular labelling & single-cell stimulation techniques in behaving mice (see "Method Development" below).

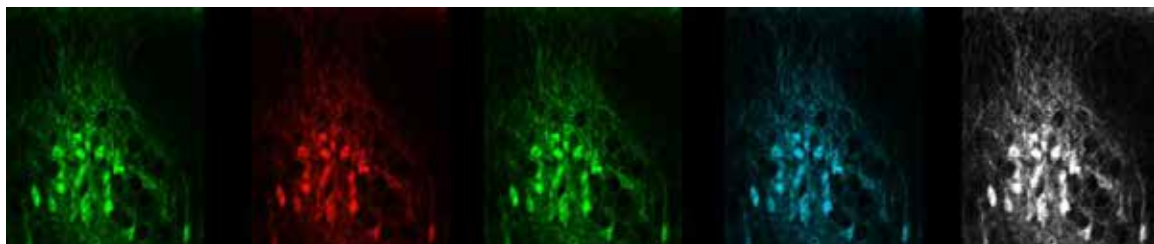
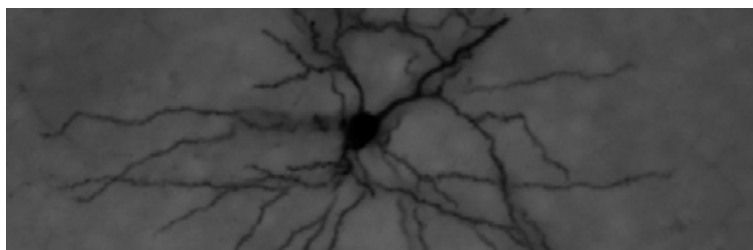


Fig. 1

Fluorescence labeling of cortical neurons

Brain states, sleep and memory

How are spatial representations modulated by behavioral states? What is the role of sleep in shaping memory representations? In this research line, we study the role of 'brain states' (including NREM and REM sleep oscillations) on the plasticity of hippocampal representations.

**Fig. 2**

Labeling of a single neuron

Method Development

A key focus of our research is on improving in-vivo methodologies for neural circuit analysis. To this end, we have developed and further optimized techniques for recording, identifying, and stimulating single neurons in behaving mice. Our approach leverages both single-cell identification and targeted single-cell stimulation to investigate the structural correlates and plasticity of spatial coding within hippocampal circuits.

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**GROUP LEADER**

Andrea Burgalossi
Head of Research Group
Neural Circuits and Behavior

OPHTHALMIC RESEARCH

Our eyes receive a constant stream of images from the visual world around us. The processing of this massive amount of information already starts in the retina, a neuronal tissue that lines the back of the eye and is part of the brain. The retina is not only a mere light sensor, it also performs a first analysis of the visual scene: It extracts and encodes potentially salient information to be forwarded to higher visual centers in the brain. Our research aims at unravelling the sophisticated neural computations that take place in the retina. To this end, we present a diverse set of light stimuli to the explanted retina, while following the signals “trickling” through its synaptic networks using two-photon microscopy. From our work, we expect new insights into the function and organization of retinal circuits in the healthy and diseased retina – towards a better understanding of the underlying computational principles in the early visual system.

SENSORY SYSTEMS / EARLY VISUAL SYSTEM / EYE / RETINAL CIRCUITS

What does the eye tell the brain?

All visual information from the retina to the brain travels along the optic nerve. However, due to its limited capacity, the optic nerve represents a major information bottleneck in the visual system. Therefore, before the transmission to the brain, behaviorally relevant features of the observed scene must be extracted and encoded. These include basic visual properties, such as brightness and color, but also more complex features like edges, object motion and direction.

Evolutionary and behavioral context of retinal Computations

What features are extracted is shaped – on the evolutionary scale – by the behavioral needs of an animal species. For example, for a mouse, detecting a small dark moving object may provide potentially crucial information about food or danger depending on its position in the visual field: In the lower visual field, it may represent an insect on the ground and, hence, prey; in the upper visual field, it may indicate a predatory bird approaching in the sky. This simple example also illustrates that the context in which visual features appear, can be important.

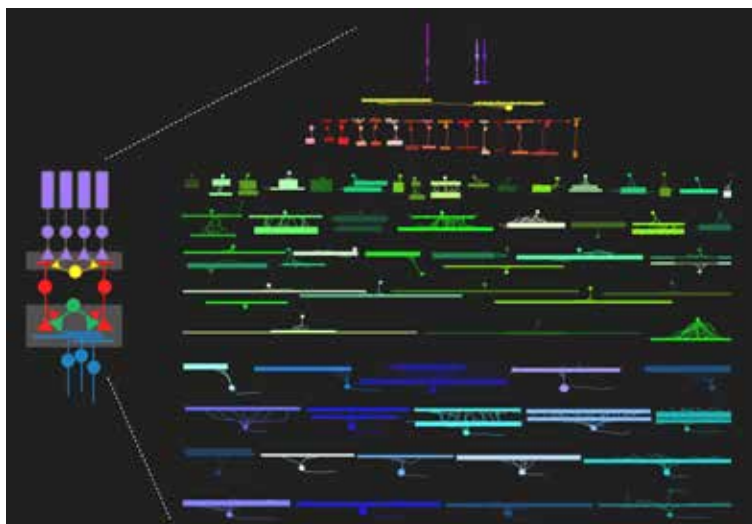


Fig. 1

“Parts list” of the mouse retina with photoreceptors (3 types, magenta), horizontal cells (1 type, yellow), bipolar cells (14-15 types, red), amacrine cells (more than 60 types, green), and retinal ganglion cells (around 42 types, blue).

Rich diversity of retina cell types

The retina's computational abilities rely on likely more than 120 types of neurons organized in five distinct neuronal classes, which form complex circuits to allow the extraction of dozens of visual features. Each feature is represented by a distinct type of ganglion cell. They are the retina's output neurons; their axons form the optic nerve and send the visual feature representations in parallel to higher visual areas in the brain. In our lab, we aim to elucidate the fundamental computational principles underlying early vision. Specifically, we investigate the functional organization of retinal circuits. We want to understand what visual information is encoded – in different parts of the visual field and especially in the context of the animal's visual ecology. In addition, we want to learn how diseases, such as progressive photoreceptor degeneration, impact the retina's structure and function.

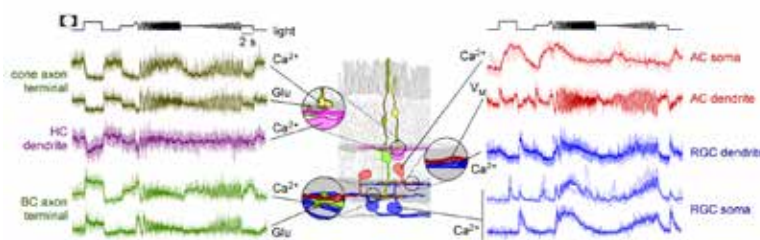


Fig. 2

Two-photon imaging light-evoked activity across retinal layers.

Interrogating visual circuits with two-photon imaging and natural movies

To address these questions, we established a comprehensive imaging approach for measuring neuronal activity driven by light stimuli along the retina's entire vertical pathway using synthetic and genetically-encoded fluorescent activity sensors. Our key technique is two-photon microscopy, which enables us to excite fluorescent probes in the intact living retinal tissue using infrared laser light with minimal effects on the light-sensitive photoreceptor pigment. Therefore, we can simultaneously record activity in neurons at both population and subcellular levels, while presenting a range of light stimuli – from simple spots to natural color movies. This approach is complemented by single-cell electrophysiology and immunocytochemistry. In parallel, we developed a comprehensive set of software tools, including stimulus presentation software and analysis pipelines for large-scale neural datasets. In addition, we started building retina models using deep learning. These allow us to perform experiments in silico, such as efficiently exploring the vast visual stimulus space to derive qualitative predictions for targeted ex-vivo experiments.

Challenges

In the future, we plan to build on our recent modeling efforts and “close the loop” by integrating online-analysis and model prediction in the biological experiments. Also, we will continue to tackle one of the big challenges of the retina: Understanding the computations provided by amacrine cells, with more than 60 types, the largest and most diverse class of retinal neurons.



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GROUP LEADER



Thomas Euler

Head of Research Group
Ophthalmic Research

FUNCTIONAL AND COMPARATIVE NEUROANATOMY

Our group examines the neuroanatomical and (neuro-)physiological communication between the brain and the body. The brain is one of the most complex systems in the Universe. With billions of neurons and trillions of synapses, it evolved around the most primitive needs of the organism: surviving and optimizing energy usage. It is therefore not surprising that even our most sophisticated human brain functions are shaped by the central integration of sensory afferent signals representing bodily states or “interoception”. In primates, a phylogenetically novel pathway conveys interoceptive signals to special parts of the brain, including the insular cortex. The integration of interoception with salient environmental cues in the insular cortex produces affective homeostatic states and subsequent autonomic regulations of bodily functions. Doing so, the insular cortex actively switches the allocation of metabolic resources across the brain’s functional networks, with great implications for the evolutionary emergence of subjective feelings.

NEUROANATOMY / INTEROCEPTION / PRIMATE / AUTONOMIC NERVOUS SYSTEM

Mission

The mission of our group is to provide novel and highly rigorous evidence on the structural and functional organization of the primate brain, concerning the interoception-autonomic control circuit loop that intertwines brain states and bodily states, while also majorly impacting emotion and cognition. Our group benefits from a unique international synergy in which our data acquisition and analysis are distributed across several different sites, including the CIN and MPIBC in Tübingen, the International Center for Primate Brain Research in Shanghai, and funded collaborations at the Nathan Kline Institute for Psychiatry Research in New York and the Laboratory of Neuro- and Psychophysiology in Leuven.

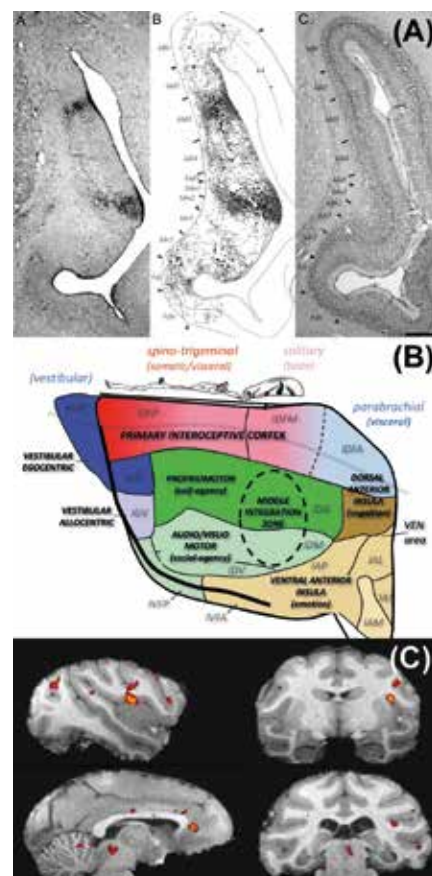


Fig. 1

(A) Front cover of our new monkey brain atlas (Paxinos et al., in press). (B) 3D views of our Subcortical Atlas of the Rhesus Macaque (SARM; Hartig et al., 2021).

Figure 2:

(A) Overlap of tract-tracing (left and middle panels) and cytoarchitectonic (right panel) boundaries (Krockenberger et al., in press). (B) Neuroanatomical and functional model of the monkey insular cortex (adapted from Evrard, 2022). (C) Focal activation of the dorsal fundus of the insula with trigeminal thermal laser stimuli in the macaque (Poppa et al., 2023).

Recent achievements

- Rhesus Monkey Brain in Stereotaxic Coordinates, 4th Edition: After 4 years of work, this atlas book is finally completed in 2023 (Elsevier, 2024).
- Highly organized and overlapping patterns of connectivity and architectonics in the primate insula (J Comp Neurol, 2023).
- fMRI evidence for a tripartite functional interoceptive network in primates (Front Neurosci, 2022).
- Various efforts towards international data sharing (Neuron 2022; Curr Res Neurobiol 2023).
- Reviews, comments, and editorials on the organization of the interoceptive pathways (Cambridge U Press, 2022; Nature Neurosci 2023; Pain, 2024; Pain, accepted).
- Comprehensive preprocessing and analysis pipeline for our macaque monkey fMRI and electrophysiology data, used now across our entire team (in preparation).
- Organized the 10th and 11th CIN-NIPS-ASIA PACIFIC Systems Neuroscience Symposium, online (2022) and on site in Tübingen (2023).
- Organized the 1st International Interoception Workshop, on site in Shanghai (2023).
- Designated formal legator of the A.D. (Bud) Craig scientific legacy.
- Graduate Training Center: Neuroanatomy block course.

Future direction

- Ongoing works to be completed in 2024-2025:
 - Definition of the projections of the von Economo neuron in primates
 - fMRI activation of the insula's trigeminal thermosensory representation using thermal laser stimulation.
 - Representation of parasympathetic cardiovascular control in the anterior insula.
 - State-dependent patterns of fMRI activation during direct electrical microstimulation of the anterior insula.
 - fMRI BOLD signal triggered by LFP event detection in the left and right anterior insula using a refined NMF approach, in collaboration with Michel Besserve and Shervin Safavi.
 - Test the effects of insular manipulation on addiction.
- Long term directions beyond 2025:
 - Initiate 5 experimental projects:
 - Development of new NHP models of human mental disorders.
 - Cortical control of brainstem and spinal pre-ganglionic centers.
 - Cartography of the dorsal insular cortex inner bodily map.
 - Single cell recording and sequencing of the von Economo neuron.
 - Vagus nerve control of brain states and emotional behaviors.
 - Role of interoception and the insula in emotional embodiment.
 - Establish a viable status for a European-based preservation, analysis and sharing of our existing brain collections.
 - Establish a viable status for a European-based preservation, analysis and sharing of our existing brain collections.

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**GROUP LEADER****Henry Evrard**

Head of Research Group
Functional and Comparative
Neuroanatomy

PHYSIOLOGY OF NEURAL CIRCUITS

Our research focuses on (i) functional analysis of neuroglial networks in vivo, especially in the context of perception of sensory stimuli as well as sleep-dependent learning and memory formation; (ii) interactions between the nervous and the immune systems of the brain; (iii) understanding the rules governing the integration of adult-born neurons in the preexisting neural networks as well (iv) neural network maturation, aging and neurodegeneration (in particular, Alzheimer's disease). To address these objectives, we use in vivo two-photon microscopy/Ca²⁺ imaging, combined with electrophysiological, behavioral, RNA sequencing and immunocytochemical techniques. Our preclinical studies focus on mechanisms underlying network dysfunction in genetic epilepsies and amyloidosis-induced neuroinflammation and the resulting therapeutic implications.

NEUROGLIAL NETWORK / MICROGLIA / NEUROINFLAMMATION /
ADULT-BORN-NEURONS / ALZHEIMER'S DISEASE

Mission

Our main scientific interest is to understand the mechanisms underlying in vivo function of neuroglial networks in health and disease. The major research aims are to characterize endogenous brain rhythms during (un)healthy development and aging as well as understand the cellular/molecular mechanisms underlying

the processing and memorizing of sensory signals by healthy, aged and diseased brains. Besides mechanistic studies, we aim to identify new therapeutic approaches for treating developmental and epileptic encephalopathies and amyloidosis-induced neuroinflammation.

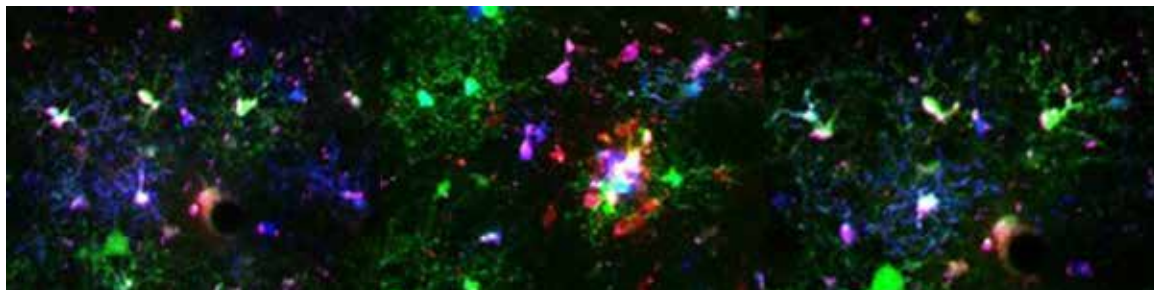


Fig. 1

In vivo images of cortical microglia in a mouse model of Alzheimer's disease. Note that each microglial cell expresses a unique combination of red, green, and blue fluorescent proteins, thus enabling longitudinal fate mapping.

Methods

Cellular activity is often associated with an increase in intracellular calcium concentration. We use this property of neuronal and glial cells to monitor their function by means of in vivo two-photon calcium imaging. In combination with state-of-the-art electrophysiological, optical and molecular biological techniques (multi-color two-photon microscopy, novel genetically-encoded calcium indicators, cell-attached and whole-cell patch clamp recordings, single-cell RNA sequencing) this approach allows studying functions of multi-cellular networks at single cell or even subcellular resolution.

Recent achievements

During the reporting period we analyzed (i) cellular and molecular mechanisms of neuro-glial network dysfunction in mouse models of glioma and Alzheimer's disease; (ii) morphological appearance, process motility and Ca^{2+} signaling of microglia in conditions of peripheral and neuroinflammation; and (iii) the mechanisms controlling migration, morphogenesis and survival of wild-type adult-born interneurons and those expressing K^+ channels with mutations, known to cause genetic epilepsies. We have identified the plaque vicinity as a hotspot of microglial turnover in the amyloid-depositing brain and the dependency of glioblastoma networks on periodic Ca^{2+} signaling in hub neurons. While neuronal silence helped the survival of wild-type adult-born interneurons, adult-born interneurons overexpressing mutated K^+ channels had diminished neuronal activity, retarded growth and maturation as well as impaired periodic Ca^{2+} signaling.

Future direction

Currently, we focus on (i) comparative analyses of Ca^{2+} signaling in human and mouse microglia; (ii) understanding how de novo mutations in voltage-gated K^+ channels compromise neuro-glial network function in mouse models of developmental encephalopathies and (iii) developing new approaches for alleviating microglial dysfunction in conditions of amyloid-induced neuroinflammation.



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GROUP LEADER



Olga Garaschuk
Head of Research Group
Physiology of Neural Circuits

COMPUTATIONAL SENSOMOTORICS

Our group investigates computational principles of the perception and control of motor behavior and social communication. Research is organized around four main topics: 1) Clinical movement control and rehabilitation, 2) Neural mechanisms of the visual processing and control of actions and social communication signals, 3) Biologically-inspired technical applications, e.g. in robotics, 4) Neural mechanisms of non-invasive brain stimulation, including nano agents.

Our research is highly interdisciplinary, including psychophysical, neurophysiological, and clinical experimentation, the development of mathematical and computational models, and the development of technical systems that exploit brain-inspired principles, or support diagnosis and rehabilitation training in neurological and psychiatric diseases. We collaborate closely with the University of Stuttgart, and the MPIs for Intelligent Systems and Biological Cybernetics.

NEURAL MODELS / COMPUTER ANIMATION / SOCIAL VISION / MOVEMENT MODEL-
ING AND QUANTIFICATION / NON-INVASIVE BRAIN STIMULATION

Mission

Unravelling the neural and theoretical principles that underlie the perception and control of complex motor behaviour, especially in social communication, and exploiting such knowledge for related clinical applications.

Methods

Our research is highly interdisciplinary and includes the development of neural and computational models, machine learning, control theory, biologically-inspired technical approaches, psychophysical, neurophysiological, and clinical experimentation including neurological and psychiatric patients.

Recent Achievements (Reporting Period)

Clinical Movement Control and Rehabilitation: Applying advanced computational and machine learning methods, our group has made significant progress in analysing and quantifying body movements of patients in everyday life. This includes approaches relying on wearable inertial sensors and methods for the analysis of complex movements with high relevance for activities of daily living. In addition, we have developed in collaboration with the Depts. of Psychiatry and Informatics a technical system that is suitable to identify stress-inducing visual stimuli in everyday life for children with Obsessive Compulsive disorders.

Neural and Computational Principles of the Processing of Boidies and Movements: In the context of the ERC SYNERGY project relevance we have studied neural representations of perceived bodies and their movements in humans and nonhuman primates, combining electrophysiology, functional imaging and high-end methods for stimulus generation using computer vision and computer graphics. Specifically, we have developed probably the most sophisticated dynamic macaque face avatar model that is presently available worldwide, which is driven by motion capture data from real monkey faces. Also, we have developed the first highly realistic monkey body avatar that is animated with real tracking data from monkeys in 3D.

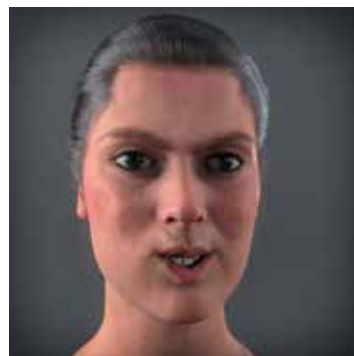


Fig. 1

Human LipSmacking: Human face doing a compelling monkey expression

This method is based on a marker less tracking approach that is based on CNNs, but can be trained with a minimum of labelled frames, however allowing to create highly veridical 3D animations that are perceived by monkeys as veridical. In the context of this work we have shown uncanny valley effects in macaques for dynamic faces as well as for dynamic bodies. Noninvasive brain stimulation: Together with the MPI for Biological Cybernetics and the laboratory of C. Schwarz, we have established the first worldwide approach to realize electrophysiological single-cell recordings in rodents for single pulse Transcranial Magnetic Stimulation (TMS). The method is based on a set of methods to minimize capacitive, inductive and triboelectric artifacts with the development of novel amplifiers for electrophysiology that eliminate the strong electrical perturbation signals that are caused by the TMS pulse stimulation. Presently, the method allows to measure largely unperturbed physiological signals even less than 1 MS after the TMS pulse.



Fig. 2

Going out of the lab with the inertia sensors

Future Directions

We will extend our work in neuroscience to the use of real-time controlled highly-realistic avatars to study neural responses of visual neurons in closed-loop social interaction. We will further extend our methods towards a quantification and therapy support by training systems of everyday behaviours. This work will specifically include patients with genetically characterized deficits, e.g. cerebellar ataxia. An important application of our methods will be the validation of the efficiency of novel gene therapy approaches for such diseases. The work on non-invasive stimulation will be extended towards approaches that exploit nano agents.



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GROUP LEADER



Martin Giese

Head of Research Group
Computational Sensomotrics

PHYSIOLOGY OF ACTIVE VISION LABORATORY

Our research aims to investigate the neural mechanisms through which visual perception interacts with motor control. We employ techniques for monitoring and focally perturbing neural activity to understand the functional contribution of individual brain circuits in coordinating perception and action. This entails conducting careful behavioral experiments in both humans and animals, coupled with neurophysiological experiments in behaving animals as well as computational modeling. Besides clarifying our understanding of the sense of vision, our research also sheds light on how neural activity that is distributed across multiple brain areas is organized to support behavior.

VISUAL PERCEPTION / EYE MOVEMENTS / BRAINSTEM CONTROL OF EYE MOVEMENTS / PERCEPTUAL STABILITY / VISUAL FIELD REPRESENTATIONS

High-resolution vision in humans is only limited to a small area of the visual field. Despite this fact, humans have the perception of a vivid, clear scene throughout the visual field, and this is due to the fact that humans are active observers. By moving their eyes around, humans effectively compensate for the resolution limitations that are inherent in the retina. However, the mere act of moving the eyes creates retinal image shifts and motions that are not present in the real world. The visual brain is therefore perpetually faced with both: 1) a need to move the eyes in order to align the high-resolution portion of the retina with objects of interest,

and 2) a need for spurious visual signals caused by eye movements to escape perception in order for us to experience a stable and clear vision of our environment. Our research addresses both of these challenges to visual perception using a multi-disciplinary approach involving human perceptual experiments, invasive neurophysiology in non-human primates, and theoretical modeling. The insights that we gain have strong relevance for understanding clinical orders of stability, balance, and bodily reference frames (e.g. dizziness, vertigo, schizophrenia-related internal self-monitoring deficits, and so on).

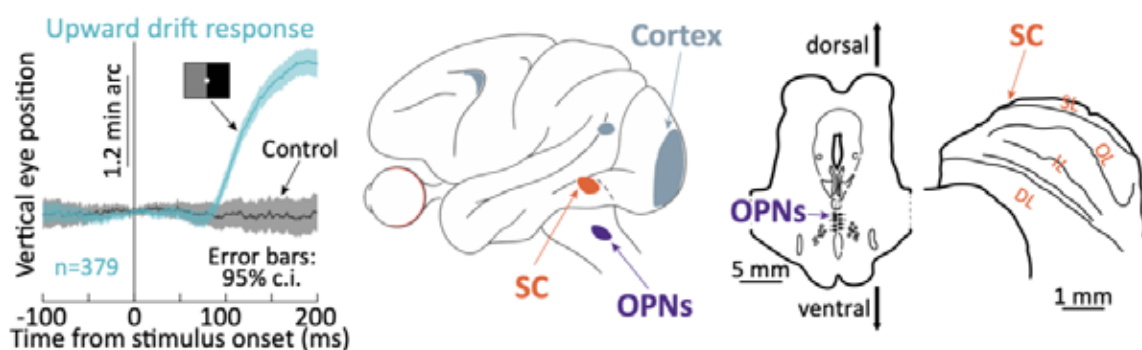


Fig. 1

Our oculomotor system exhibits exquisite control over eye position, allowing the shaping of retinal visual images on the scale of individual foveal cone photoreceptors. Such exquisite control is achieved via a large network of cortical and subcortical areas, culminating in a precise coordination between two brainstem areas, superior colliculus (SC) and the omnipause neuron (OPN) region, within the final oculomotor control pathway.

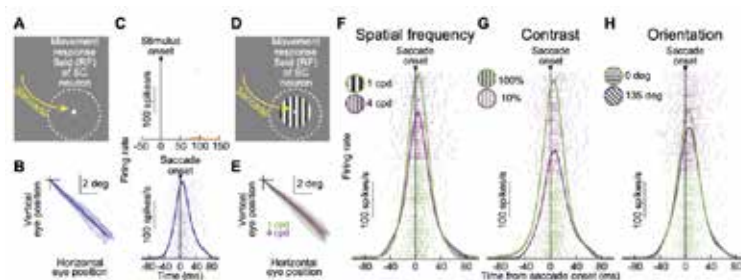


Fig. 2

Legend: Eye movement commands emitted by the superior colliculus, a structure classically associated with controlling how saccadic eye movements proceed, embed within them a visual sensory representation of what the eye will foveate. This sensory signal may be used by the brain to internally predict images across saccades, thus bridging the periods of sensory uncertainty that are necessarily caused by rapid eyeball rotations.

Sensory and cognitive drives for eye movements

There are two main classes of eye movements that are employed by humans in everyday life: saccades, which are rapid changes in eye position that align gaze on peripheral objects, and smooth pursuit eye movements, which are smooth movements that stabilize the image of a moving object on the retina. Associated with every eye movement are various sensory and motor processes that not only ensure that the eye lands on its intended target, but that also serve higher-level perceptual and cognitive processes. We are interested in learning about these processes in more detail.

Fixational eye movements

An additional hallmark of our work is to explore a much-less understood class of eye movements that occur during maintained gaze fixation. These tiny subliminal eye movements were traditionally considered to be completely irrelevant for action and perception, but it turns out that they are highly systematic, and with substantial impacts on vision and cognition. Our research is uncovering interesting analogies between these subliminal eye movements and their larger counterparts, resulting in unifying theories on the entire gamut of oculomotor behavior that the brain is capable of exhibiting. The transformative aspects of this research relate to how changes in perception caused by these tiny eye movements can amplify changes often attributed to cognitive state, like attention, independently of oculomotor behaviour.

Active perception and natural scene statistics

Finally, our work investigates action and perception taking into account ecological constraints on brain function. Ultimately, our brain operates in a natural environment, and therefore, is expected to be optimized to the statistics of this environment. Such intuition implies both anatomical and functional specializations in the eye movement system in order to best serve perception in the natural environment, which we are systematically uncovering.



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GROUP LEADER



Ziad Hafed

Head of Research Group
Physiology of Active Vision
Laboratory

NEUROBIOLOGY OF SOCIAL COMMUNICATION

Our research aims to understand the neuronal mechanisms underlying social communication with a focus on vocal communication. The main goal of our research is to understand, how audio-vocal integration mechanisms are modulating vocal production and vocal perception as well as how cognitive and motivational processes are involved in vocal behavior. Furthermore, we investigate how developmental processes affect vocal output. Recently, we also started to investigate auditory perception and its role in vocal production. We use combined psychophysical, neuroethological and neurophysiological methodologies to tackle our questions.

COMMUNICATION / AUDIO-VOCAL INTEGRATION / HEARING / MOTOR CONTROL /
COGNITIVE BEHAVIOR

Mission

The leitmotif of our research is the neurobiology of vocal communication, which a focus on vocalizations of our closest relatives, non-human primates. Recent behavioral and neuroethological experiments including our own revealed that marmoset monkeys exhibit vocal flexibility and learning mechanisms in vocal development making them a compelling model system to investigate the neurophysiological principles underlying different aspects of vocal communication.

We tackle four main challenges within this field: (1) The neural basis for cognitive call production in monkeys as a putative phylogenetic precursor for speech control in humans. (2) The role of cortical and sub-cortical mechanisms underlying audio-vocal integration processes, which are involved in audio-vocal communication of primates, including humans. (3) Intrinsic properties of the vocal pattern generating network in the monkey brainstem and (4) the influence of social interaction on early vocal development in monkeys.

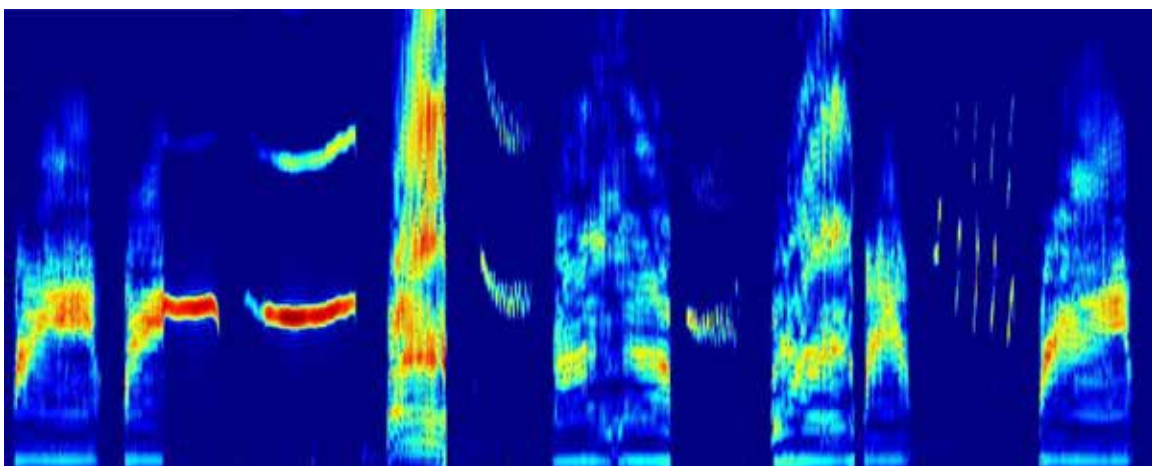


Fig. 1

Vocal babbling sequence of juvenile marmoset monkeys

Methods

We use a broad range of behavioral, psychophysical, neuroethological and neurophysiological methodologies to tackle our research questions and to approach our classical topic of systems neuroscience from the animal's behavior to the single cell level.

Recent achievements

In the last year, we presented additional evidence supporting the idea that marmosets can adaptively control their vocal behavior in a goal-directed manner. First, we observed that when given the freedom to choose what to vocalize, marmosets exhibit vocal statistical regularities consistent with linguistic Zipf's law of brevity extending beyond their context-specific natural vocal behaviour. This suggests the emergence of linguistic laws in non-linguistic vocal systems within the primate lineage (Risueno-Segovia et al. 2023). Second, we investigated the vocal behavior of marmosets in response to perturbing noise, identifying both adaptive and reflexive avoidance strategies, suggesting vocal flexibility at different complexity levels within the marmoset brain (Löschner et al. 2023). In collaboration with the Siegel lab, we conducted an MEG study to explore the neural correlates of human speech production (Voigtländer et al. 2023). Our findings revealed robust neural information about vocalization content and production, predominantly originating from speech areas of the left hemisphere. These results provide valuable insights into the neural dynamics underlying human vocalization.

Future direction

In recent years, we have successfully established marmoset monkeys as a suitable animal model for studying neuronal networks underlying vocal communication. Using our established neurophysiological recording system, we are now well-positioned to explore the neural substrate governing all aspects of rapid vocal flexibility. Of particular interest is the insular cortex, which not only plays a significant role in auditory processing of vocal sounds but also contributes to vocal motor production making in a central hub for enabling rapid audio-vocal adaptability. Moreover, our objective is to uncover both the commonalities and differences within neural mechanisms governing monkey vocalization and human speech production. This comparative approach is instrumental in comprehending the extent and limitations of monkey vocalization as a model system for human speech. It also allows us to pinpoint the additional and significant steps in speech evolution within the primate lineage. Finally, we are aiming to understand the influence of sex on vocal communication processes in both monkeys and humans. We will set out to identify commonalities or sex-specific features in the neural networks underlying social communication and to unravel mechanisms that give rise to sex-specific differences in sensory impairments and brain disorders. This multifaceted exploration will reveal valuable insights into the intricate interplay of (neuro)biology and behavior in vocal communication across species and genders.



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GROUP LEADER



Steffen Hage
Head of Research Group
Neurobiology of Social
Communications

NEUROMECHANICS AND REHABILITATION ROBOTICS

Our group focuses on the generation and control of active biological movements. We develop computer models and simulations of the neuro-musculo-skeletal system. In our approach, we consider the different hierarchical levels contributing to movement generation. This interdisciplinary approach is mainly based on biophysics, biomechanics, and computational motor control.

We use our models to investigate fundamental sensorimotor control mechanisms and their dysfunction in neurological disease. A deeper understanding of dynamics, impaired control and interaction will serve as a basis for the development of functional assistive devices.

BIOMECHANICS / NEUROMECHANICS / HUMAN MOVEMENT / COMPUTER SIMULATIONS / REHABILITATION ROBOTICS

In our group, we combine computational motor control and musculoskeletal biomechanics. Our goal is to understand how the different hierarchical levels of the neuronal network interact with the musculo-skeletal system to form a closed-loop system generating movement. In particular, we are very interested in how the muscle dynamics influence and simplify human motor control. For this, our unique research expertise is the development of information entropy-based criteria to quantify what is commonly referred to as Embodiment or Morphological Computation. Both represent the notion that the neuronal system interacts with the environment through its body, which, in consequence, shapes hu-

man behavior. We quantify this contribution of the morphology with the help of mathematical models and forward-dynamic computer simulations of the sensorimotor system.

For this, we develop detailed neuro-musculoskeletal models which allow us to quantify information processing requirements for motor control tasks.



Fig. 1

Neuromechanics modelling of human movement

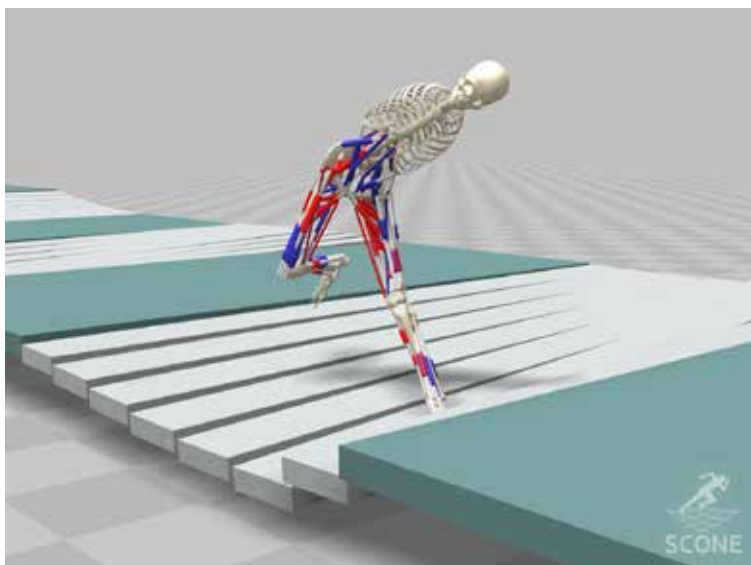


Fig. 2

We use computational neuromechanical models of human walking to investigate complex locomotion control and impairments by neurological disorders.

Combining motor control and biomechanics

To this end, we combine two research areas: computational motor control in healthy and impaired humans (typically studied without detailed musculoskeletal dynamics) and musculoskeletal computer simulations (typically driven by optimal control approaches neglecting neuroscientific control concepts). In addition, we investigate the translation of these findings into rehabilitation robotics and biorobotics.

Current and future research topics are:

- Neurorehabilitation: wearable assistive devices for neurorehabilitation and support in arm movements of daily life
- Neuromechanics of complex movements: Computational motor control and reinforcement learning
- Computational systems neuroscience: developing predictive models of impaired human motor control
- Morphological Control: The role of morphology in learning and information processing in hierarchical neuronal motor control systems
- Leveraging morphological computation in learning autonomous control for robotic systems



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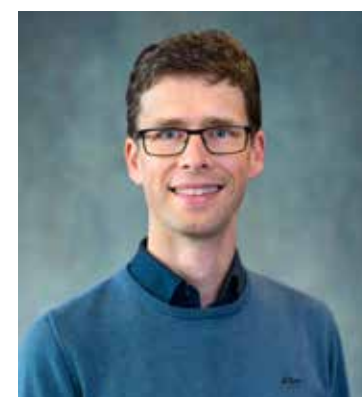
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GROUP LEADER



Daniel Häufle

Head of Research Group
Neuromechanics and
Rehabilitation Robotics

SELF-ORGANIZATION AND OPTIMALITY IN NEURONAL NETWORKS

Our group uses modeling and data analysis to uncover principles of how neurons coordinate their dynamics to perform computation. We are particularly interested in computations in recurrent circuits, understanding how circuit features influence their efficiency and how plasticity and adaptation shape these features. Beyond various modeling approaches, we use machine learning approaches to analyze data and fit models to the data.

COMPUTATIONAL NEUROSCIENCE / POPULATION DYNAMICS / CRITICALITY / PLASTICITY / E/I BALANCE

Systems made of many interacting components are ubiquitous in physics, in the biosphere, and in the anthroposphere. I am fascinated by unifying principles for describing and comprehending such complex systems, particularly one of the most complex systems we have – the human brain. My research goal is to

understand the dynamical states of the brain, their suitability to particular tasks and self-organization processes, to gain insights into neurological disorders and their treatments, to advance comprehension of natural information processing, and to improve our artificial models thereof.

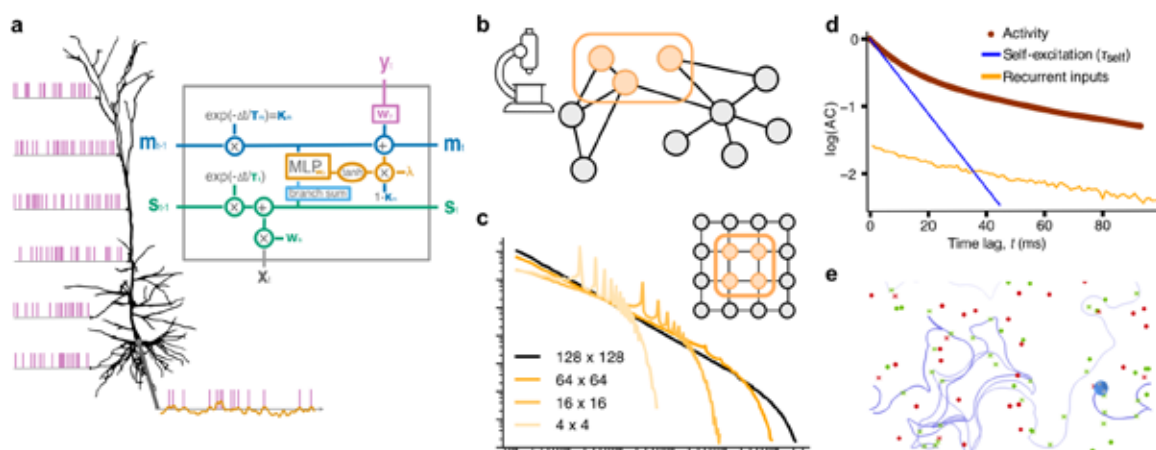


Fig. 1

a. Layer 4 pyramidal neuron and ELM neuron model for training b. Spatial subsampling an c. resulting changes in the distribution of observed events d. Slow and fast timescales in the autocorrelation function of individual neurons. e. Trajectory of foraging agent on the arena with healthy (green) and poisonous (red) food particles.

Our approach

To achieve this goal, we must address a wide range of open challenges. We need models capable of capturing the dynamical states in the brain and their self-organization in a manner relevant to understanding the nervous system, yet still simple enough to allow for rigorous analysis. For example, we recently demonstrated that modeling slow adaptation is necessary to match data from hippocampal cultures accurately. This study revealed that neural systems tend to self-organize to maintain a balance between excitation and inhibition after a strong external perturbation alters the relative cell counts. Building upon this study, we collaborated with Prof. Lerche to investigate how these mechanisms fail in patients with genetic epilepsies. To capture how they self-organize, we investigate synaptic plasticities and their combinations. Particularly, we are interested in how structural network constraints can lead to various outcomes of plasticity, sometimes varying across the entire range from successful learning to failure.

Brain states

Complementing the modeling investigations, we aim to establish a methodology for defining the brain states from available data in a consistent way. We are developing new methods to account for systematic biases generated by subsampling or short trial length and use them to infer how various states affect computations. For example, using our recently developed method, we found that spatial attention modulates activity timescales of the local V4 network in the primate brain and showed that it correlates with behavioral response time. The modulation of timescales hints at potential modulation of distance to the critical point at the second-order phase transition that was hypothesized to be an optimal state for the neural network's functioning. We explore this possibility in various models, including RNNs trained to perform cognitive tasks and information theory.

Paired with the increasing availability of various types of neuronal data, including the recording of spiking activity from unprecedented numbers of neurons, the development of new theoretical models and methods can lead to decisive advances in uncovering the mysteries of neuronal computation.



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GROUP LEADER



Anna Levina

Head of Research Group
Self-organization and optimality
in neuronal networks

SENSORY AND SENSORIMOTOR SYSTEMS

The Department for Sensory and Sensorimotor Systems studies the processing of sensory information (visual, auditory, tactile, olfactory) in the brain and the use of this information for directing body movements and making cognitive decisions.

We use a multidisciplinary approach to investigate sensory and sensorimotor transforms in the brain. Our approaches consist of both theoretical and experimental techniques including human psychophysics, fMRI imaging, EEG, electrophysiology and computational modelling.

NEURAL CIRCUITS / PERCEPTION / CODING / ENCODING / SENSORY

A trilogy between (1) neural circuits, (2) perception & action, and (3) theory & models (Figure 1) is our view how the brain should be understood. For example, the neural circuit of the primary visual cortex (V1) is linked with visually driven gaze or attentional shifts by the V1 Saliency Hypothesis (V1SH) that the primary visual cortex creates a saliency map to exogenously guide spatial attention. This trilogy has been the philosophy of our approach, while I focus on brain's sensory systems, particularly vision and olfaction.

I have a track record of theory/model building and human psychophysics, and I collaborate with neurophysiologists and psychologists. I am the author of V1SH, the leading theory of visual cortices closely linked with visual behavior in terms of the number of non-trivial and easily falsifiable predictions that have been experimentally confirmed. In the next 5-10 years, I aim for the next breakthrough in understanding vision, and when we can, going beyond vision and primates.

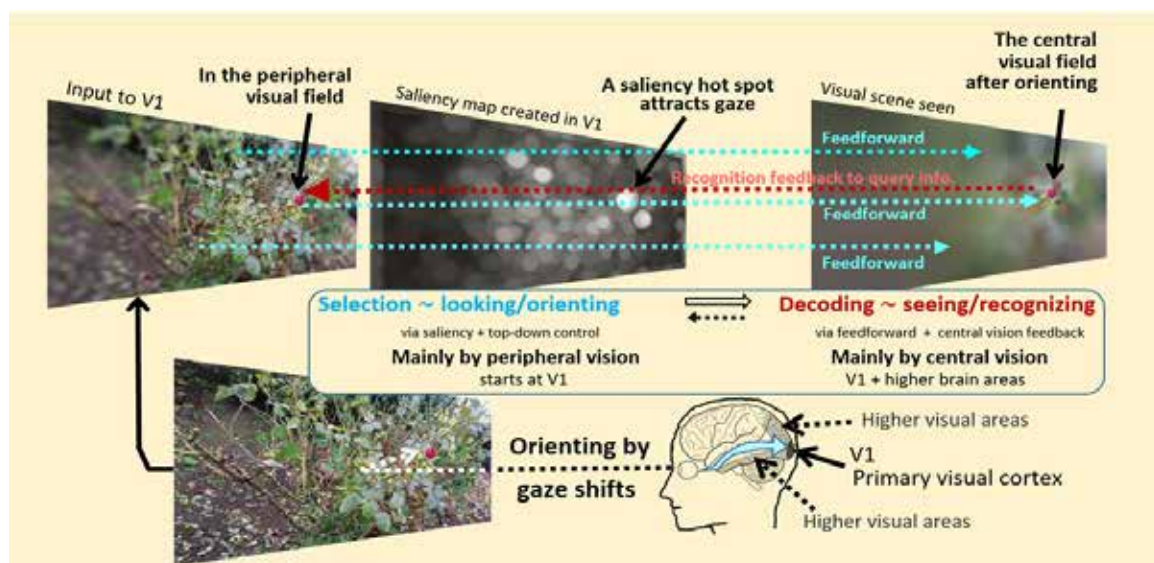


Fig. 1

Our new framework for understanding vision

We identify the essential problems in sensory processing as object segmentation and object recognition (see Li 1990, Zhaoping 2014, 2016, 2019). In olfaction, an odor object needs to be segmented from a background mixture of odor objects in order to be recognized, e.g., coffee in a kitchen. In human vision, an object is attentionally selected in a scene via gaze shifts to be recognized.

Motivated by V1SH and an attentional bottleneck, I recently proposed a new framework for vision (Zhaoping, 2014, 2019, Figure 2). This framework essentially hypothesizes

1. attentional selection starts at V1 along the visual pathway,
2. A Central-Peripheral Dichotomy (CPD), such that
 - (2a) : peripheral vision is for looking (attentional selection), central vision is for seeing (recognition),
 - (2b): top-down feedback (from higher to lower brain areas along the visual pathway) for better seeing is mainly for the central visual field.

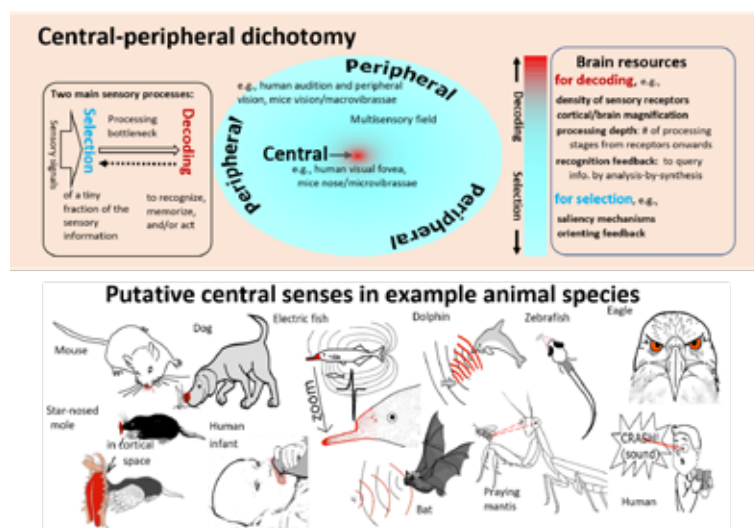


Fig. 2
Central-Peripheral Dichotomy in multisensory process across species

It places attentional selection at center stage for vision. Accordingly, recognition must be understood in light of the attentional bottleneck. This perspective can hopefully enable us to overcome more difficulties for research progress on higher visual cortical areas such as V2, V3, V4 than those on V1 by Hubel and Wiesel in 1960s.

Experimental evidence supporting this framework has emerged (Zhaoping & Ackermann 2018, Zhaoping 2025), and the framework can be extended to multiple senses across animal species when central and peripheral visual field is generalized to central and peripheral multisensory field (Zhaoping 2023).



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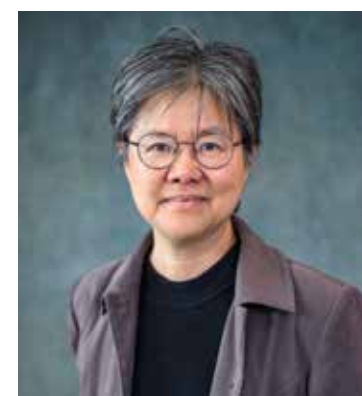
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GROUP LEADER



Zhaoping Li
Head of Research Group
Sensory and Sensorimotor
Systems

ANIMAL PHYSIOLOGY

Our research interests focus on understanding how higher brain centers facilitate intelligent, goal-directed behaviors from a comparative perspective. The laboratory investigates the functioning of highly intelligent human, monkey, and corvid songbird brains.

COGNITIVE NEUROSCIENCE / SINGLE-NEURON CODING / PRIMATES / CROWS / EVOLUTION

Executive functions in the prefrontal cortex of nonhuman primates

In nonhuman primates, we investigated how the prefrontal cortex (PFC) supports numerical representation and working memory. Using a geometric state space framework (Lin et al., 2023), we analyzed PFC neuron activity during a working memory task with interference. This approach revealed sequential memory representations—including recovery after distraction—not captured by conventional methods. These dynamics were driven by small neuronal subpopulations with distinct spiking patterns, consistent with recurrent PFC circuits. This work links representational geometry to cellular mechanisms of information encoding.

In a separate study, we examined dopamine's role in modulating reward signals in the PFC during cognitive control (Ott et al., 2023). Monkeys performed a memory task with variable rewards while lateral PFC activity was recorded during selective D1 and D2 receptor stimulation. Many neurons encoded expected reward size throughout the task. D1 stimulation had mixed effects post-cue but reduced expectancy signals during memory delay, while D2 stimulation enhanced expectancy coding across multiple task periods. Both enhanced reward selectivity at outcome, highlighting dopamine's contribution to motivational aspects of cognitive control.

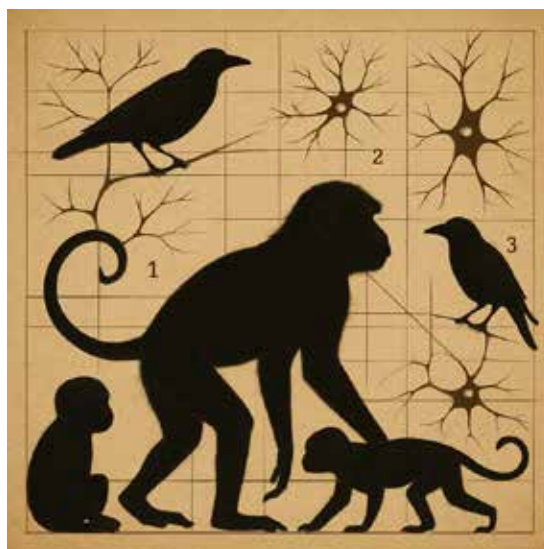


Fig. 1

The Department of Animal Physiology at the Institute of Neurobiology is investigating how neuron activity in behaviorally trained rhesus monkeys and crows produces complex brain functions such as numerical reasoning and geometric processing.

Cognitive control in crows

In crows, we studied the nidopallium caudolaterale (NCL), the avian analogue of the primate PFC. In one study, crows categorized line lengths as “short” or “long” (Wagener & Nieder, 2023). NCL neurons reflected these learned categories, and population activity predicted decisions. When re-trained with three categories (“short,” “medium,” “long”), representations dynamically adapted shortly before choice, illustrating flexible magnitude categorization.

In another study, we explored shape–number associations in crows (Kirschhock & Nieder, 2023b). NCL neurons encoded the numerical values of symbolic shapes in a behaviorally relevant and highly selective manner—more so than for dot arrays. This suggests a phylogenetic predisposition in corvids for linking visual symbols with numerical meaning. These findings were complemented by behavioral work on statistical inference (Johnston et al., 2023), spatial attention (Hahner & Nieder, 2023), and number processing (Kirschhock & Nieder, 2023a), showcasing the cognitive sophistication of crows.

Number neurons in the human brain

In humans, we collaborated with Prof. Florian Mormann (University of Bonn) to record single-neuron activity in the medial temporal lobe (MTL) of neurosurgical patients during number tasks (Kutter et al., 2023). We identified two distinct neural systems separated by a coding boundary around number 4, corresponding to the behavioral shift from subitizing to estimation. Subitizing-range neurons showed sharp tuning and suppression effects suggestive of surround inhibition. For larger numbers, tuning became broader and ratio-dependent. Decoding and clustering confirmed this dual-system organization. The subitizing system also showed links to attention and working memory, reflecting shared capacity constraints.



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GROUP LEADER



Andreas Nieder
Head of Research Group
Animal Physiology

MOLECULAR MECHANISMS OF AXONAL INJURY

Maintaining the integrity of axons, the long projections of nerve cells, is essential for the proper functioning of the nervous system. Axons transmit electrical signals and transport cargoes between nerve cell bodies and synapses. Due to their unique roles, they can cover remarkable distances and are highly susceptible to injury. In neuroinflammatory diseases like multiple sclerosis, axons suffer damage from infiltrating immune cells, yet the factors governing this intricate interplay remain largely unknown. Our research centers on developing new tools for understanding molecular mechanisms underlying neurological diseases, with a focus on advanced microscopy and chemical biology-based approaches to study the factors regulating axonal biology in the healthy and diseased nervous system at the cellular and molecular levels.

MICROSCOPY / CHEMICAL BIOLOGY / AXONS / NEURONAL INJURY /
PROTEIN ENGINEERING

Mechanisms of neuronal and axonal injury

Our research focuses on understanding the mechanisms regulating axonal stability and breakdown. As axons play a crucial role in transmitting electrical impulses and transporting cargoes between neuronal cell bodies and synapses, the integrity of axonal structure and function is paramount for the normal functioning of the nervous system. Due to their unique roles, axons can cover remarkable distances and are highly susceptible to injury. Although certain mechanisms in the cellular response to different forms of damage are shared, the specific details of the initial triggers and downstream pathways are still under investigation.

Our particular interest lies in neuroinflammatory axonal injury, as observed in multiple sclerosis. Previous research identified a novel form of neuroinflammatory axon loss—focal axonal degeneration (FAD; Nikić et al., *Nature Medicine* 2011). FAD is a sequential process induced by neuroinflammatory oxidative stress, featuring focal axonal swellings that may persist, progress to degeneration, or even spontaneously recover. However, many questions regarding this process, such as the determinants of axonal recovery, events at the earliest injury sites, and mediators of changes in axonal shape, remain open.

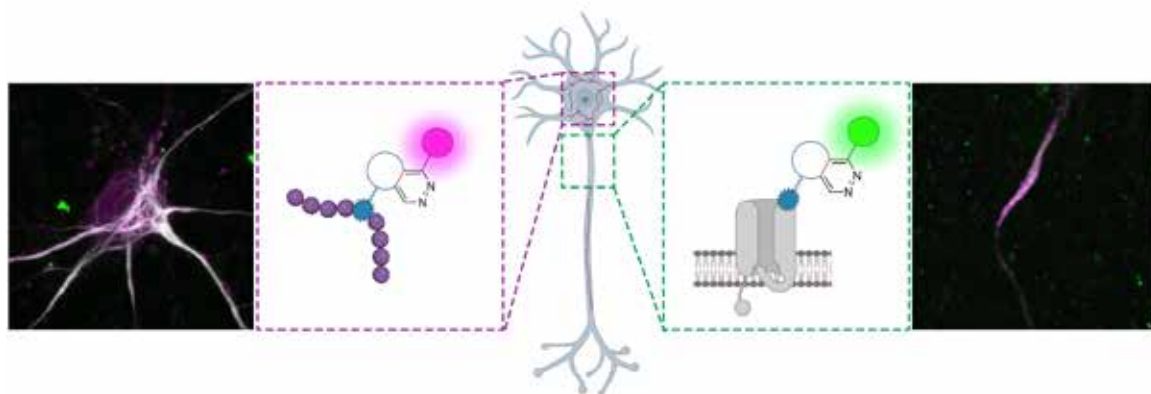


Fig. 1

Minimal click chemistry-based tags for fluorescent labelling of cytoskeleton and ion channels in neurons

Advanced protein labelling and imaging techniques

My group adopts an interdisciplinary approach to studying axonal biology, integrating diverse techniques from cellular, molecular, and chemical biology, as well as in vitro and animal disease models and microscopy. Beyond conventional methods, we use advanced super-resolution microscopy to attain molecular-scale insights into neuronal organisation. Another major focus of our research is the development of cutting-edge protein engineering tools, which rely on the selective incorporation of unnatural amino acids (UAAs) and bioorthogonal click chemistry (Nikić-Spiegel, *ChemBioChem*, 2020; Nikić et al., *Angewandte Chemie* 2014; Nikić et al., *Nature Protocols* 2015; Nikić et al., *Angewandte Chemie* 2016). Incorporation of UAAs by genetic code expansion provides us with a unique opportunity to introduce new properties and functional groups, such as dyes and affinity tags into proteins. However, this emerging protein engineering technology has primarily been used in conventional cell lines and at the proof-of-principle level. To fully harness the potential of this technology for fundamental and translational research, genetic code expansion-based click labeling of proteins in complex biological systems, such as primary neurons, needed to be established. We addressed this challenge in my laboratory by establishing this advanced protein labelling in primary neurons for the first time (Arsić et al., *Nature Communications* 2022; Stajković et al., *Journal of Cell Science* 2023; Taylor et al., *Wiley Analytical Science* 2023).

Future Directions: Proteome Dynamics and Cell-Cell Interactions

Another significant focus of our research involves using chemical biology to identify novel mediators and signaling pathways involved in neuroinflammation and axonal injury by studying proteome dynamics. To decipher unbiased changes in neuronal proteomes, we have adapted genetic code expansion-based UAA incorporation technology for cell-specific UAA incorporation, targeting specific cell types and proteome subsets. This approach allows us to identify time-specific and cell-specific changes in proteomes during various phases of neuroinflammatory diseases like multiple sclerosis. In the future, we plan to integrate this method with novel proximity-based labeling for studying cell-cell interactomes, providing fresh insights into the complex signaling pathways involved in cellular interactions in multiple sclerosis and other neurological diseases.



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GROUP LEADER



Ivana Nikić-Spiegel
Head of Research Group
Molecular mechanisms of
axonal injury

HUMAN VERBAL COMMUNICATION LABORATORY

Our main goal is to understand the neurocognitive computations that underlie humans' ability to comprehend speech in natural spontaneous communicative settings. In all sensory modalities, object recognition requires robust and efficient mechanisms for extraction and integration of relevant features. This is particularly true for speech, which is highly complex and characterized by considerable variability within and between speakers. Robust communication requires neural networks to recognize and adapt to this variability. We study the underlying cognitive processes and neural computations, their temporal dynamics and brain regions involved.

SPEECH / LANGUAGE / COMMUNICATION / HUMAN INTRACRANIAL
ELECTROPHYSIOLOGY / M/EEG

Neural tracking of speech temporal dynamics

For this, we record large-scale network dynamics using non-invasive recordings with Magneto -and electro-encephalography (M/EEG), and local neuronal processing with intracranial electrophysiology (iEEG) in neurosurgical patients. Further, we use behavioral psychophysics to study the contribution of different acoustic features to the final percept of complex (speech) sounds. Using MEG and computational modeling, we recently adjudicated between two competing theories of speech envelope tracking. We showed that neural markers in slow frequency ranges in MEG, such



as phase alignment to acoustic edges, reflect overlapping evoked responses, not the alignment of endogenous oscillations to the speech envelope (Oganian, Kojima et al, 2023, Journal of Neuroscience, in collaboration with Dr. Assaf Breska, MPI for Biological Cybernetics). In an ongoing project, PhD student Andrey Zyryanov is exploring the role of acoustic edges for tracking of and normalization for speech rate. PhD student Charlotte Mock is working to isolate the bottom-up neural processing of acoustic edges, from perceptually defined processing of perceptual onsets of complex sounds, such as musical tones or words (Mock et al, 2025, RPPW workshop).

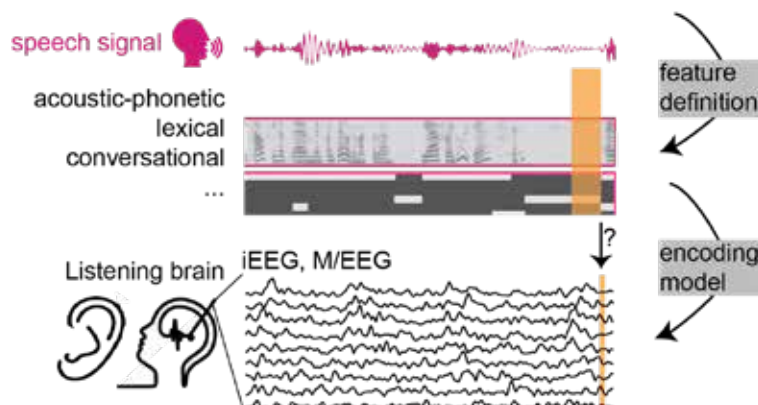


Fig. 1

To disentangle neural tracking of multiple concurring dimensions of the speech signal, we use encoding models such as temporal receptive field modeling. These models link neural activity at any given timepoint to variation in acoustic-linguistic content of the preceding speech signal.

Local cortical representations of speech sounds

Using intracranial recordings, we have recently revealed how local neural populations in the human speech cortex process the spectral content of vowel sounds (Ogania, Bhaya-Grossman et al., 2023, *Neuron*). We found that two-dimensional formant receptive fields dominate these representations, which give rise to distinct vowel categories when combined across neural populations. This work also found that throughout human speech cortices, vowel formant representations integrated between their acoustics and talker voice characteristics, creating the optimal basis for speech recognition.

Each language has its unique set of distinct vowel categories. In German (but not in English), vowel durations can change the meaning of a word (e.g., /ban/ (spell) vs /ba:n/ (train)). Work in progress by PhD student Mara Wolter is showing that neural response amplitudes throughout auditory cortices encode durational information relative to speaker speech rate, supporting the notion of context-dependent encoding of speech sounds.

Cortical tracking of intonational patterns in neurotypical and autistic individuals

Funded by an Explorer Grant of the Simons Foundation Autism Research Initiative (SFARI), postdoc Dr. Peter Bang is extending our inquiry towards understanding how intonational patterns and underlying acoustic cues are processed by neurotypical and autistic individuals. Using complementary behavioral and MEG studies, we are testing the hypothesis that perception and neural tracking of social-pragmatic acoustic cues (turn-taking, linguistic and affective prosody) are linked to self-reported socio-pragmatic skills in both populations.



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GROUP LEADER



Yulia Ogania

Head of Research Group
Human Verbal Communication
Laboratory

BIOMEDICAL MAGNETIC RESONANCE, HIGH-FIELD MR CENTER

Our goal is the development and application of novel magnetic resonance techniques at very high magnetic fields to specifically probe the anatomical and functional microstructure of the brain. We aim to understand how physiological processes and microstructure impact the measured resonance signal, and how these magnetic fingerprints can be used to reliably detect brain activation.

MAGNETIC RESONANCE IMAGING / FUNCTIONAL MRI / RADIOFREQUENCY TECHNOLOGY / NEURO-VASCULAR COUPLING

Our major goal is the robust detection and identification of brain activity using ultra high-field MRI and concurrent combination of MRI and other read-outs such as optical and electrophysiological recordings. This goal is closely related to the advancement of structural and functional MRI technology at ultra-high fields. It is further related to a more specific understanding of the measured hemodynamic contrast, the variability of this contrast across different cortical and subcortical regions, its dependence on the underlying structure and shape of the microvasculature, and the correlation of this contrast to neuronal activation as a function of spatial and temporal resolution. An important step towards a better understanding of MR signal formation in neuronal tissue will be achieved

with multimodal integrated micro devices composed of MR detectors, optical and electrical detectors with a size of only a few hundreds of micrometers.

MR Technology

We develop highly dedicated radio-frequency multi-channel transmit and receive arrays with optimized efficiency, receive performance and coverage. Further projects include local shim arrays, parallel transmit technology and ultra-low field MR with hyperpolarization. In addition, we started to develop novel spatial encoding techniques that rely on local, high-frequency modulation of magnetic fields (B_0) and receive coil sensitivities (B_1) during the acquisition process (ERC advanced grant).

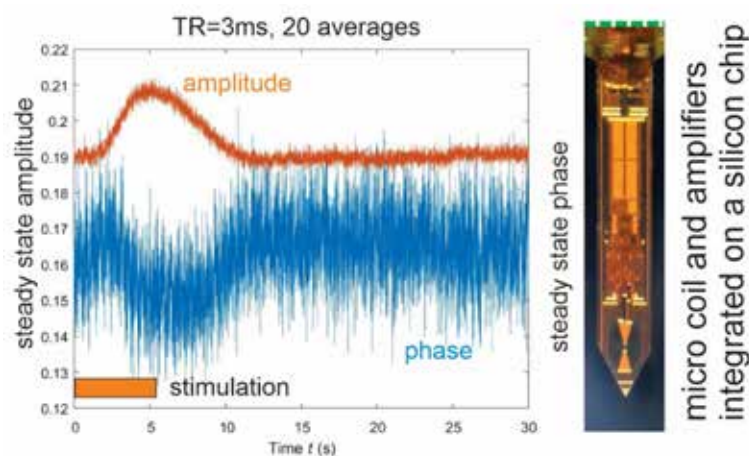


Fig. 1

Signals acquired in-vivo with the micro needle during a forepaw experiment using a $TR=3ms$ infinite FID sequence at 14.1T. Compared to a 10 mm surface coil the micro coil has an improved SNR of about a factor of 150. Adapted from Handwerker, J.; Pérez-Rodas, M.; Beyerlein, M.; Vincent, F.; Beck, A.; Freytag, N.; Yu, X.; Pohmann, R.; Anders, J.; Scheffler, K.: A CMOS NMR needle for probing brain physiology with high spatial and temporal resolution. *Nature methods* 17 (1), S. 64 - 67 (2020).

Fingerprints of Neuronal Activation

A major line of our research is a more specific understanding of the measured MR signal during brain activation, the variability of this contrast across different cortical and subcortical regions, its dependence on the underlying structure and shape of the microvasculature, and the correlation of this contrast to neuronal activation as a function of spatial and temporal resolution. This will substantially improve our ability to measure neural activity from fMRI through detailed biophysical modeling of the hemodynamic response.

Structural and metabolic brain imaging

Brain activation is (sometimes) reflected in changes of the acquired MR signal, and depending on the selected acquisition method, may reflect underlying neuronal activation, or just very unspecific changes in local blood oxygenation or flow. The magnetic fingerprint of neuronal activation strongly depends on local physiological processes and on the underlying microscopic composition of the neuronal tissue and microvascular architecture and dynamics.

Neuroinformatics

At present the full complexity of fMRI data is poorly understood. Our own previous research, as well as that of several other research groups around the world, has shown that only a small percentage of the variance of fMRI time courses is explained by standard analysis techniques. Ultra-high field data show much more detail, making it even more difficult to understand and interpret the full information content. We aim to harvest as much of the information content of fMRI as possible in order to advance our understanding of human brain function. Specifically, our work has focused on the development of novel techniques for statistical inference and for the analysis of functional brain networks.



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GROUP LEADER



Klaus Scheffler

Head of Research Group
Biomedical Magnetic Resonance,
High-field MR Center

ECHOLOCATION IN BATS

Bats have to solve a multitude of different echolocation tasks depending on where they fly and forage, what they eat and how they acquire food. In the course of evolution bats evolved a repertoire of species-specific echolocation signals and behaviors that have been adapted to the echolocation tasks that have to be performed. We compare and analyze the echolocation behaviors of different species of bats in typical echolocation tasks to understand their foraging strategies and to conceive the adaptive value of their signal design and flight morphology.

BATS / ECHOLOCATION / DOPPLER SHIFT COMPENSATION / FORAGING STRATEGIES / GPS AND SOUND TAGS

In our current research we cooperate in comparative field studies with the research groups of Prof. Yossi Yovel, Tel Aviv, Israel; Ass. Prof Laura Stidsholt, Aarhus, Denmark; and Prof. Vu Dinh Thong, Hanoi, Vietnam.

Project with Yovel and Stidsholt

The research with Yossi Yovel and Laura Stidsholt is dominated by a new method where the echolocation and flight behavior of freely moving foraging bats is recorded by a miniature GPS and sound tag and analyzed afterwards. With this approach we found that “Echolocating horseshoe bats foraging in the wild adjust sensing to maintain prey echoes at the center of their auditory fovea”. The results of this study can be summarized as follows: How animals handle the immense incoming information they receive while moving through the world, and properly regulate sensing

accordingly has hardly been studied under natural conditions. Using miniature GPS and sound tags, we monitored the sensory input of freely foraging Greater horseshoe bats. Stationary bats foraging from a perch and bats flying along vegetation in permanent acoustic contact to the environment detected echoes from fluttering prey within many clutter echoes by adjusting their emission frequency according to the incoming sensory input. Thereby they maintain behaviorally relevant information in echoes from fluttering prey at the center of their auditory fovea just above the masking range of clutter echoes. This unique animal model monitors sensing under natural conditions, and reveals active sensing strategies which could be generalized to many other species. In future we will use a similar methodological approach to study the behavior.

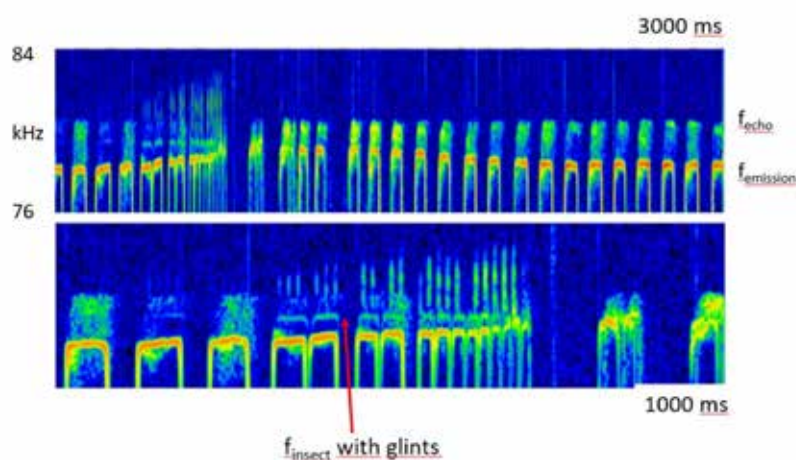


Fig. 1

Color spectrograms of the sound sequence of a Greater Horseshoe bat capturing a fluttering insect recorded with a tag on the foraging bat



Fig. 2

Greater horseshoe bat catching prey

Project with Vu Dinh Thong

In the studies with Prof. Vu Din Thong we describe on the basis of sound recordings in a field and in a flight tent, a so far not known foraging strategy of some bats "Burst echolocation – a strategy of some small low duty cycle bats to forage for fluttering insects in dense clutter". The results of this study can be summarized as follows: About one sixth of the bats with laryngeal echolocation use the high duty cycle flutter detection strategy and search in narrow space for fluttering prey with long signals of constant frequency. These search signals are emitted at high duty cycle and are used to sense rhythmical modulation pattern in echoes from fluttering insects. We show that five insectivorous species with low body mass and low wing loading use another strategy to forage for fluttering insects in dense clutter: the low duty cycle flutter detection strategy. These small and highly maneuverable bats sample in search flight their densely cluttered foraging areas with groups or bursts of short (0.4 – 2.0 ms), downward frequency-modulated search signals of ultra-high frequency, large bandwidth and very low sound pressure level. Pulse intervals within the bursts are short (11 - 17 ms) and the duty cycle is low (3 – 12%). Species from which we recorded capture sequences increased their sampling rate after prey detection by emitting bursts with more and shorter pulses at reduced pulse intervals. In field studies of some species bats were attracted by a rotating propeller simulating the beating wings of an insect which indicates the use of flutter information. Ensonifications of a flutter simulator with burst sequences generated specific glint pattern in echoes encoding flutter information which may be used for the detection of insects. The prey spectrum suggests that all burst echolocators also use the active gleaning echolocation strategy to capture insects, their larvae, and web building spiders.

Future projects

In the future we will use a similar methodological approach to study the behavior of other species of bats while foraging in the field.



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GROUP LEADER



Hans-Ulrich Schnitzler
Head of Research Group
Echolocation in bats

SYSTEMS NEUROPHYSIOLOGY

Touch is an actively scanning system. We use our hands to rub across textures. Whisker movements of rodents serve the same purpose. How are mechanical deflections of the integument decoded for tactile perception? How are these tactile feedbacks used to guide motor learning and predictive coding? Which functional roles are played by neocortex and cerebellum?

TACTILE CODING / SENSORIMOTOR INTEGRATION / LEARNING AND MEMORY / NEO-CORTEX AND CEREBELLUM

Our group studies the sensorimotor system of mice and humans, with a focus on the cortical structures neocortex and cerebellum. A long-term interest has been the question how mechanical deflections of the integument are encoded in the brain. We study primary tactile neocortical contributions to Pavlovian reflex

conditioning. Further, we attempt to disentangle the function and neuronal bases of neuronal systems that attenuate ascending tactile signal flow. Finally, we study the micro-circuitry of the cerebellar nuclei, the output of the cerebellum and a major player in sensorimotor interaction.

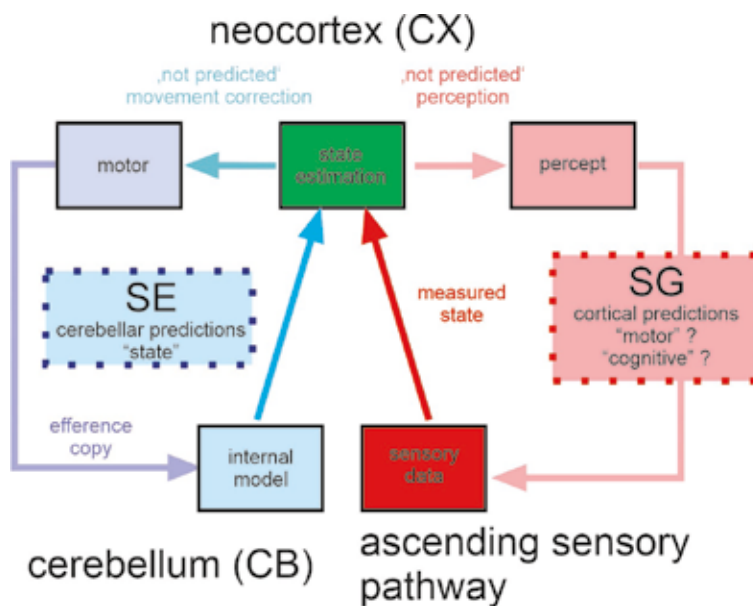


Fig. 1

Two entangled predictive systems studied in the lab (related to hypothesis 2, above). Both modulate tactile signal flow. SE: State Estimation the modern formulation of the classic reafference principle. An efference copy (and other contextual signals; violet) are integrated by an internal model to generate a prediction of sensory consequences of an executed movement (blue). These predictions of state are compared to the actually measured state that arrives via the tactile system to yield an optimal estimation of state. SG: is assumed to be a direct cortical modification of sensory flow in the periphery (pink), perhaps related to rewards, cognition, etc.

Neocortical contributions to Pavlovian reflex conditioning

In vivo two-photon imaging of dendritic spines, recording multielectrode extracellular signals and optogenetic blockade of S1 demonstrated that its synaptic architecture and neuronal activity is highly plastic during Pavlovian conditioning of eyeblinks, and that it is instrumental for acquisition but not retention of the task. We posit that these findings reflect the acquisition and consolidation of explicit memory ("the rule of the game") along the classical implicit content of procedural memory ("learn the eyeblink movement in response to a neutral stimulus").

A new decoding scheme employing frictional movement of the integument

Inspired by the biomechanics of frictional movements, our hypothesis challenges the long-held belief that the tactile system is organized in similar ways as the auditory system: Integrating the sensory signal according to pitch (frequency) and intensity. We have carried out biomechanical, electrophysiological, and behavioral studies in rodents and humans that argue in favor of the idea that tactile texture encoding uses instantaneous (non-integrative) encoding of kinematic variables of movement of hair and skin. The frequency and intensity of pulsatile stimuli is a poor determinant of performance, while it is decisively driven by the instantaneous kinematic outline of a deflection.

The functional connectome of the deep cerebellar nuclei. (Project leader: Christine M. Pedroarena).

Despite the fact that all cerebellar-cortex signals must pass through the deep cerebellar nuclei, a complex structure composed of different neuron types, the functional role of the cerebellar nuclei is unclear. We are currently pursuing the aim to reveal the unknown anatomical and functional circuit of these nuclei, using *in vitro* patch clamp recordings, electrical and optical stimulation and neuron reconstructions, under conditions that emulate those found in behaving animals. Using this approach, we identified, for instance, a rare form of slow-short-term-depression in the synapses made by the Purkinje cells onto the principal cells of the cerebellar nuclei, which enables a form of gain control in the time scale of tens of seconds while allowing linear transfer of the transient signals occurring in the sub-second time scale of movements.

Two central neuronal systems attenuate tactile signal flow

An important brain function is to build internal models of the world in order to generate predictions to guide behavior. Aiming to disentangle two prediction systems, we have found two systems that both attenuate sensory signal flow in S1 and the ascending tactile pathway. One is called state estimation (SE) and predicts sensory consequences of movement. The second one, sensory gating (SG) is active during movements independent on kinematic variables. SE attenuates tactile signal flow in temporally precise manner. SG, on the other hand, is active during the full duration of ego-movement. We posit that SE is the reflection of the classical idea of reafference principle, guiding motor learning and tactile perception, while SG may be concerned with predictions on the cognitive level, perhaps indicating the availability of reward.



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GROUP LEADER



Cornelius Schwarz
Head of Research Group
Systems Neurophysiology

NEURONAL DYNAMICS AND MAGNETOENCEPHALOGRAPHY

Our thoughts, feelings and actions arise from the activity of billions of specialized neurons. The activity of each of these neurons and the information it encodes result from complex interactions with many other neurons in local and large-scale circuits across the entire brain. However, little is known about the specific interactions that generate information and the dynamics of neuronal activity. Similarly, the relationship between the dynamics of neuronal activity and our thoughts and actions remains poorly understood. The aim of our research group is to better understand these relationships and thus to gain new insights into the neuronal basis of our thoughts, feelings and actions.

COGNITION / PERCEPTION / BEHAVIOR / NEURAL NETWORKS / ELECTROPHYSIOLOGY

Integration across scales

Brain dynamics comprise large-scale networks of brain regions, but the underlying causal interactions take place at the cellular level. To integrate these scales, we use an interdisciplinary multi-scale approach. Non-invasive MEG and EEG enable investigation of the entire human brain and animal models provide access to neuronal dynamics at the cellular level.

Spectral fingerprints of brain function

One focus of the research group is the oscillatory dynamics of neuronal activity. Brain activity exhibits periodic oscillations across different frequencies and spatial scales. These oscillations may not only serve as informative markers or “spectral fingerprints” of circuit interactions involved in various cognitive functions but may also dynamically mediate these interactions.

We investigate how different brain regions coordinate their oscillations and whether these rhythmic networks could serve as biomarkers for various neurological diseases. Furthermore, we investigate the temporal microstructure of different brain rhythms and how they are linked to information coding.



Fig. 1

MEG system installed at the Tübingen MEG Center that allows for measuring the magnetic fields generated by brain activity.

Neuronal dynamics during cognition and behavior

Another focus of the research group is the neuronal dynamics that underlie specific cognitive functions. For example, the researchers characterize the flow of information and neuronal interactions in cortical and subcortical networks during complex behavioral tasks, such as visual and auditory decision-making, attention, working memory, vocalization and sensory perception. The research group investigates how information flow is modulated depending on context and how it is related to neuronal oscillations, dynamics and interactions. Together with our clinical cooperation partners, we also investigate changes in neuronal dynamics in pathological conditions.

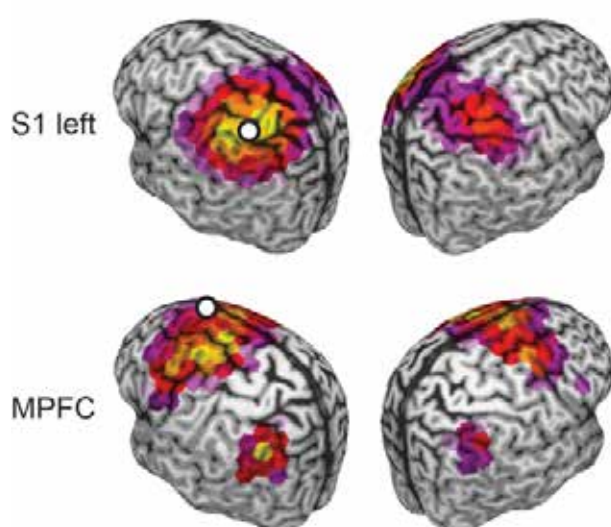


Fig. 2

Coupled brain networks imaged with MEG. Top: Left primary somatosensory cortex (S1) couples with the homologue region in the right hemisphere. Bottom: Medial prefrontal cortex (MPFC) couples to a bilateral frontoparietal network.

Magnetomyography – quantum sensing of muscle activity

A recent focus of our research is on magnetomyography (MMG), i.e. the measurement of magnetic fields generated by muscle activity. The development of so-called optically pumped magnetometers (OPM) has enabled flexible and contact-free MMG without the need of cryogenic cooling. Together with our collaborators and clinical partners, we investigate OPM-based MMG for basic research and clinical applications.



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GROUP LEADER



Markus Siegel

Head of Research Group
Neuronal Dynamics and
Magnetoencephalography

COGNITIVE NEUROLOGY

We are interested in the neural basis of social interactions and the role of the cerebellum in motor learning and fatigue compensation. We seek to use the insights gained into basic functional principles of brain mechanisms to advance the understanding of disorders of social interactions such as autism and cerebellar ataxia, the latter a major consequence of cerebellar disease.

To this end we conduct experiments on trained macaque monkeys and marmosets using electrophysiological recordings and focal neurochemical interventions to establish causality, accompanied by complementary work on healthy human subjects and patients using behavioral and fMRI approaches.

MIRROR NEURONS / ATTENTION / AUTISM / SOCIAL COGNITION / MOTOR LEARNING / FATIGUE / ATAXIA / (CONTROL OF) EYE MOVEMENTS

Cortical Underpinnings of social interactions

We study the basis of social interactions and their disruption by disease, such as schizophrenia or autism: how is it possible to understand the intentions, desires and beliefs of others, in other words to develop a Theory of (the other's) Mind (TOM)? Developing a TOM requires identifying the focus of another person's attention and understanding the purpose of their actions. The other person's eye, head, and body orientation are a particularly powerful class of sensory cues that reveal the other person's location and object of interest and allow the observer to shift her/his attention to

the same object, thereby establishing joint attention, which allows one's object-related intentions and desires to be mapped onto the other person. The Cognitive Neuroscience Laboratory seeks to elucidate the neural structures and mechanisms that enable joint attention and understanding of the other's intentions, as well as information about the other's emotional state as documented by facial expressions. It is hypothesized that dysfunction of these structures, involving larger areas of cortex around the superior temporal sulcus and the adjacent temporo-parietal junction, may indeed underlie the inability of autistic individuals to use gaze cues efficiently when interacting with others.

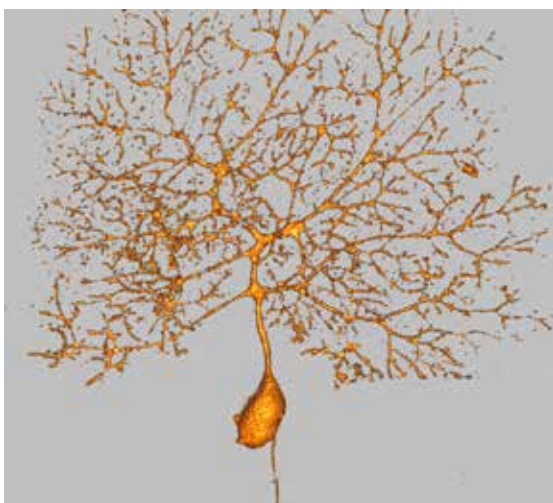
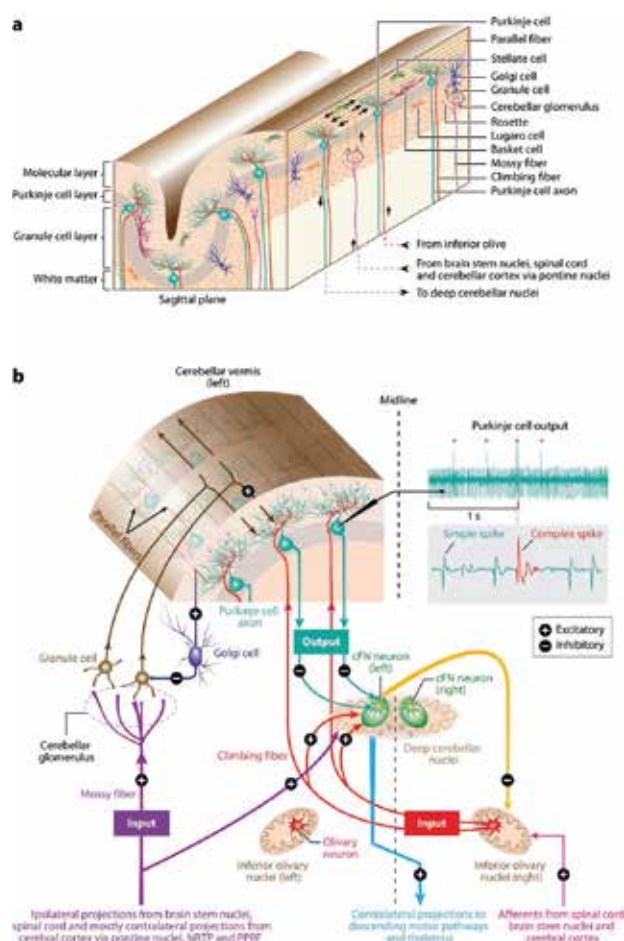


Fig. 1
Cerebellar Purkinje Cell

Complementary work on the basis of social interactions addresses the role of the mirror neuron system in the premotor cortex. Mirror neurons are a class of neurons in the premotor cortex of monkeys that are activated by certain types of goal-directed motor actions. Using electrophysiological recordings, the group has studied the responses of mirror neurons in the premotor cortex to test their long-believed role in action understanding. In short, the accumulated evidence does not support this role. It is more consistent with a role in selecting behavioural responses.

**Fig. 2**

Cerebellar cortex. (a) The cerebellar cortex is anisotropic with three layers and two distinct axes defined by parallel fibers and the flat dendritic trees of Purkinje cells. (b) The canonical cerebellar circuit integrating information from two types of afferents – climbing fibers and parallel fibers. From: Thier and Markanday. *Ann. Rev. Vis. Sci.* 5: 247-261

Cerebellum-based motor learning

A second major interest of the laboratory is in the role of the cerebellum in motor control and motor learning, relying primarily on short-term saccadic adaptation as an appropriate model behaviour. Evidence gathered by the group suggests that the biological purpose of cerebellum-based learning is to compensate for motor or cognitive fatigue. This view has allowed the group to propose a new perspective on cerebellar ataxia, the key deficit in patients suffering from cerebellar diseases. Ataxia, characterized by lack of precision, reduced speed and increased variance, is an inevitable consequence of the inability of the motor system to compensate for fatigue. We have provided support for the idea that such deficits result from a loss of the ability to make rapid, optimized predictions of the consequences of movement, using the same neural principles that enable short-term motor learning and fatigue compensation. In our recent work on the role of the cerebellar climbing fibres, traditionally thought to be limited to reporting information about current performance errors, we have shown that this afferent system taps into many other sources of information that are valuable for learning.



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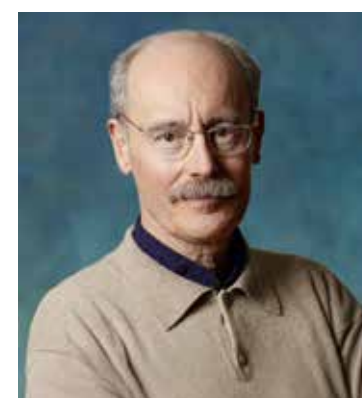
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GROUP LEADER

**Peter Thier**

Head of Research Group
Cognitive Neurology

NEUROBIOLOGY OF VOCAL COMMUNICATION

Our group aims to understand the flexible control of complex behavior. We combine traditional neuroethological approaches with behavioral training to study the neuronal basis of flexible song sequencing in Bengalese finches. Songbirds like Bengalese finches are important animal models for vocal learning and skilled motor behavior more generally. We use electrophysiology, lesions, and behavioral manipulations to study neural circuits involved in motor learning and flexible motor control in the avian brain. Our interests also include exploring the behavioral rules governing flexible sequencing and computationally modelling the interesting song structure of Bengalese finches.

BIRDSONG / SYNTAX / VOCALIZATION / MOTOR SEQUENCE / SOCIAL CONTEXT

Variable vocal sequences to understand the composition of complex behavior

We started our group at the CIN & Institute for Neurobiology in 2020. Since 2024, the group is additionally funded as an Emmy Noether Group. Our main goal is to decipher the neuronal mechanisms underlying the sequential structure of Bengalese finch song. This song is composed of acoustically distinct syllable types, which are strung together into variable sequences, offering a unique opportunity to study the generation and interpretation of variable and syntactically organized vocal sequences, with a complexity that is much more limited than in human language. The control of sequencing is a fundamental aspect of cognition, as speech, thought and many other behaviors are composed of ordered sequences of simpler elements.

State of the art techniques

We use machine learning techniques to automatically capture and annotate the syllables in Bengalese finch song. We then analyze statistically the order of transitions and long-range dependencies in their syllable sequence with a particular focus on syllable repetition. On a behavioral level, we use song-triggered manipulation of auditory feedback in real time to investigate sensorimotor influences on ongoing song production, as well as to introduce learned changes to the song sequence. Using this technique, we have recently shown that Bengalese finches can associate arbitrary contextual cues (colored lights) with learned modifications in their syllable sequence (Fig. 1). This demonstrates top-down control over the avian song production circuit, which can adjust behavior to contextual demands more flexibly than previously appreciated.

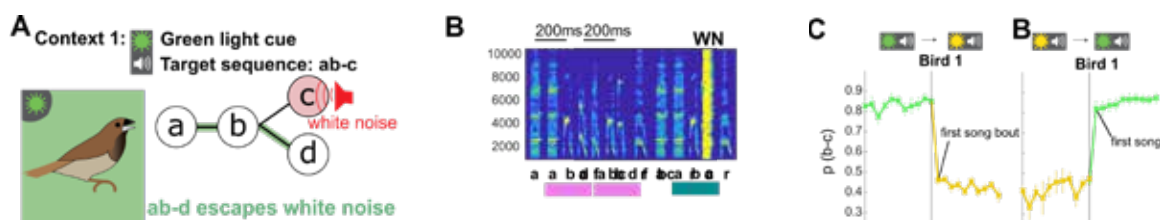


Fig. 1

A) Schematic of the contextual learning protocol. A specific syllable transition in the song was targeted with a short burst of white noise (WN), which leads birds to sing an alternative transition more frequently in future non-targeted probe songs. B) Example spectrogram highlighting points in song with variable sequencing. Syllables are labeled based on their spectral structure, target sequences for the different experiments (ab-c and ab-d) are marked with colored bars. C) After training, birds immediately shifted the sequence probability of the target syllables in the first song bout after context changes.

On a neuronal level, we have recently shown that lesions to a specific part of the song production circuit influence the variability of syllable sequencing. The transitions at branch points in the song became less predictable, and new branches appeared in previously stereotyped subsequences ("chunks") (Fig. 2). Our findings suggest that the lesioned pathway is selectively involved in species with complex song syntax.

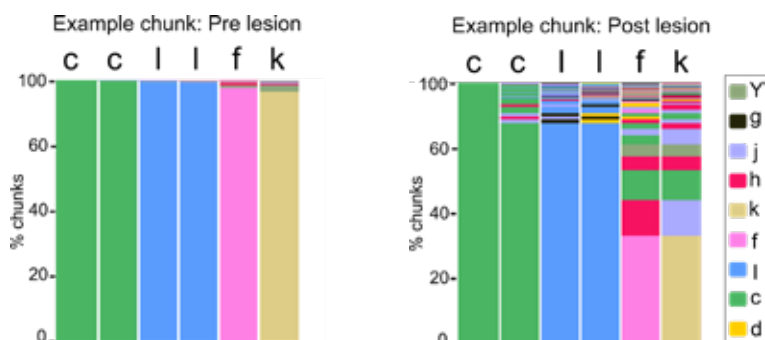


Fig. 2:

Transitions within an almost completely stereotyped subsequence ("chunk") of syllables ("c-c-l-l-f-k") became more variable after lesions to the mMAN (medial magnocellular nucleus of the anterior nidopallium), a nucleus in the song production circuit.

Ongoing research projects

In a project funded by the Daimler Benz foundation, we are investigating the role of social context on song syntax learning. We are also working on finding a neurophysiological correlate of the syntactic dependencies in song (for example, syllable sequence 'a-b' is typically followed by 'c', while 'x-b' is typically followed by 'y'), and making technological improvements to the song targeting protocol for behavioral training. Together with colleagues in Israel, we are developing an understanding of complex song sequencing across multiple species, funded by the DFG Middle East Collaboration. Together with colleagues from the MPI for Biological Cybernetics, we are developing a new computational model of Bengalese finch song.

Teaching and Outreach

Five master students and two Bachelor students have finished their thesis in the lab. We were also active in various outreach activities. Lena Veit has given a lecture at the Kinder-Uni "Warum singen Vögel?" and at the Girl's Day event of the Schülerlabor Neurowissenschaften. PhD Student Jacqueline Göbl appeared in a CampusTV Science Slam, and PhD Student Avani Koparkar was an organizer of the student-run NeNa conference and has participated in "Pint of Science" outreach activities.



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GROUP LEADER



Lena Veit

Head of Research Group
Neurobiology of Vocal
Communication

NEURAL INFORMATION PROCESSING

My group's research goal is to understand visual perception. We investigate visual perception from the level of simple artificial stimuli up to object and scene perception, combining psychophysical experiments and computational modelling. Currently we have three research foci: First, to improve our image-based model of early spatial vision. Second, to connect early spatial vision with mid-level vision: perceived lightness, brightness and contrast in relation to surface reflectance and illumination in images of real scenes. Third, we investigate object recognition abilities in human observers and explore differences and similarities between human visual perception and that of deep convolutional neural.

VISUAL PERCEPTION / OBJECT RECOGNITION / PSYCHOPHYSICS / MACHINE LEARNING / COMPUTATIONAL MODELLING



Fig. 1

Texture-content cue-conflict images used in our research on object recognition, exploring similarities and differences between human observers and artificial neural networks

Vision as inference

The Wichmann-lab's research goal is to understand visual perception: How does the visual system transform the photons absorbed by the retinal photoreceptors into meaning, into perceived scenes, objects and actions? Hermann von Helmholtz (1867) is typically credited to have been the first to realize that visual perception is a form of inference: visual percepts are—typically reasonably accurate—hypotheses about the world based on incomplete sensory evidence.

Psychophysics and computational modeling

To make progress towards understanding this inference, we investigate perceptual processes from the level of simple artificial stimuli up to complex object and scene perception, combining psychophysical experiments and computational modeling.

Recent research highlights include our detailed behavioural comparisons between deep neural networks (DNNs) and human observers, establishing that current DNNs and the human visual system see or sense the world differently (Geirhos et al., 2018; 2019; 2020; 2021; Wichmann & Geirhos, 2023). In addition, we showed that ordinal embedding algorithms from machine learning can be used to understand human perceptual decisions, and that ordinal embedding methods have significant advantages over traditional psychophysical so-called scaling methods (Haghiry et al., 2020; Künstle et al., 2022; Sauer et al., 2024).



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GROUP LEADER



Felix A. Wichmann
Head of Research Group
Neural Information Processing

PHILOSOPHY OF NEUROSCIENCE

The philosophy of neuroscience sits at the boundary of cognitive neuroscience and philosophy of mind. Advances in empirical research have generated an abundance of data, calling for philosophical interpretations that engage with these findings. The Philosophy of Neuroscience (PONS) group contributes to this dialogue by examining questions related to the foundations of integrative neuroscience, perception and action, body cognition, and rationality.

PHILOSOPHY OF NEUROSCIENCE / AGENCY / EMBODIMENT / COMPARATIVE PSYCHOLOGY / EVOLUTION

Foundations of Integrative Neuroscience

PONS explores how various levels of neuroscientific investigation—such as Marr’s computational, algorithmic, and implementational levels—relate to each other, to psychology, and to philosophical issues about the mind. The group examines whether these are the only, or the best, ways to think about levels in neuroscience (Craver, 2007), and to what extent current neuroscientific explanations can and should be integrated (Bechtel, 2008, Mitchell, 2003).

PONS also aims to investigate whether neuroscience can provide pluralistic explanations (Dale, 2008), the role of reductionism, and the concept of emergence (Bechtel 2009, Bickle 2006). PONS also scrutinizes classical conceptual dichotomies—like conscious/unconscious perception and rational/irrational decision-making—to assess their ongoing usefulness.

Perception and Action

The group investigates the relationship between perception and action, particularly the extent to which action is controlled by the agent and the role of perceptual consciousness in this control (Roessler and Eilan, 2003). Findings in motor control challenge the assumption that conscious perception is necessary for action (Milner and Goodale, 2008). Conversely, the group also asks whether perceptual consciousness depends on agency, or a reflective awareness of oneself as an agent. These inquiries engage with philosophical concepts such as egocentric and allocentric perception (Evans, 1985; Hurley, 1998; Baldwin, 1995) and draw on neuroscientific models like the Dual Visual Systems Hypothesis (Milner and Goodale, 2008) and the Comparator Model of action-awareness (Frith, 2005).

Body Cognition

Recent research views the body as a constitutive component of human cognition, raising questions about the role of bodily awareness in cognition and its mechanisms. Empirical studies using virtual reality, lesion analysis, and behavioral methods have revealed phenomena like sense of body disownership (Marchetti/ Della Sala 1998), Anarchic Hand syndrome (de Vignemont 2007) and outer body experience (Lenggenhager et al. 2007). PONS works in close collaboration with the perception and action group and the VR group at the MPI to understand how the body contributes to cognition and to refine concepts such as agency, bodily ownership, and the self.



Fig. 1

From Robert Fludd: "Utriusque Cosmi, Tomus secundus de supernaturali, naturali, praeternaturali et contranaturali Microcosmi historia", Oppenheim 1619

Rationality

Rationality concerns whether behaviors or decisions are optimal or adaptive. PONS investigates this in two areas: (1) the rational link between perception and action—whether perception provides reasons for action—and (2) decision-making models. In collaboration with the CIN Neural Basis of Intuition Group, PONS evaluates whether neo-classical models of rational choice accurately reflect human decision-making. The group also studies moral decision-making to better characterize human agency and its philosophical implications.



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GROUP LEADER



Hong Yu Wong
Head of Research Group
Philosophy of Neuroscience

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