DBI^2 Annual Report

Year 2 | October 2023 – September 2024

DBI²
DUTCH BRAIN
INTERFACE INITIATIVE

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Disclaimer

All DBI[2] experiments comply with ethical protocols approved by the relevant regulatory bodies.

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Acronym

CLS: Closed-Loop Stimulation

DBI^2: Dutch Brain Interface Initiative

Erasmus MC: Erasmus University Medical Center

EB: Executive Board

MDJ: Mesodiencephalic Junction

Nat-B Lab: Naturalistic Behaviour Lab

NIN: the Netherlands Institute for Neuroscience

RU: Radboud University

TI: Temporal Interference

TUD: Delft University of Technology

TUe: Eindhoven University of Technology

TU: Twente University

UvA: University of Amsterdam

UMCU: University Medical Center Utrecht

SAB: Scientific Advisory Board

SteerCo: Steering Committee

SWOT: Strength, Weakness, Opportunity, and Threat

WG: Workgroup

WP: Work package

YTC: Young Talent Council

DBI^2 Introduction

The **Dutch Brain Interface Initiative (DBI^2)** seeks to enhance our understanding of brain functions and brain-environment interactions by leveraging the development of a new generation of effective and minimally disruptive brain-machine interfaces. DBI^2 combines an integrated methodological platform, including computational, software and hardware elements, geared towards facilitating long-term closed-loop manipulations and brain monitoring in a naturalistic setting, with a neuroscience research program encompassing three main goals:

- *To understand the common principles of global brain dynamics and feedback interactions between brain areas subserving cognition.*
- *To make major advances in closed-loop feedback control of the brain, enabled by novel computational and technological advances, to devise effective, ecological, minimally invasive ways to influence brain dynamics, towards new practicable avenues for therapy and cognitive enhancement.*
- *To understand how animal behaviour is generated by studying the brain during complex, free-flowing interactions between the animal and the environment and between animals under increasingly natural conditions. For this, we will study the brain in a naturalistic environment throughout different life stages using computational simulations, novel neurotechnology and advanced behavioural monitoring and tracking building on advances in machine learning, breaking away from the highly restricted laboratory experiments that are conventional in neuroscience and allowing us to answer long-standing neuroscience questions.*

We will tackle these goals with a tight integration between neurotechnology, systems/cognitive neuroscience and computational neuroscience, which this consortium brings together. We will develop and leverage an **integrated platform for manipulating brain activity** based on its neural context (by means of closed-loop stimulation) and environmental context (animal behaviour, in unprecedentedly wild-like conditions, and characterised in an expressive and detailed fashion). The platform will include custom-developed neurotechnology for brain monitoring and perturbation, as well as novel ways for applying artificial intelligence (neural networks, biophysical modelling, advanced statistics) to the study of the brain.

Closed-loop and naturalistic behaviour are two emerging trends in neuroscience research. Our program will be the first to combine the two, providing an **unprecedented window into how information is encoded and processed**. By better controlling neural variability and testing the developed devices against a much wider array of behavioural conditions than currently used, this methodological approach will also enable brain interfaces of unmatched reliability and effectiveness

DBI^2 is a broad consortium, leveraging the world-class expertise in Dutch neuroscience, neurotechnology and computational sciences. It also has the goal of being **the centre of gravity of a new Dutch School of Neuroscience and Neurotechnology**, connecting scientists in fundamental and engineering disciplines in (technical) universities and research institutes across the country. The large presence and role assigned to mid-career and young scientists ensure that this school will be a long-lasting player in the Dutch research landscape.

The consortium organisation

The consortium includes researchers with an extensive track record in neuroscience, computational neuroscience, control theory, and electrical engineering towards the fusion of neuroscientific and microsystems, computing architectures, and technological goals. Below, we formulate their collaborative track record, grouped in the three main areas of study in our project: **neuroscience, computation, and neurotechnology**. Each of these groups is represented as a work package.

Figure 1 provides an overview of the DBI^2 governance structure.

The **Executive Board** (EB) is the highest governing body of the DBI^2 consortium, consisting of the Programme Director and eight members representing the participating institutions. The **Steering Committee** (SteerCo) is composed of the program director, six area leaders, and co-applicants in the

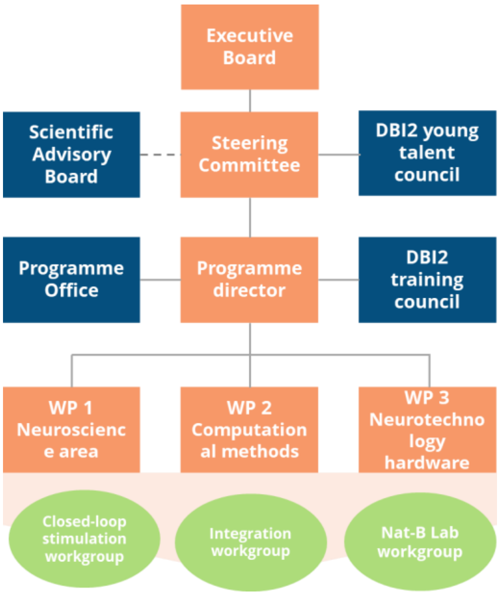

Figure 1 DBI² Governance structure

project plan who are not area leaders. The SteerCo works as the daily administrative body, ensuring integration between areas and implementing the EB's policies on scientific direction, coherence, and collaboration. Additionally, the Steering Committee includes one non-voting member from the Young Talent Council to ensure a broader perspective.

Francesco Battaglia, the **Programme Director**, spearheads the strategic management of the program. His efforts are supported by the Programme Office.

The **Young Talent Council (YTC)**, an integral part of the consortium, is made up of two postdocs and five PhD students. These members are elected for a three-year term by their peers among all PhD students and postdocs in the consortium. The YTC aims to empower young researchers by giving them a voice in both the operational and strategic management of the consortium. This initiative fosters enhanced synergy across DBI² and its participating institutions through a bottom-up approach.

Prioritising the training of the next generation of scientists is fundamental to DBI², securing the project's enduring legacy. The **Training Council**, led by Fleur Zeldenrust and Martin Vinck from Radboud University, is charged with organising the training program. They collaborate closely with the YTC to refine and expand the programme, ensuring it meets the needs of its participants.

The consortium's main external advisory body is the **Scientific Advisory Board (SAB)**. The SAB provides guidance on all consortium aspects, including research strategy, international competitiveness, organisation, and knowledge transfer, to maintain and enhance the consortium's effectiveness.

The **Programme Office**, crucial for day-to-day operations, includes a Programme Manager, Grant Advisor, and Scientific Coordinator. The Programme Manager is responsible for communication, data management, dissemination, financial administration, and various project management tasks. The Grant Advisor maintains contact with the funding organisation and the financial departments of DBI² organisations regarding the tranche fee recipient and its allocation. Meanwhile, the Scientific Coordinators focus on overseeing the consortium's scientific collaborations and assisting the Programme Managers with dissemination activities, ensuring a cohesive and collaborative environment within DBI².

Work Packages and Workgroups

Work in DBI² is organised into three main areas: **Neuroscience** (**Work Package 1**), **Computational Methods** (**Work Package 2**) and **Neurotechnology Hardware** (**Work Package 3**). The Neuroscience area encompasses methods development, validation and scientific aims. The aims of the Computational Methods and Neurotechnology Hardware areas are designed to support at least one Neuroscience aim.

Efforts on the two principal methodological innovations, closed-loop analysis and study on naturalistic behaviour, are undertaken by the **Closed-Loop Stimulation (CLS) Workgroup** and the **Naturalistic Behaviour Lab (Nat-B) Workgroup,** respectively. Each workgroup comprises researchers from all three work packages to encourage collaboration across different areas. In 2024, a new framework was developed by the Work Package 2 team that integrates AI/deep learning with scientific domains utilising differential equations to model neural systems. To facilitate integrational effort between experimental data-producing labs and the Work Package 2 team, a new Workgroup**, the Integration Workgroup for computation and experimental neuroscience**, has been introduced in December 2024.

1. Annual Report summary

This Annual Report summarises the progress of our project in Year 2 (from October 2023 to September 2024). For the sake of description, we subdivide the work into the three main areas: Neuroscience (Work Package 1), Computational Methods (Work Package 2) and Neurotechnology Hardware (Work Package 3), while highlighting the collaboration between research groups both within and across work packages. The Neuroscience work package showed considerable progress in the analysis of neural activity in multiple brain areas, including visual, frontal, retrosplenial, cortex, the hippocampus and the cerebellum. Techniques enabling the monitoring of the brain state at the mesoscopic level, for example, by using ultrasound imaging, have also been developed. Clusters of research groups are working on social behaviour and behaviour under naturalistic conditions in adult and developing rodents. These experiments represent the ideal platform for the development of new brain interface strategies. This is taking place already, with work on near-real-time closed-loop brain interfaces, with a first use case under development for the disruption of memories. We made progress on the development of brain interfaces for vision (in primates) and for speech (in human patients).

The Computation work package had several major achievements, including novel paradigms for neural data analysis based on machine learning and advanced statistics, which improve the state of the art both in terms of accuracy and efficiency. We developed methods to implement computationally intensive workloads on advanced processing modalities such as GPUs and FPGAs, as well as the computational frameworks for EEG-based neural set-ups/interfaces/recordings. An important component of this work package is computational modelling, with work on the sensory system, on memory systems and Parkinson's disease.

Work in the Neurotechnology work package includes novel devices for neural activity transduction and stimulation in the electrical, optical and ultrasound modality, making use of advanced materials such as graphene. New designs for low-power consumption (potentially implantable) chips for neural signal processing have been developed, as well as systems to improve the wearability of neural implants, such as optical power transfer. The work set the stage for the new generation of brain interface devices.

We then describe activity in the cross-package workgroups that begins to be a hub of collaborations: two work groups, CLS and NAT-B Lab, were already active at the beginning of year 2, whereas a third one on data analysis integration has been started during this period. The workgroups are meeting regularly and see an active core of researchers, which we seek to expand to a larger share of the consortium

We account for the work of our training program, which provides regular activities to 25 junior researchers (18 PhD candidates, 7 Postdocs), with a high degree of satisfaction.

We present our plans for the upcoming year and conclude with a reflection on the current state, potentialities and risks of the project (SWOT analysis).

2. Progress and achievements

2.1 Work packages

Chapter 2.1. delineates the progress and achievements of the DBI² work packages. The full list of research outputs and publications is available in Appendix C.

2.1.1 Work Package 1 | Neuroscience

NS 1	*How do global brain dynamics during sleep determine dreams and memory processes?*
NS 2	*How do spontaneous activity and environmental factors affect brain development?*
NS 3	*How can visual perception guide decision-making?*
NS 4	*How can the brain support active perception and voluntary action?*
NS 4-1	*Cortical and subcortical contributions to active perception (How can the brain support active perception and voluntary action?)*
NS 4-2	*Descending cortico-cerebellar loops (How can the brain support active perception and voluntary action?)*
Ns 4-3	*Ascending cortical-subcortical loops (How can the brain support active perception and voluntary action?)*
NS 5	*What are the principles of human closed-loop brain interfaces for vision and action?*
NS 5-1	*Brain interface to restore vision for the blind (What are the principles of human closed-loop brain interfaces for vision and action?)*
NS 5-2	*Brain interface for locked-in patients (What are the principles of human closed-loop brain interfaces for vision and action?)*
NS 6	*What are the brain circuits of social transmission of emotion?*
NS 7	*How do emotions propagate in a social group?*

Table 1. Overview of the WP 1 Neuroscience specific aims

In the second year, the focus of the Neuroscience work package was on further development of collaborations, developing methodology and experimental setups, and recruitment. In addition, several results were already obtained.

NS1 (PIs: Vinck -RU, Gazzola-Nin, Battaglia-RU)

Achievements and realised outputs:

- The ONIX interface for closed-loop electrophysiology was adopted, and algorithms were implemented for closed loop stimulation, with first successful tests.
- A virtual reality memory task for mice was defined, developed, and validated. Viral strategies for perturbing the hippocampus at different time scales were developed. Causal tests are ongoing to test the dependence of remote and recent memory formation on the hippocampus.
- Machine-learning algorithms for the online detection of hippocampal sharp wave ripples based on temporal convolutional neural networks, a class of deep learning ML algorithms, were developed, validated and tested against previous algorithms, showing enhanced detection performance.
- We set-up and optimised the measurement of behavioural variables (movement, facial expression, whisking) and of variables related to the autonomic state (respiration, pupil diameter), in experiments in head-fixed mice under virtual reality conditions or integrated with ultrasound imaging.

NS2 (PIs: Olafsdottir-RU, Hoebeek-UMUC)

Achievements and realised outputs:

- We designed the analysis pipeline for the Cylinder Rearing Test (collaboration with Federico Stella-RU) for the analysis with Anipose data with AI methods (incl. DeepLabCut), validated with a set of mice affected by neonatal brain damage.

- A novel model for neonatal stress, using limited bedding and nesting, was initiated
- We analysed the first cohort of neonatal hypoxia-ischemia mice.
- Simple movements can be analysed automatically now using Live Mouse Tracker. Our power analyses reveal that 20-50 mice are required for sufficient statistical power.
- Complex social interactions require additional analysis that needs to be designed.
- A tethered system for in vivo electrophysiological monitoring has been tested.
- Heidi Lesscher (Utrecht University) joined the consortium for additional options to monitor complex naturalistic behaviour.
- PhD candidate, José Teixeira (Olafsdottir group) designed and produced the first prototype of the semi-naturalistic homecage. A single rat litter has already been video recorded in the homecage and behavioural analysis is underway.
- José Teixeira purchased neurologgers to start wireless ephys experiments in rat pups. First chronic recordings have been done, and more are planned in the coming's months.
- Laurens Witter (Hoebeek group) has developed a video tracking system consisting of 3 cameras to enable 3D reconstructions and subsequent kinematic analyses of mouse behaviour.
- Laurens Witter has implemented tracking of social behaviour in adult mice via Live Mouse Tracker.
- Laurens Witter has set up electrophysiological approaches for the recording of brain activity in juvenile mice.
- Michael van der Kooij (Hoebeek group) has set up a mouse model for neonatal stress using limited bedding and nesting.
- Data analyst Ella Sommer (Hoebeek group) analysed videos from mice with DeepLabCut for naturalistic behaviour, including nest attendance and nest sorties under stressful and under control conditions.
- Master student Nicky Marcus collected videos from juvenile mice that displayed social interaction (stress and control). She scores complex behaviours emanating from these interactions using Observer. The aim here is to obtain a blueprint for later use to automate behavioural scoring.
- Postdoc Niilo Valtakari (funded outside DBI^2) has analysed videos to automatically track both parental mice to investigate naturalistic behaviour.

NS3 (PIs: Pennartz-UvA, Roelfsema-NIN, Vinck-RU)

Achievements and realised outputs:

- Postdoc Sjoerd Murris (the Roelfsema group) continued training two non-human primates on visual perception tasks (i.e. visual detection, memory-guided saccade task),
- Sjoerd Murris implanted a third non-human primate with a novel headpost, designed to have a smaller footprint (Roelfsema, in collaboration with Jake Westerberg (affiliated researcher in the Roelfsema group)
- Sjoerd Murris helped with the development of MRI-compatible neural probes, which can be used to map them onto the neural anatomy. The probes were developed and tested for functionality and visibility (in the MRI/CT). Insertion techniques were practiced using dummy probes. (Roelfsema, in collaboration with scientists outside of DBI^2)
- A new method to study neural coding in high-dimensional neural ensembles was successfully applied to identify a stable and precise neural code for natural movies that is based on the

temporal structure of neural activity alone, outperforming codes based on energy (spike counts) alone (Sotomayor, Battaglia, Vinck).

- Progress was made in acquiring the necessary microscopic equipment for the UvA two-photon imaging project: the setup was built, and conditions were created for starting up the 3D all-opto experiments. In particular, the Femto 3D Atlas allows us to simultaneously image and/or optogenetically stimulate up to hundreds of cells in 3-dimensional (3D) anatomical space. It will be the first microscope of this capacity in the Netherlands. This microscope will allow us to address how cell assemblies responsive to different sensory modalities causally interact, and to these interactions affect perception as gauged by behavioural reports. In addition, specific compartments of distinct neural classes can be stimulated to study their causal relevance for animal behaviour (Pennartz group).
- We have made major progress in showing how different modalities and contextual factors interact to influence processing in the primary visual cortex (Pennartz group).

NS 4 (PIs:Roelfsema, Pennartz, Vinck, de Zeeuw, Narain:

Achievements and realised outputs:

- We have made progress on elucidating the role of the mesodiencephalic junction (MDJ) in discrimination learning, decoding of cerebellar nuclei activity during covert attention, and the timing-dependent integration of information in the inferior olive. (de Zeeuw group)
- We further made major progress in the design of machine learning algorithms for spike detection, crucial for real-time closed-loop feedback manipulation. (de Zeeuw group)
- A new e-phys setup for recordings in freely moving animals was established at Erasmus MC (de Zeeuw group).

NS 5 (PIs: Roelfsema-NIN, Ramsey-UMCU, Berezutskaya-UMCU, van Steensel-UMCU):

Achievements and realised outputs:

- PhD candidate, Maureen van der Grinten (NIN) completed the design of a phosphene simulator and published the results. The software for the simulator was turned into an open-source tool. Extensive simulations were performed to identify optimal stimulation paradigms. (the Roelfsema group)
- Maureen van der Grinten trained one (previously implanted) non-human primate on a phosphene detection task designed to estimate the visual characteristics of phosphenes.
- Maureen van der Grinten recorded data from one (previously implanted) non-human primate for a study looking into the effects of repeated stimulation on phosphene perception.
- The PhD candidate, Elena Offenberg completed the implementation of the online closed-loop speech classification in a locked-in person with a brain implant (Ramsey, Berezutskaya, van Steensel).
- Julia Berezutskaya performed word classification offline in a person with a brain implant (Ramsey, Berezutskaya, van Steensel).
- Julia Berezutskaya tested the online speech classification using file replay from a person with a brain implant (Ramsey, Berezutskaya, van Steensel).

NS 6 (PIs: Gazzola-NIN, Olafsdottir-RU, Hoebeek-UMCU, Battaglia-RU)

Achievements and realised outputs:

- The Gazzola group finished the ultrasound imaging setup for the recording of emotional contagion while monitoring behavioural responses (body and tail movements, running, pupil dilation, and facial expressions). A full data set has been recorded and partly analysed. (Gazzola group)
- A workshop on the technique has been offered to the DBI^2 community. (Gazzola group)
- Analyses approach has been defined, with particular attention on cleaning motion artifacts. A method paper is in preparation. (Gazzola group)
- We are integrating multiple physiological measures (e.g. heart rate, pupil dilation, respiration) into the emotional contagion experimental designs to test their explanatory power in predicting brain activity and behaviour. (Gazzola group)
- The optimisation of the pipeline for pupil dilation and facial expression automated analyses is in progress, which is relevant for CS 1-1 as well. (Gazzola group)

NS7 (PIs: Gazzola, Vinck, Battaglia)

Achievements and realised outputs:

- A paper on the effect of early life adversity on emotional contagion is in preparation. (Maldonado et al., in prep.). (Gazzola group)
- The digitalisation of the Paxinos atlas is almost completed. (Gazzola group)
- A head-fixed implementation of a two-animal social decision-making paradigm is currently being developed and tested. A postdoc who will develop the 3 freely moving animal social interaction paradigm has been hired. (Gazzola group)
- A collaborative effort to build a wireless system to measure ultrasound vocalisation and sniffing for the NAT-B environment is in progress (together with NS6). (Gazzola group)

2.1.2 Work package 2 | Computational methods – Highlights and progress

Table 2 lists the scientific goals for WP 2 that were defined in the project proposal.

CS1	*Feature extraction of neural and behavioural data*
CS1-1	*Automated behavioural recognition | Detection, characterization and segmentation of states (key PIs: van Gerven, Tangermann)*
CS1-2	*Neural decoding / "Brain reading" (key PIs: van Gerven, Güçlü, Tangermann)*
CS1-3	*Nonlinear dynamical systems and manifold learning (PIs: Narain, van Gerven)*
CS2	*Computational models for the development and validation of neural closed-loop control*
CS2-1	*Neural Models: single neuron and ensemble models (key PIs: Zeldenrust, Jafarian)*
CS2-2	*Model validation of closed-loop feedback control | Stability and plasticity (key PIs: van der Helm, Jafarian, Schouten, Kappen, van de Ruit)*
CS2-3	*Machine learning and control theoretical methods for neural control (key PIs: van Gerven, Tangermann, Kappen, van der Helm, van de Ruit, Jafarian)*
CS3	*Implementation*
CS3-1	*Neural Data Analysis | Neurophysiological data acquisition, extraction, and inference (key PIs: Strydis, van Gerven, Battaglia)*
CS3-2	*Edge computing (key PIs: Strydis, Serdijn, Battaglia)*

Table 2 Overview of the WP 2 Computational Methods specific aims

The WP 2 team has made significant contributions across its original objectives, driving advancements in both neuroscience and computational modeling.

Given the interdisciplinary nature of WP 2, the team's work simultaneously supports multiple neuroscience and computational methods objectives. The achievements and research outputs are detailed per PI.

The van Gerven and the Güçlü groups (RU)

Achievements

The Van Gerven and the Güçlü groups achieved multiple progress during Year 2:

- PhD candidate Siddharth Chaturvedi a framework for agent-based modelling (Foragax). This is an efficient Jax-based framework for simulation of many agent systems that solve foraging tasks (where many organisms compete for resources). These simulations shed light on how real organisms operate in real-world foraging tasks where based on sensory input decisions about next actions must be made (NS3) (van Gerven).
- Van Gerven and Güçlü collaborated with PhD candidate Maureen van den Grinten (NIN, Roelfsema team) on the design of new bio-plausible algorithms for AI-based vision restoration (NS 5-1)
- The Güçlü lab developed new reconstruction approaches for brain decoding (CS 1-2). These new approaches give better reconstructions of neural representations compared to earlier approaches.
- Yuzhen Qin (RU, van Gerven Group) developed a front-end for visualizing control of epileptic seizures (CS 2-2).
- Postdoc Sander Dalm (RU, van Gerven group), in collaboration with affiliated DBI^2 researcher Nasir Ahmad (RU), created new learning algorithms capable of efficient machine learning, providing a basis for online control of neural implants (CS 2-3).
- Yuzhen Qin and Postdoc Ahmed El-Gazzar (RU, van Gerven team) developed a vibrational control approach for neural dynamics, introducing two models to capture distinct epileptic dynamics. These models can serve as a data-drive framework for modelling the latent dynamics that underlie neural recordings (CS2-3).
- Ahmed Elgazzar developed new algorithms for efficient AI that allow analysing neural data at scale. To this end, we introduced a latent SDE approach for neural data science. (CS1-3)
- AI software engineer Umut Altin (RU, van Gerven lab) developed an FPGA compiler for edge computing. This compiler makes it easy to automatically translate neural networks into hardware implementations, which often remained a largely manual labor-intensive task (CS2-3).
- We established collaboration with the Roelfsema group (NIN) on vision restoration for blind people and brain decoding (CS 3-2)

Realised outputs:

- Foragax (https://github.com/i-m-iron-man/Foragax) as a framework for agent-based modeling (NS3)
- New bio-plausible algorithms for AI-based vision restoration. (NS5-1)
- New reconstruction approaches for brain decoding (CS 1-2)
- A front-end for visualizing control of epileptic seizures. (CS 2-2)
- A new learning algorithm capable of online system control (CS 2-3)
- A vibrational control approach with models for epileptic dynamics, which can be used as a data-driven framework for modelling the latent dynamics that underlie neural recordings. (CS 2-3)
- New algorithms for efficient AI that allow for analysis of neural data at scale (CS 2-3).
- A latent SDE approach for neural data science. (CS 3-1)
- An FPGA compiler for edge computing (CS 3-1).

The Tangermann group (Radboud University)

Achievements:

- A novel, sample-efficient decoding method of event-related potential signals, unsupervised mean-difference maximization, relevant for the soon-to-be hired PhD candidate. (CS 1-2)
- Initiated a collaboration with the lab of PI Nick Ramsey at UMCU in order to investigate the feasibility and efficiency of our brain state decoding methods using evoked visual potentials with novel sEEG recordings. A data transfer agreement has been put in place, and a first publication is under preparation. (CS 1-2, 3-1)

Realised outputs:

- Published a preprint with a code demo showcasing the novel decoding method for event-related potential signals.
- Released a software platform “Dareplane”, which is modular and open source, that allows to run closed-loop experiments. (CS3-1, CS1-2, CS2-3)
- Submitted a review of deep representation learning techniques for brain-computer interfaces in the reporting time window (now published)
- Contributed data and code to the MOABB platform, which simplifies the benchmarking of machine learning methods for the decoding of BCI datasets. (CS 1-2)

The Narain group (Erasmus MC)

Achievements:

- Validated and tested a new closed-loop setup testing contextual control of movement timing in humans. Manuscript authored by PhD candidate, Luca Mangili in press. (CS 2-1)
- Rodent closed-loop Brain Computer Interface setup has been tested, and data has been collected using a novel decision-making paradigm. Results presented at Neural Control of Movements conference 2025. (CS 1-2, CS 3-1)
- Dimensionality reduction method Riemannian Alignment of Tangent Spaces (RATS) has been further improved and validated on several new neuroscience datasets as part of the review process. Identification of a new method that helps estimate the intrinsic dimension of a high-D manifold. (CS 1-2, CS 3-1)

Realised outputs:

- Luca Mangili’s manuscript on cortico-cerebellar closed-loop control is provisionally accepted for publication in Scientific Reports.
- Erasmus MC PhD candidate Ilse Klinkhamer will present closed-loop BCI results at NCM 2025 and DNM 2025.
- Cosyne poster 2024, NCM poster 2024 for Luca Mangili (CS 2-1)
- Manuscript on neural manifolds in press at Nature Neuroscience. Expected publication Q2 2025
- The manuscript by Ilse Klinkhamer on temporal statistics is undergoing revision, and we have developed a new spike sorting pipeline to address reviewer concerns. Expected resubmission Q1 2025. (CS 1-3, CS 3-1)

The Zeldenrust lab (Radboud University)

Achievements:

In October 2025, a new DBI^2 PhD candidate will start in the Zeldenrust lab. This person will use recent experimental data from the Englitz lab (RU, affiliated researcher) in combination with the recent theoretical insights from the Zeldenrust lab[1] to develop cortical models of how prediction errors are coded in the brain (top-down or locally. This PhD candidate will use these models to formulate testable predictions, which will be tested by both analyzing existing data from the Englitz lab and formulating new experimental paradigms that are suitable to distinguish between the local and top-down hypothesis. For DBI², the proposed research will be a fundamental step forward because in order to develop closed-loop stimulation technology, it is essential to know how and where error signals are encoded in the cortex and how it is possible to perturb these. The proposed data analysis/modelling approach and the close collaboration between the modelling/theoretical team of Zeldenrust and the experimental team of Englitz experienced in modeling will provide a bridge between WP 1 (neuroscience) and WP 2 (computational neuroscience).

- Recent publication in Neuroinformatics on the role of pre-thalamic processing (CS 1-2, CS 1-3) - first author: Nicolas Rault (funded by EU MC ETN SmartNets). This insight will help with modelling the (pre-cortical) input the cortical model will receive.
- Publication in PloS Computational Biology on the influence of input feature selectivity on the diversity of cellular properties (CS 1-2, CS 1-3, CS 2-1) - first author: Niccolò Calcini. This insight will help with fitting neuron models for the cortical model
- CNS abstract on understanding the robustness of the cortical network to sparse connectivity. (CS 2-2). - first author: Téa Tompos (funded by the Donders Center for Neuroscience). This insight will help with developing the cortical model (see above).
- Cosyne abstract on local circuit mechanisms of cortical plasticity in spiking networks (CS 2-2) first author: Téa Tompos (funded the Donders Center for Neuroscience). This insight will help with developing the cortical model (see above).
- CNS abstract on the role of inhibition on the dimensionality of networks and understanding computations in cortical layers (CS 1-3, CS 2-1) first author: Arezoo Alizadeh (funded by the an NWO Vidi grant to Fleur Zeldenrust). This insight will help with developing the cortical model (see above).
- Perceptual switches are a consequence of resolving uncertainty by (online) adapting the precision (inverse variance, postsynaptic gain) of prediction errors. Result: this way we can model the rubber hand illusion (CS 1-3, CS 2-1) - first author: Filip Novicky (funded by EU MC ETN Serotonin and Beyond). This insight will help to model prediction errors (see above).
- ARES: a new calcium imaging analysis method (CS 3-1) - This method will help with analyzing the Englitz data.

The Heida group (UT)

- The UT research group aims to improve our understanding of the neural mechanisms underlying auditory rhythmic cueing as a therapeutic intervention to improve gait in mouse models of Parkinson's disease. This includes:
- Characterizing existing mouse models of Parkinson's disease in terms of their gait deficits.
- Assessing the effects of auditory rhythmic cueing (ARC) on gait parameters.
- Investigating the neural mechanisms behind (successful) ARC.
- Two types of complementary Parkinson's disease models will be implemented in the coming period: 1) MPTP model - degeneration of nigrostriatal dopamine neurons, and 2) A53T model – formation of Lewy body-like inclusions in neocortical and spinal motor neurons.
- A PhD candidate, Matthijs Hulsebos started on February 1st 2024.
- We established the following collaboration:

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[1] N'dri, A. W., Gebhardt, W., Teulière, C., Zeldenrust, F., Rao, R. P. N., Triesch, J., & Ororbia, A. (2024). Predictive Coding with Spiking Neural Networks: A Survey (arXiv:2409.05386). arXiv. https://doi.org/10.48550/arXiv.2409.05386[2] Rao, R. P. * Zeldenrust, F., Gutkin, B., & Denéve, S. (2021). Efficient and robust coding in heterogeneous recurrent networks. PLOS Computational Biology, 17(4), e1008673.

- Noldus Information Technology (Lucas Noldus): collaboration/training with regard to the CatWalk system for gait analysis of mice.
    - The Battaglia lab: collaboration with senior researcher Jeroen Bos to get advice on details of the high-speed gait and electrophysiology setup regarding mouse experiments.

Realised outputs:

- The PhD candidate, Matthijs Hulsebos has been working on the following topics/aspects of the research we are planning to do (regarding aims CS 1-1, 1-2 and 3-1):
    - Formulated of the research proposal and animal procedures
    - Submitted the research proposal and animal procedures to the Animal Welfare Body (AWB)
    - Attended an introductory workshop to CatWalk gait analysis system
    - Is currently designing and building a prototype of the experimental setup

The Jafarian, the van der Helm, the Schouten, and van de Ruit groupsout (TUD)

Achievements:

- PhD candidate Ioannis Kyriaizis performed a detailed quantification of the effect of data quantity and source localisation methods on the signal-to-noise ratio at the source level.
- Ioannis Kyriaizis Initiated work on using pulse-modulated continuous inputs for frequency domain system identification.
- An MSc student jointly supervised by Jafarian and van de Ruit realized a state-space model to describe EEG source connectivity.
- The following collaborations have been established:
    - Work package 1 - Matin Jafarian - Data-driven framework for modeling and control dynamics of memory consolidation.
    - Work Package 3 - Rob Mestrom - Temporal interference stimulation as an input tool to reveal cortical network dynamics using 4DEEG and study the effects of TI.

Realised outputs:

- Ioannis Kyriazis delivered the first complete 4DEEG data processing pipeline.
- Postdoc Marije ter Wal showed the effect of periodic input signals to simple neural networks representative of the somatosensory cortex.

The Strydis, the Battaglia, and the Serdijn groups (ErasmusMC, Radboud University and TU Delft)

Achievements:

- Large-scale brain simulations; AI resource-recommender for Cloud-HPC simulations. (CS2-1). Simulations are based on highly scalable deployment on multiFPGA systems (Maxeler Dataflow Engines) which can now deliver real-time, highly biologically plausible neural simulations; best-in-class simulations results in the world. The resource recommender goes hand-in-hand with the simulator in permitting the deployment of best-performance, lowest-cost or best value-for-money simulations on heterogeneous cloud deployments, making large simulations more accessible to more labs.
- Spike-classification architecture. Ultrasound-based brain imaging. (CS 3-1). The spike classifier is a low-power design, suitable for FPGA and memristor-based deployment, potentially useful for neural interfaces. The ultrasound-imaging modality is another key-enabling technology for doing brain recordings minimally invasively, in real time and at unprecedented temporal and spatial resolution.
- A new postdoc was hired.
- A new collaboration with Francesco Battaglia (RU) has been established.

Realised outputs:

- Distributed neural reading/writing implants; lightweight spike-sorting architecture: Improvement of existing set: Open-Ephys 2 (ONYX) system enhancement with GPU card and GPUDirect acceleration. (CS 3-2)
  a) MSc Thesis: https://repository.tudelft.nl/record/uuid:29160098-5018-4595-9743-8affc30fda75
  b) Incorporating results to open-ephys company in the US.

Activities from WP 2 affiliated researchers:

PI: Ben Zion (RU)

Dr. Ben Zion's group works on swarm intelligence and is joining the DBI² team as an affiliate researcher at the AI Department at Radboud University.

PI: Sander Keemink (RU)

Dr. Keemink's team is investigating the principles underlying network function and is embedded in the AI department at Radboud University.

Overall, the WP 2 team's interdisciplinary efforts across different universities and research groups illustrate a comprehensive approach to tackling the complexities of neural processing, computational modelling, and the development of therapeutic interventions for neurological disorders.

2.1.3 Work package 3 | Neurotechnology hardware - Highlights and progress

The Year 2 research plan focused on developing and refining neural interface technologies. A technician (Lukasz Pakula) has started the design of a wireless head-stage for animal vocalization recording. Efforts in graphene-based neural interfaces include prototype creation, performance characterization, and biocompatibility testing aiming for preclinical trials. Two PhD candidates respectively worked on calibrating ultrasound phased arrays for brain stimulation and studying neuromodulation effects. Further tasks involved validating a spatial spike sorting chip, exploring optical wireless power transfer, enhancing Temporal Interference (TI) stimulation through conductivity analysis, improving the Open-Ephys platform with GPU acceleration and developing a new spike-sorting algorithm, potentially for use with memristor chips.

In the 1st phase of DBI², i.e., the first 5 years, the scientific work in WP 3 is subdivided into 8 tasks (TS1 to TS8). The progress on these tasks is reported below.

Table 3 delineates the scientific goals of WP 3 defined in the project proposal.

TS1	*Hardware for the naturalistic behaviour (Nat-B) lab; system integration*
TS2	*Microfabricated multi-modal neurostimulator technology for ensembles of neurons and single-cell resolution*
TS3	*Flexible ultrasound-phased array design for ultrasound-based stimulation of deep brain circuits*
TS4	*Pliable/flexible/stretchable freely floating active electrode array technology*
TS5	*Electronics for large-scale (100,000+) single-cell resolution bi-directional neural interfaces*
TS6	*Directional magnetostatic wireless power and data transfer*
TS7	*Using non-linear cell properties to arrive at effective electrical stimulation using beamforming at multiple frequencies*
TS8	*Specification, design & piecemeal implementation of DBI2 final platform components including CPU-FPGA partitioning/coupling aspects, as well as algorithmic aspects (spike sorting, signal processing, deep learning, DSS etc.)*
TS9	*Microchips to be placed above the dura mater for focused ultrasound brain stimulation and functional ultrasound neuronal recording with high-spatial resolution and whole-brain coverage.*
TS10	*Pliable/flexible/stretchable freely floating active electrode array technology for longitudinal (chronic) use*

TS11	*Electronics for fully-implantable brain imaging*
TS12	*Thermal energy harvesting and subcutaneous ultrasound wireless power transfer electronics*
TS13	*MRI and US compatibility of multiple and multimodal stimulation modalities and minimizing the interference*
TS14	*Advanced DBI2-platform aspect design; security provisions for reliable chip operation, wireless communication, implant-to-cloud continuum etc.*

Table 3 Overview of WP3 Neurotechnology hardware specific aims, (TS 9 - 14 are to be executed in the 2nd phase of the DBI^2, which is from Year 6 till Year 10)

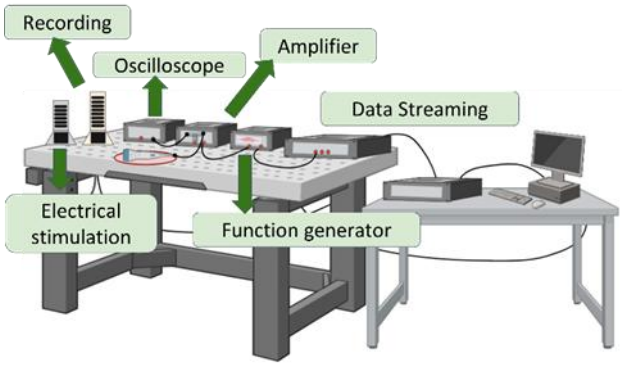
TS1 (PI: Wouter Serdijn – TUD)

No updates yet as this activity has just started.

TS2 (PI: Vasiliki Giagka– TUD)

Achievement & realised output (Vasiliki Giagka, Niloufar Behzadpour - PhD candidate)

- A new experimental setup is being prepared to study the effects of electrical and ultrasound stimulation on neural tissue



TS3 (PI: Tiago Costa – TUD)

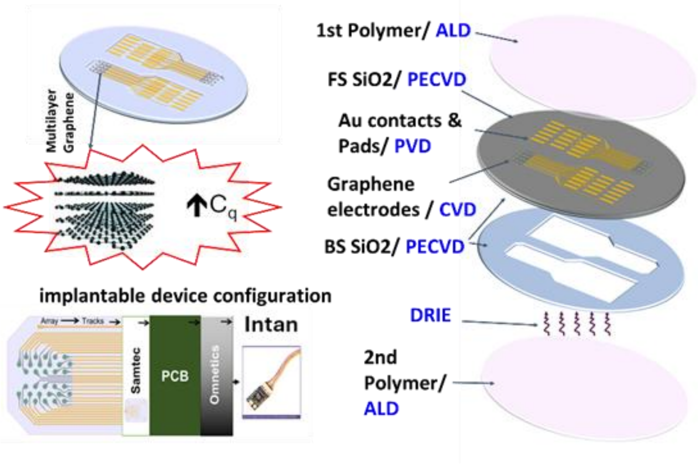
Achievement & realised output (Tiago Costa, Samuel Desmarais - PhD candidate)

- An algorithm has been created to calibrate the location of each transducer within a flexible ultrasound-phased array, which has been validated through simulations (Samuel Desmarais)
- Interface electronics to connect custom-made flexible ultrasound phased arrays with the Verasonics Vantage 256 ultrasound research system have been developed.
- A flowchart for the implementation of flexible and stretchable ultrasound-phased arrays has been designed.

TS4 (PI: Vasiliki Giagka – TUD)

Achievement & realised output (Vasiliki Giagka, Christos Pavlou - postdoc)

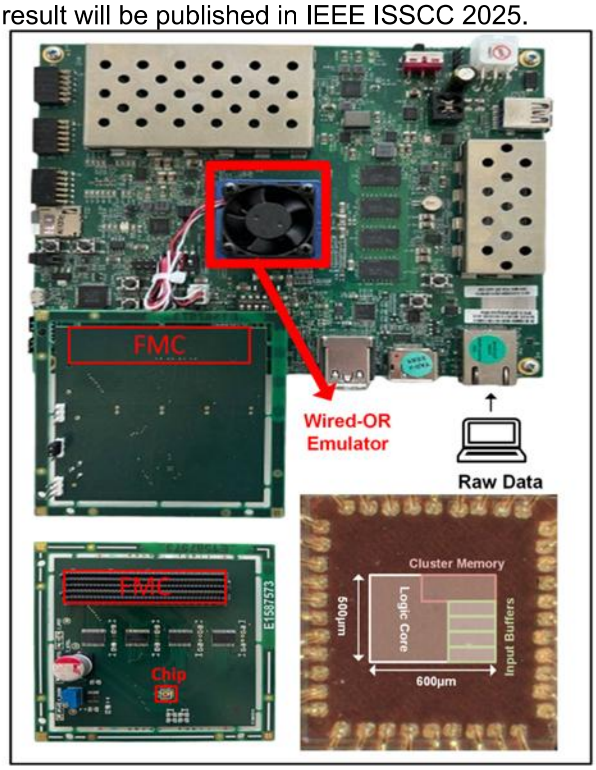
- Graphene electrode designs have been developed in collaboration with the Battaglia lab (RU).
- Preliminary two-photon tests confirmed the transparency of graphene sheets.
- Graphene MEAs (electrode diameters of 30 μm) on transparent substrates were used to record spikes from brain slices.



TS5 (PI: Dante Muratore – TUD)

Achievements & realised outputs (Dante Muratore, Arash Akhoundi-PhD candidate)

Dante Muratore and Arash Akhoundi achieved hardware validation of on-chip spike sorting, showing more than a 10x improvement in power and area efficiency compared to the state-of-the-art. The result will be published in IEEE ISSCC 2025.

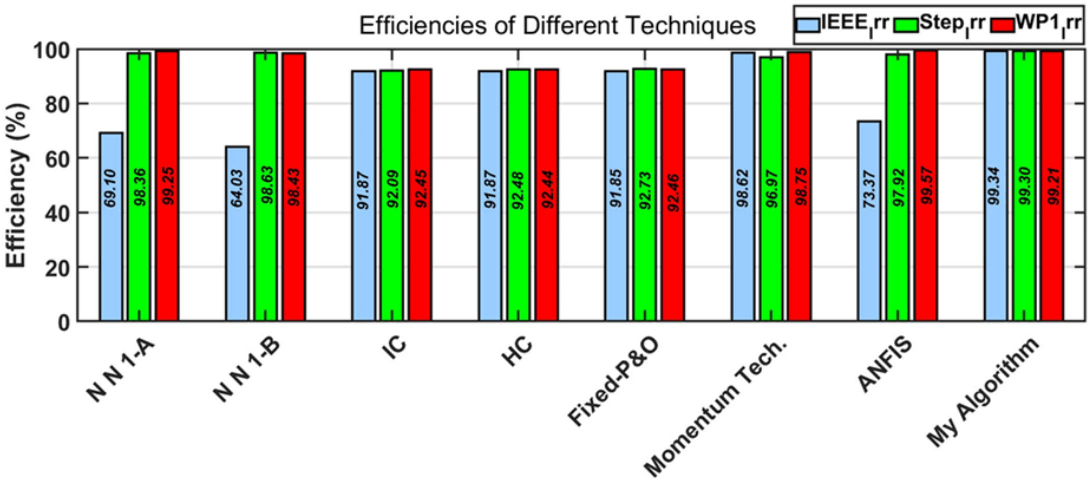


Technology		40nm	
Area	Chip	1.4 mm x 1.2 mm	
	Core	500 µm x 600 µm	3X
#Channels		1024	3X
Core V_{DD}		0.72 V	
Operating Freq.		10.24 MHz	
On-Chip SRAM		14 kB	
Power		76.3 µW	24X
Latency		<50 µs	Real Time

TS6 (PI: Wouter Serdijn - TUD)

Achievements & outputs Wouter Serdijn, Kimia Ahmadi – PhD candidate)

- A thorough literature review on optical wireless power transfer has been completed (currently under review).
- A miniature demonstrator of an optically powered headstage for freely moving rodents has been developed.
- A new maximum-power tracking algorithm has been invented, achieving 99.89% efficiency.



TS7 (PI: Rob Mestrom – Tue)

Achievements & realised outputs (Rob Mestrom, Paria Mansourinezhad - PhD candidate)

- Uncertainties in tissue conductivity have been identified as a key factor for accurate predictions of target location and the efficiency of temporal interference stimulation.
- A systematic review, titled Systematic Review of Experimental Studies in Humans on Transcranial Temporal Interference Neuromodulation, has been completed.

TS8 (PI: Christos Strydis – Erasmus MC)

Achievements & realised outputs Christos Strydis, River Betting-Postdoc:

- A spike-classification architecture has been built.
- The Open-Ephys 2 (ONYX) system has been upgraded with a GPU card and GPUDirect acceleration.

2.2 Workgroups

Chapter 2.2 outlines the achievements and outputs of three Workgroups, composed of members collaborating across multiple work packages.

2.2.1 Nat-B Lab Workgroup

This workgroup brings together researchers from all three work packages. Since Year 2, meetings have been held approximately every two months. The Nat-B workgroup focuses on three main areas relevant to all work packages:

1) Developing devices and an instrumented environment for detailed monitoring of naturalistic behaviour
2) Creating and deploying software platforms for the characterisation of behaviour at different levels
3) Formulating specifications for the work of new neurotechnological devices specifically targeted at work in (semi) naturalistic environments.

We summarise here the relevant activities (in some cases, already reported in the relevant work packages).

Devices and Environments

Affiliate PI Bernhard Englitz (RU*)* developed a system for the recording and localisation at high resolution of ultrasonic vocalisation from rodents. In Year 2, the following activities were carried out.

- Integration of visual and acoustic tracking completed
- Prototype system built which can perform audiovisual tracking in real-time
- Improvements to the longevity of tracking (currently: multiple minutes without switching identities)
- Started to work on reidentification

PI Freyja Olafsdottir (RU) started work towards the realisation of an instrumented environment for the hosting of a rat litter with monitoring of behaviour using video and ultrasonic recordings. A PhD student, José Teixeira, has been hired for this project. At the end of year 2, a design of the environment has been developed and approved. The setup is designed to meet, at the same time, the requirements of scientific research, and those dictated by animal husbandry.

2.2.2 Closed-Loop Stimulation (CLS) Workgroup

Similarly, the CLS workgroup is a cross-work package group that meets approximately bi-monthly. The initial work has been in two main directions:

1) Developing the first complete use case for CLS
2) Creating a platform for real-time GPU-based computation based on neural data.

Both lines of work are based on the OpenEphys ONIX platform, which is currently being considered as a potential standard for upcoming neurotechnological work in DBI².

CLS use case: memory disruption by intervention on sleep brain dynamics
We aim to test the hypothesis that recent and remote memories may be selectively disrupted by interfering with two brain dynamical patterns, respectively, hippocampal sharp waves and neocortical K-complexes. The work, currently led by PIs ***Francesco Battaglia*** and ***Martin Vinck,*** and also part of WP 1, has resulted in Year 2 in the following achievements:

1) A virtual reality memory task for mice was defined, developed, and validated.
2) Viral strategies for perturbing the hippocampus at different time scales were developed.
3) Causal experiments are ongoing to test the dependence of remote and recent memory formation on hippocampus.
4) Machine-learning algorithms for the online detection of hippocampal sharp wave ripples based on temporal convolutional neural networks, a class of deep learning ML algorithms, were developed, validated and tested against previous algorithms, showing enhanced detection performance.

Real-time GPU computation
PI Christos Strydis has been exploring the possibility of directly streaming neural data from the ONIX system into a GPU for fast, high-performance computing. A first software stack for this purpose has been developed (see also WP2, CS3-2).

2.2.3 Integration work group for computation and experimental neuroscience

Ahmed El-Gazzar (RU) and Marcel van Gerven (RU) introduced a new framework that integrates AI/deep learning with scientific domains utilising differential equations to model neural systems. To refine the research questions and apply this framework, a new work group has been introduced to set a new standard in neural data analysis. This new work group was approved by the board after consultation with the advisory board.

2.3 Programme office

2.3.1 Networking and Outreach

On September 25, 26 and 27 2024, the DBI² consortium organised a joint retreat with the INTENSE (Innovative Neurotechnology for Society) program. INTENSE is a Dutch neuroscience program aiming to develop high-bandwidth, wireless interfaces to the human nervous system to partially restore functionality. This collaborative event was an enriching experience, bringing together experts and enthusiasts from both projects to share knowledge, insights, and innovations in the fields of neuroscience and neurotechnology.
As part of this event, DBI² and INTENSE hosted a public roundtable discussion, "The Future of Neurotechnology." This session featured a panel discussion exploring the boundaries of brain-computer interfaces, followed by networking drinks. The roundtable aimed to foster collaborative dialogue, ensuring that the future trajectory of neurotechnology aligns with societal values and addresses ethical considerations. This event was attended by 120 people from the DBI² and

INTENSE consortium as well as a few external guests. The summary of this event will be shared publicly.
Collaboration with NeurotechEU is also ongoing. DBI^2 intends to provide educational materials for the NeurotechEU online learning platform. Currently, efforts are underway to upload a Neuro-data Analysis course. Additionally, DBI^2 has agreed to organise a summer school in collaboration with NeurotechEU, planned for 2026.

DBI^2 is active on LinkedIn and X (former Twitter). Major news and vacancy information are shared on the platform.

2.3.2 Programme management

Internal communication
Slack has been introduced as a communication channel, and an internal bi-monthly newsletter is published there.
The list of DBI^2 outputs has been created and maintained regularly.

Tracking and progress of DBI^2
The Annual Report is published annually to follow up on the progress of the DBI^2 per research aims and share the information publicly. On top of that, the DBI^2 work package and workgroup leaders will create an internal milestone overview to steer the collaboration and integration of DBI^2 research activities with a specific agenda and timelines.

2.3.3. Training for junior researchers

In total, four training events were organised during Year 2.

GitHub workshop
February 15th, 2024
DBI^2's AI Engineer, Umut Altin (RU) hosted a 1.5-hour GitHub workshop. The workshop was organised in a hybrid setup. The workshop introduced advanced GitHub and software concepts to boost for researchers.

Mini lectures and workshops at Radboud University
March 27th - March 28th, 2024
This 2-day workshop was jointly organised by the Francesco Battaglia Lab and Marcel van Gerven Lab in two themes:

1. Day 1 | Application of artificial intelligence in neuroscience, comprising (7 hours)
2. Day 2 | Techniques for behavioural and systems neuroscience, comprising (7 hours)

It was participated by 19 junior researchers.

Training Week
April 29th – May 2nd, 2024
Training Week was organised by DBI^2 junior researchers to foster peer-to-peer learning. Participants led a diverse range of lectures and workshops tailored to their expertise, resulting in a powerful exchange of knowledge and skills. The topics covered during the Training Week included:

- Electrophysiology
- Neuroanatomy
- Electronic Interfaces
- Electronic circuits
- Python programming for neuroscience and deep learning

Training Week was attended by 23 PhD candidates and postdoctoral researchers.

fUSI Workshop

November 4th, 2024
A one-day training event was organised by Valeria Gazzola's lab (Flora Nelissen and Laura Hammock) at the Netherlands Institute for Neuroscience (NIN). The programme introduced functional Ultrasound Imaging (fUSI), highlighting its research applications, experiment suitability, and limitations. Participants toured the rodent facility to observe the fUSI set-up, gaining practical insights into its applications. Additionally, they visited the non-human primate facility guided by Postdoc Sjoerd Murris, from Pieter Roelfsema's group. The entire programme lasted a total of 7 hours. The workshop was attended by 12 PhD candidates.

3. Plan for the next period (Year 3 | Oct 2023 – Sep 2024

3.1 Work packages

3.1.1 Work Package 1 | Neuroscience – Year 3 Plan

In general, Year 3 will continue to integrate the variety of technologies for neural recording and causal stimulation and use these technologies for the various objectives of WP 1. Specifically, the following actions will be taken:

NS 1 (PIs: Vinck, Gazzola, Battaglia)

- Finalising the testing of the behavioural protocol for spatial memory using the virtual reality task, including a chemogenetic approach to testing the hippocampal dependency of the memory.
- Finalise the sharp wave ripple detection algorithms and implement them in the hardware system; disseminate these results in two research/methods papers.
  - The use of closed-loop algorithms to disrupt recent vs remote memory
- Set up the simultaneous electrical stimulation and two-photon imaging using graphene grids.

NS 2 (PIs: Olafsdottir-RU, Hoebeek-UMUC)

- First publications on automated video analysis of motor and social behaviour in mice following neonatal hypoxic-ischemic brain damage and following neonatal stress evoked by limited bedding and nesting.

NS 3 (PIs: Pennartz-UvA, Roelfsema-NIN, Vinck-RU)

- Implanting two non-human primates with MRI-compatible probes (Sjoerd Murris). Initial fMRI experiments will be conducted with these two trained non-human primates, looking into the effects of electrical microstimulation. Sjoerd will train two more non-human primates on visual perception tasks (i.e. visual detection task, memory-guided saccade task).
- Further study temporal coding and phase coding in mouse V1 in the context of multisensory interactions (Pennartz).
- Establish optoscanning experiments to identify mouse cortical areas in multisensory segregation.
- Follow up on Oude Loohuis et al. by studying the coding of information by auditory cortex cells projecting to the visual cortex.

NS 4 (PIs:Roelfsema, Pennartz, Vinck, de Zeeuw, Narain:

- Further efforts in cerebellar projects will focus on deciphering the descending output from cerebral cortex to cerebellum.
- Finalise the design of machine learning algorithms for spike detection, crucial for real-time closed-loop feedback manipulation.

NS 5(PIs: Roelfsema-NIN, Ramsey-UMCU, Berezutskaya-UMCU, van Steensel-UMCU):

- Maureen, PhD student in Roelfsema group, will build a VR setup for the non-human primates to train them on prosthetic vision tasks before they receive an implant.
- A second non-human primate will be trained on basic visual tasks (i.e. visual detection task, Maureen, Roelfsema lab). A total of two non-human primates will be trained on phosphene detection tasks.

- Test a word classification model in real time in a person with severe motor impairment who has received a brain implant
- Develop a toolbox for optimal neural feature selection in BCI decoding
- Develop a model that learns population-general articulation profiles from speech data
- Develop a model that decodes population-general word articulation profiles from individual participants brain data

NS6 (PIs: Gazzola-NIN, Olafsdottir-RU, Hoebeek-UMCU, Battaglia-RU):

- Data collection of brain activity during the harm aversion paradigm (decision making task with negative consequences for a conspecific).
- Development of a 3 freely moving animals decision-making task
- Dissemination of a method paper on the ultrasound imaging set-up and analyses, a research paper on the ultrasound imaging of the anterior cingulate cortices during emotional contagion, and a research paper on the effect of early life adversities on emotional contagion.

NS7 (PIs: Gazzola, Vinck, Battaglia):

- Finalise paper on the effect of early life adversity on emotional contagion.
- Complete the digitalisation of the Paxino atlas.
- Finalize the testing of a head fixed implementation of a two-animals social decision making paradigm using, and extend to a 3 freely-moving animal social interaction paradigm.
- Set-up a wireless system to measure ultrasound vocalisation and sniffing for the NAT B environment.

3.1.2 Work package 2 | Computational methods – Year 3 Plan

The Van Gerven group (RU)
In Year 3, we anticipate publishing multiple papers on the following topics:

- Control of epileptic seizures
- Latent SDEs for neural data analysis and faster training of neural differential equations.
- Adaptive algorithms for on-chip learning and control
- Open-source software on Foragax, latent SDEs and FPGA compiler
- Demonstration of online control of simulated brain dynamics on FPGA.

Additionally, we are introducing High-performance computing infrastructure for efficient AI Simulation. We also aim to develop a computational framework for neural data analysis, providing robust tools for data-driven neuroscience research.
As an initial step, the new Integration Workgroup is actively seeking collaboration across DBI² groups and beyond.

The Tangermann group (RU)
Year 3's research will focus on invariant decoding models, and foundation models, with further exploration of deep learning representation models that are invariant of EEG channel sets.
We will also work on decoding of behavioural information from video recordings, exemplified in deep-learning approaches for estimating the disease progress of Parkinson's patients (collaboration with RUMC, lab of Bas Bloem).
For lab infrastructure, we will use EEG setups at Donders Centre for Cognition (Radboud University) to support our experiments.
A new PhD candidate will be hired to work on closed-loop optimisation of experiment/stimulation parameters.

The Narain group (Erasmus MC)
The Narain group will complete data collection on the closed-loop optogenetics interface.
Three papers are currently under review, and we expect to be able to publish these in the coming year.
For the lab setup, a new closed-loop system for hemiparetic restoration will be operational
A new PhD candidate, Ilse Klinkhamer, will join the team from January 2025.

The Zeldenrust group (RU)
The Zeldenrust group is planning to hire a new PhD candidate in 2025, ideally in October. To define the PhD project, they will reach out to the DBI² consortium members (potentially the Gazzola group at NIN, and RU's AI department) to identify key open modelling questions.

The Heida group (UT)
The Heida group will focus on the following activities in the coming year:

- Determine the final work protocol for doing the mouse experiments and getting the approval of the DEC
- Building the experimental set-up for performing gait analysis, physiological recording and cueing experiments
- Acquire preliminary data from healthy animals and develop the data analysis pipeline
- Write a draft of the first experimental results

The expected outcomes of this research include the finalised experimental protocol and manuscript of the first experiment results.

To support these activities, various lab materials will be purchased:

Supplier: Basler (baslerweb.com)

- High-speed camera (acA1920-155um)
- Cable USB 3.0, Micro B 90° A1 sl/A (ace downwards), P, 3 m | Basler AG
- Camera Bracket: 360 / 90 | Basler AG
- Tripod Mount ace | Basler AG

Other suppliers

- Transparent running-wheel; KineMouse Wheel – LABmaker
- 50 mm lens, C-mount; Lens Hik KF5028M 12MPE

The Strydis group (Erasmus MC)
The Strydis group focuses on the following research activities in the coming year:

- Distribute brain-simulation strategies and technical specifications for next-generation neural implants.
- Build Memristor-based neuron models.
- Establish ONYX-based closed-loop setup.
- Realise ultrasound-based enhancements for 4D brain imaging, large-scale brain simulations enabled via multi-FPGA and also via AI platforms.

For this research, we will utilize open-ephys 2 (ONYX) platform, potentially modified PC workstation; FPGA accelerator platform(s).

The van de Ruit and the Jafarian groups (TU Delft)
In Year 3 the van de Ruit group and the Jafarian group will work on the following activities:

- PhD candidate Ioannis Kyriaizis will work on the identification of brain network dynamics based on frequency-domain identification and pulse-modulated input signals
- Postdoc Marije ter Wal will provide a first complete neuronal network model to simulate EEG and validate neuronal dynamics revealed in experimental settings based on EEG.
- Data-driven modelling of the interplay of hippocampus and neocortex in mice brain (collaboration with Battaglia lab)
- A non-linear dynamics reduction techniques for control
- State-space identification based on EEG data

The van de Ruit group expected research outputs include a paper demonstrating the effect of data quantity and source localisation methods on the signal-to-noise ratio at the source level, as well as a conference paper demonstrating the importance of input signal design for revealing brain network dynamics.

Moreover, the Jafarian group expect two or three journal paper submissions on data-driven modelling as well as nonlinear dynamics reduction techniques.

Regarding team expansion, there is a possibility of hiring a new postdoc at the end of 2025.

3.1.3 Work package 3 | Neurotechnology hardware – Year 3 plan

Work package 3 Team will focus on the following activities and outputs in Year 3.

TS1 (Lukasz Pakula, Wouter Serdijn, Kimia Ahmadi)

- Develop a battery-powered head-stage for recording individual rodent vocalisations.
- Develop a wirelessly powered head-stage for recording individual rodent vocalisations.

TS2 (Vasiliki Giagka, Niloufar Behzadpour):

- Develop a setup for ultrasound and electrical stimulation.
- Conduct ultrasound neuromodulation experiments on neuronal cultures (focus on parameters and effects).

TS3 (Tiago Costa, Samuel Desmarais):

- Perform acoustic validation of ultrasound beam focusing and steering using a thin, two-dimensional, flexible ultrasound phased-array with curvature compensation (output: submission to IEEE Transactions on Ultrasonics, Ferroelectrics, and Frequency Control).
- Conduct initial in-vivo experiments on focused ultrasound targeting and activation in collaboration with Valeria Gazzola's group.
- Prototype and perform preliminary structural characterisation of flexible and stretchable ultrasound phased-arrays.

TS4 (Vasiliki Giagka, Christos Pavlou):

- Fabricate and test graphene electrode arrays with two-photon imaging.

TS5 (Dante Muratore, Arash Akhoundi):

- Design a new chip combining a dynamically configured compressive readout based on the results of the on-chip spike sorter, capable of performing lossless compression with a compression rate >100x.

TS6 (Wouter Serdijn, Kimia Ahmadi):

- Publish the literature review on optical wireless power transfer.
- Benchmark the invented maximum-power tracking (MPPT) algorithm.

- Implement the MPPT algorithm in a circuit.
- Tapeout and measure the performance of the MPPT algorithm implementation.

TS7 (Rob Mestrom, Paria Mansourinezhad):

- Finalise and submit the Systematic Review on Experimental Studies in Humans on Transcranial Temporal Interference Neuromodulation.
- Initiate a similar review on animal studies in collaboration with UZ Ghent (Prof. Paul Boon and Prof. Robrecht Raedt).
- Extend the results from the uncertainty analysis (presented in two conference contributions) into a full journal paper.
- Obtain ethical approval for studies involving volunteers in temporal interference research.

TS8 Christos Strydis, River Betting:

- Develop distributed brain-simulation strategies and technical specifications for next-generation neural implants.
- Implement memristor-based neuron models.
- Enhance the ONYX-based system for a closed-loop setup.

3.2 Work Groups

3.2.1 Nat-B Lab Workgroup

The Nat-B Lab workgroup will work on the following activities in Year 3:

- Start using the advanced setup for studying mother/litter behaviour
- Deploy an advanced acoustic camera that will serve as the main sensor for acoustic tracking of vocalizations. The previous audiovisual tracking system relied on an acoustic camera that had issues with temporal synchronisation and the quality of the audio recording. The new acoustic camera, when delivered, will resolve these issues.
- Compare multiple algorithms for behavioural tracking and segmentation

The following outcomes are expected as a result:

- Preliminary report on mother litter behaviour
- A platform for behavioural data analysis

3.2.2 Closed-Loop Stimulation Workgroup

The CLS Workgroup will focus on the following activities in Year 3:

- Carry out experiments on the memory disruption paradigms
- Consolidate the CLS platform on the ONIX system
- Develop real-time neural activity detection algorithms

The following outcomes are expected as a result:

- Technical report on CLS manipulation with the ONIX system
- Preliminary report on memory disruption
- Articles on algorithms for brain dynamical pattern detections

3.2.3 Integration work group for computation and experimental neuroscience

In Year 3, the group will identify core members of the workgroup. A 2-year plan for the workgroup with the main objectives, projects will be defined, and kickstart 2-3 projects with concrete deliverables that combine computational and experimental researchers across the consortium

3.3 Programme Office

3.3.1 Networking and Outreach

The DBI² Office will work on the following networking and outreach activities:

- A joint retreat with the INTENSE consortium is planned in November 2025
- An online seminar with ESDiT will be organised in February 2025 to explore potential collaboration activities.
- Publishing an online magazine
- Publishing DBI2 GitHub repository page

3.3.2 Programme management

In Year 3, the Office will finalise the long-overdue dissemination plan and publish the first draft of the White Paper. Additionally, the current version of the Data Management Plan will be reviewed and updated as needed. The list of DBI² Resources will also be revised to ensure it remains accurate and up-to-date.

3.3.3 Training for junior researchers

As part of the regular training program, a four-day Training Week will be organised, emphasising peer learning to foster bottom-up collaboration among junior researchers across different research fields. This initiative aims to create an interactive environment where participants can exchange knowledge and develop cross-disciplinary competencies. Additionally, the Office will continue organising DBI² site visits, featuring workshops and mini-lectures, to facilitate hands-on learning and engagement with ongoing research.

Furthermore, in collaboration with the NeurotechEU program, a summer school will be co-organized. NeurotechEU is a European alliance of eight universities focused on advancing neurotechnology. The summer school is targeting international bachelor’s, master’s, and PhD candidates. PIs will contribute to designing the school’s curriculum, and junior researchers will have the opportunity to participate and benefit from this immersive learning experience.

4. SWOT analysis

	Helpful to achieve the objectives	Harmful to achieve the objectives
Internal origin	**S**trengths • A unique Dutch constellation of neuroscientific and neurotechnology excellence. • A well-balanced combination of disciplinary work packages and thematic working groups, fostering scientific depth, multidisciplinary collaboration, and project coherence. • Strong and inclusive leadership (though not fully diverse).	**W**eaknesses • Thematic working groups are not yet fully established and lack sufficient ownership. • Building a truly multidisciplinary project and consortium is challenging due to the geographical and disciplinary spread of the involved institutes.
External origin	**O**pportunities • With careful planning and organisation, the New School of Neuroscience and Technology, as promised in the proposal, can become highly successful and lay the foundation for larger initiatives, similar to developments in Freiburg (Germany) and Geneva (Switzerland). • Groundbreaking insights and results from this project have the potential to generate new products, startups, and make a lasting contribution to the Dutch economy.	**T**hreats • Cuts in university funding may jeopardise planned investments in infrastructure and staff. • Public and political debate over the necessity and acceptance of animal testing could pose challenges.

Table 4 SWOT analysis summary

Strengths
DBI^2 is built upon a unique Dutch constellation of neuroscientific and neurotechnology expertise, positioning it as a leader in the field. Its well-balanced structure, combining disciplinary work packages with thematic working groups, fosters scientific depth, promotes multidisciplinary collaboration, and ensures coherence across research efforts. Strong and inclusive leadership further supports the project, providing strategic direction and fostering collaboration, though there is still room for greater diversity within leadership roles.

Weaknesses
Some structural challenges need to be addressed for the project to reach its full potential. The thematic Workgroups are not yet fully developed and lack clear ownership, which limits their effectiveness in driving collaboration and research outcomes. Additionally, integrating a truly multidisciplinary project across geographically and disciplinarily dispersed institutes presents logistical difficulties. Coordination and communication require significant effort to bridge these divides and create a more cohesive research environment.

Opportunities:
There are significant opportunities to expand the project's impact. With careful planning and organisation, the establishment of the New School of Neuroscience and Technology, as envisioned in the proposal, could become a major success. This initiative has the potential to serve as a foundation for larger research programs, following the example of successful models in Freiburg and Geneva. Furthermore, the project’s groundbreaking research could lead to the development of new products and startups, ultimately making a meaningful contribution to the Dutch economy and strengthening its position as a hub for neurotechnology innovation.

Threats:
Despite these opportunities, external challenges could hinder progress. Budget cuts in university funding may threaten planned investments in research infrastructure and staffing, affecting the long-term sustainability of the project. Additionally, public and political debates surrounding the necessity and ethical considerations of animal testing could pose regulatory and funding risks. These factors could create obstacles for certain research areas, necessitating proactive strategies to ensure continued progress and compliance with evolving regulations.

Mitigation Strategies for Weaknesses and Seizing Opportunities
From 2025 onwards, the consortium will organise the plenary meeting twice per year instead of once to provide extra opportunities for all DBI^2 consortium members to interact with each other in person.

We will also encourage bottom-up organised cross-institutional visits and workshops to promote stronger integration and knowledge exchange.

DBI^2 is developing the internal milestones per Workgroup and Work packages to structured milestones and tangible goals in the short and long terms with clear ownership.

DBI^2 consortium members are applying for additional grants to build the Nat-B Lab facility utilising the state-of-the-art technology and scientific knowledge produced by the DBI^2 consortium.

5. Overall outlook and conclusions

The project is in good shape, both in terms of the quantity and quality of work accomplished and the expansion of collaboration networks, many of which were made possible by DBI^2. We work with a highly diverse group of researchers, offering great potential for collaborative work. However, building strong connections between researchers takes time.

The workgroups have established active cores of researchers, yet they have not fully reached their growth potential. Further efforts will be made to expand these groups and provide key tools to support collaboration. The project management structure is well established, ensuring that common activities are regularly and productively organised.

Young researchers have emerged as a major driving force behind the project's success, thanks to initiatives led by the Young Talent Council, the training program, and the many informal interactions they have fostered. Moving forward, we will explore additional ways to empower them to take the lead in both scientific and non-scientific activities.

Appendix A. DBI² Consortium members in Year 2

Table 5 Full list of DBI² people in Year 2 (2025 February)

Full name	Organization	Academic position	Main Work package	Role
Chris de Zeeuw	Erasmus MC	Full professor	WP 1 Neuroscience	PI
Christos Strydis	Erasmus MC	Associate professor	WP 2 Computational methods	PI
Devika Narain	Erasmus MC	Associate professor	WP 2 Computational methods	PI
Luca Mangili	Erasmus MC	PhD	WP 1 Neuroscience	PhD
Staf Bauer	Erasmus MC	PhD	WP 1 Neuroscience	PhD
Josh Wilson	Fraunhofer IZM	Postdoc	WP 3 Neurotechnology hardware	Affiliated researcher
Christian Keysers	NIN	Full professor	WP 1 Neuroscience	Affiliated researcher
Frederic Michon	NIN	Postdoc	WP 1 Neuroscience	Affiliated researcher
Laura Hammock	NIN	Non academic project member	WP 1 Neuroscience	Non academic project member
Maureen van der Grinten	NIN	PhD	WP 1 Neuroscience	PhD
Pieter Roelfsema	NIN	Full professor	WP 1 Neuroscience	PI
Qingying Li	NIN	PhD	WP 1 Neuroscience	PhD
Sjoerd Murris	NIN	Postdoc	WP 1 Neuroscience	Postdoc
Valeria Gazzola	NIN	Associate professor	WP 1 Neuroscience	PI
Ahmed Elgazzar	Radboud University	Postdoc	WP 2 Computational methods	Postdoc
Angela Zordan	Radboud University	PhD	WP 1 Neuroscience	PhD
Antoine Wellink	Radboud University	Other		Other
Bernhard Englitz	Radboud University	Associate professor	WP 1 Neuroscience	Affiliated researcher
Bert Kappen	Radboud University	Full professor	WP 2 Computational methods	PI
Cem Uran	Radboud University	Postdoc	WP 1 Neuroscience	Postdoc
Federico Stella	Radboud University	Assistant professor	WP 1 Neuroscience	PI
Fleur Zeldenrust	Radboud University	Associate professor	WP 2 Computational methods	PI
Francesco Battaglia	Radboud University	Full professor	WP 1 Neuroscience	PI
Hauður Freyja Ólafsdóttir	Radboud University	Assistant professor	WP 1 Neuroscience	PI
Jeroen Bos	Radboud University	Senior researcher	WP 1 Neuroscience	PI
Jose Teixeira	Radboud University	PhD	WP 1 Neuroscience	PhD
Lennart Verhagen	Radboud University	Assistant professor	WP 2 Computational methods	Affiliated researcher
Lucas Noldus	Radboud University	Full professor	Not applicable	PI
Marcel van Gerven	Radboud University	Full professor	WP 2 Computational methods	PI
Martin Vinck	Radboud University	Full professor	WP 1 Neuroscience	PI
Michael Tangermann	Radboud University	Associate professor	WP 2 Computational methods	PI
Nasir Ahmad	Radboud University	Assistant professor	WP 2 Computational methods	Affiliated researcher
Richard van Wezel	Radboud University	Full professor	WP 1 Neuroscience	Affiliated researcher
Sander Keemink	Radboud University	Assistant professor	WP 2 Computational methods	Affiliated researcher
Shruti Desai	Radboud University	Non academic project member	WP 2 Computational methods	Non academic project member

Siddharth Chaturvedi	Radboud University	PhD	WP 2 Computational methods	PhD
Sookie Sookyung Shin	Radboud University	Non academic project member	Not applicable	Non academic project member
Umut Altin	Radboud University	Non academic project member	WP 2 Computational methods	Non academic project member
Umut Guclu	Radboud University	Assistant professor	WP 2 Computational methods	PI
Yasemin Atil	Radboud University	Non academic project member	Not applicable	Non academic project member
Yuzhen Qin	Radboud University	Assistant professor	WP 2 Computational methods	PI
Alfred Schouten	TU Delft	Full professor	WP 2 Computational methods	PI
Andrada Velea	TU Delft	PhD	WP 3 Neurotechnology hardware	Affiliated researcher
Arash Akhoundi	TU Delft	PhD	WP 3 Neurotechnology hardware	PhD
Chris Vink	TU Delft	Non academic project member	WP 3 Neurotechnology hardware	Non academic project member
Christos Pavlou	TU Delft	Postdoc	WP 3 Neurotechnology hardware	Postdoc
Dante Muratore	TU Delft	Assistant professor	WP 3 Neurotechnology hardware	PI
Frans van der Helm	TU Delft	Full professor	WP 2 Computational methods	PI
Ioannis Kyriazis	TU Delft	PhD	WP 2 Computational methods	PhD
Kimia Ahmadi	TU Delft	PhD	WP 3 Neurotechnology hardware	PhD
Konstantina Kolovou Kouri	TU Delft	PhD	WP 3 Neurotechnology hardware	Affiliated researcher
Marije ter Wal	TU Delft	Postdoc	WP 2 Computational methods	Postdoc
Mark van de Ruit	TU Delft	Assistant professor	WP 2 Computational methods	PI
Matin Jafarian	TU Delft	Assistant professor	WP 2 Computational methods	PI
Niloufar Behzadpour	TU Delft	PhD	WP 3 Neurotechnology hardware	PhD
Raphael Panksus	TU Delft	PhD	WP 3 Neurotechnology hardware	Affiliated researcher
Samuel Desmarais	TU Delft	PhD	WP 3 Neurotechnology hardware	PhD
Tiago Costa	TU Delft	Assistant professor	WP 3 Neurotechnology hardware	PI
Vasso Vasiliki Giagka	TU Delft	Assistant professor	WP 3 Neurotechnology hardware	PI
Wouter Serdijn	TU Delft	Full professor	WP 3 Neurotechnology hardware	PI
Paria Mansouri Nezhad	TU Eindhoven	PhD	WP 3 Neurotechnology hardware	PhD
Rob Mestrom	TU Eindhoven	Assistant professor	WP 3 Neurotechnology hardware	PI
Elena Offenberg	UMC Utrecht	PhD	WP 1 Neuroscience	PhD
Freek Hoebeek	UMC Utrecht	Full professor	WP 1 Neuroscience	PI
Julia Berezutskaya	UMC Utrecht	Assistant professor	WP 1 Neuroscience	Postdoc
Mariska van Steensel	UMC Utrecht	Assistant professor	WP 1 Neuroscience	PI
Nick Ramsey	UMC Utrecht	Full professor	WP 1 Neuroscience	PI
Ruoling Wu	UMC Utrecht	PhD	WP 1 Neuroscience	PhD
Ciska Heida	Universiteit Twente	Associate professor	WP 2 Computational methods	PI
Matthijs Hulsebos	Universiteit Twente	PhD	WP 2 Computational methods	PhD
Wilfred van der Wiel	Universiteit Twente	Full professor	WP 3 Neurotechnology hardware	Affiliated researcher
Cyriel Pennartz	Universiteit van Amsterdam	Full professor	WP 1 Neuroscience	PI
River Betting	Erasmus MC	Postdoc	WP 3 Neurotechnology hardware	Postdoc

Jamie Cardozo Blanco-Duijvelshoff	TU Delft	PhD	WP 2 Computational methods	Other
Carmen Gascó Gálvez	Radboud University	PhD	WP 1 Neuroscience	PhD
Paolo Agliati	Radboud University	PhD	WP 2 Computational methods	Affiliated researcher
Lukasz Pakula	TU Delft	Technician	WP 3 Neurotechnology hardware	Non academic project member
Maria de Neves de Fonseca	TU Delft	PhD	WP 2 Computational methods	PhD
Matan Yah Ben Zion	Radboud University	Assistant professor	WP 2 Computational methods	Affiliated researcher
Timo van Kerkoerle	Radboud University	Assistant professor	Not applicable	Other
Heidi Lesscher	Utrecht University	Associate professor	WP 1 Neuroscience	Affiliated researcher
Sander Dalm	Radboud University	Postdoc	WP 2 Computational methods	PhD
Maarten Paulides	TU Eindhoven	Full professor	WP 3 Neurotechnology hardware	Affiliated researcher
Michael van der Kooij	UMC Utrecht	Assistant professor	WP 1 Neuroscience	PI
Debby Klooster	TU Eindhoven	Postdoc	WP 3 Neurotechnology hardware	Affiliated researcher
Guido Meijer	Radboud University	Postdoc	WP 1 Neuroscience	Affiliated researcher
Ilse Klinkhamer	ErasmusMC	PhD	WP 2 Computational methods	PhD

Table 6 Members of Scientific Advisory Board (2025 February)

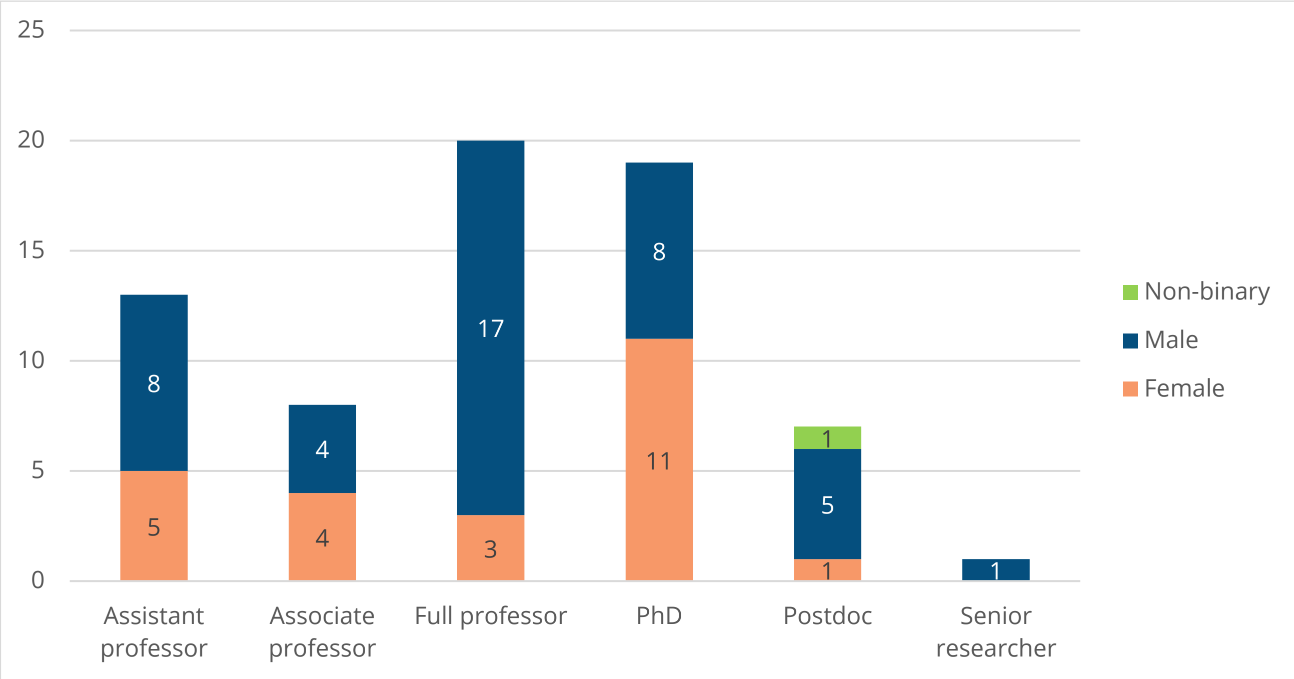
Full name	Organization	Academic position	Related work package	Role
Alex Gomez-Marin	Instituto de Neurociencias in Alicante	Associate professor	WP 1 Neuroscience	SAB
Bruce Mcnaughton	University of California	Full professor	WP 1 Neuroscience	SAB
Georges Gielen	Katholieke Universiteit Leuven	Full professor	WP 3 Neurotechnology hardware	SAB
Maria Asplund	Chalmers University of Technology	Full professor	WP 3 Neurotechnology hardware	SAB
Julijana Gjorgjieva	Technical University of Munich	Full professor	WP 2 Computational methods	SAB
Ewelina Knapska	Nencki Institute	Full professor	WP 1 Neuroscience	SAB
Taufik Valiante	University of Toronto	Associate professor	WP 1 Neuroscience	SAB
Maneesh Sahani	University College London	Full professor	WP 2 Computational methods	SAB
Joel Anderson	Universiteit Utrecht	Full professor	Not applicable	SAB

Table 7 Total number of DBI² people per role and work package (2025 February)

Row Labels	Not applicable	WP 1 Neuroscience	WP 2 Computational methods	WP 3 Neurotechnology hardware	Grand Total
Affiliated researcher		6	5	7	18
Non-academic project member	2	1	2	2	7
Other	2		1		3
PhD		9	6	5	20
PI*	1	13	13	5	32
Postdoc		3	2	2	7
SAB	1	4	2	2	9
Grand Total	6	36	31	23	96

* PI includes Full professor, Associate professor, Assistant professor, and Senior researcher.

Figure 2 Gender distribution of the DBI² in Year 2



The Figure 2 overview does not include affiliated researchers and non-academic staff

Appendix B. New Development during Year 2

Table 8 New equipment and lab setup established during Year 2

PI Name	Organisation	Work package	Please describe the new equipment or the new lab setup
Chris de Zeeuw	Erasmus University Medical Center	WP 1 Neuroscience	new e-phys set-up for recordings in freely moving animals.
Devika Narain	Erasmus University Medical Center	WP 2 Computational methods	Closed-loop ephys setup - acquisition system, electronics, microscope.
Cyriel Pennartz	University of Amsterdam	WP 1 Neuroscience	Among several options, we have chosen the Femto 3D Atlas microscope from Femtonics (https://femtonics.eu/). It allows us to simultaneously image and/or optogenetically stimulate up to hundreds of cells in 3 dimensional (3D) anatomical space. See, for example, (Geiller et al. Neuron 2020) for its functionality. As far as we know, this microscope is the only one that is commercially available with this capacity. That is why we chose this microscope. There are other options with similar capacities, but they are either commercially unavailable or require a substantial amount of time and effort to make the technique work. We have already placed the order and have agreed on being the Center of Excellence of the microscope), and the microscope is scheduled to be installed in one of our laboratories in December 2024. It will be the first microscope of this capacity in the Netherlands. This microscope will allow us to address important neurobiological questions in the coming years. The main question in DBI2 context is: how do cell assemblies responsive to different sensory modalities causally interact, and to these interactions affect perception as gauged by behavioral report?
Bernhard Englitz	Radboud University	WP 1 Neuroscience	New Equipment: An order has been placed for an advanced acoustic camera that will serve as the main sensor for acoustic tracking of vocalizations.
Wouter Serdijn	Delft University of Technology	WP 3 Neurotechnology hardware	We are setting up a new biological testing lab for in-vitro experiments using our technology. DBI2 is contributing to this activity with the hired laboratory manager.
Freek Hoebeek	University Medical Center Utrecht	WP 1 Neuroscience	Live Mouse Tracker system
Francesco Battaglia	Radboud University	WP 1 Neuroscience	ONIX setup for closed loop electrophysiology

Martin Vinck	Radboud University	WP 1 Neuroscience	closed-loop stimulation during sharp wave ripples at radboud university
Freyja Ólafsdóttir	Radboud University	WP 1 Neuroscience	We had a semi-naturalistic homecage built, bought cameras for the homecage and bought the neurologger system

Table 9 New enhancement made during Year 2

PI Name	Organisation	Workpacakge	Please describe the equipment or the lab setup, and how it has been improved thanks to the DBI2 grant during Year 2 (Oct 2022-Sep 2023) .
Christos Strydis	Erasmus University Medical Center	WP 2 Computational methods	Open-Ephys 2 (ONYX) system enhancement with GPU card and GPUDirect acceleration.
Chris de Zeeuw	Erasmus University Medical Center	WP 1 Neuroscience	Adjusted multiple unit recording system.
Bernhard Englitz	Radboud University	WP 1 Neuroscience	The previous audiovisual tracking system relied on an acoustic camera that had issues with temporal synchronization and the quality of the audio recording. The new acoustic camera, when delivered, will resolve these issues.
Freek Hoebeek	University Medical Center Utrecht	WP 1 Neuroscience	Optimized camera system and analysis pipeline for Deep Lab Cut behavioral tracking

Francesc o Battaglia	Radboud University	WP 1 Neuroscience	Virtual reality setups for mice

Appendix C. Research output produced during Year 2*

* Names of DBI^2 consortium members are in bold

** This list only includes research outputs generated during Year 2 (October 2023 – September 2024)

Title	Relevant WP	Type	Dissemination level	*Authors/ developers / Contributors	Org	DBI2 contact person	Y	M	Work of junior researcher ?
Vibrational Stabilization of Cluster Synchronization in Oscillator Networks	WP 2 Computational methods	Journal article	Public	**Yuzhen Qin,** Alberto Maria Nobili, Danielle S. Bassett, Fabio Pasqualetti	Radboud University	Yuzhen Qin	2023	November	
Synaptic mechanisms for associative learning in the cerebellar nuclei	WP 1 Neuroscience	Journal article	Public	Robin Broersen, Catarina Albergaria, Daniela Carulli, Megan R. Carey, Cathrin B. Canto, **Chris I. De Zeeuw**	Erasmus MC	Chris de Zeeuw	2023	November	
Heterogeneous encoding of temporal stimuli in the cerebellar cortex	WP 1 Neuroscience	Journal article	Public	**Chris. I. De Zeeuw**, Julius Koppen, George. G. Bregman, Marit Runge, **Devika Narain**	Erasmus MC	Chris de Zeeuw	2023	November	
Effective Learning with Node Perturbation in Deep Neural Networks	WP 2 Computational methods	Preprint	Public	**S. Dalm, M. van Gerven, N. Ahmad**	Radboud University	Sander Dalm	2023	November	Y
The Sleep Quality- and Myopia-Linked PDE11A-Y727C Variant Impacts Neural Physiology by Reducing Catalytic Activity and Altering Subcellular Compartmentalization of the Enzyme	WP 1 Neuroscience	Journal article	Public	Sbornova I, van der Sande E, Milosavljevic S, Amurrio E, Burbano SD, Das PK, Do HH, Fisher JL, Kargbo P, Patel J, Porcher L, **De Zeeuw CI**, Meester-Smoor MA, Winkelman BHJ, Klaver CCW, Pocivavsek A, Kelly MP	Erasmus MC	Chris de Zeeuw	2023	December	
Accessible and reliable neurometric testing in humans using a smartphone platform.	WP 1 Neuroscience	Journal article	Public	Boele HJ, Jung C, Sherry S, Roggeveen LEM, Dijkhuizen S, Öhman J, Abraham E, Uvarov A, Boele CP, Gultig K, Rasmussen A, Vinueza-Veloz MF, Medina JF, Koekkoek SKE, **De Zeeuw CI**, Wang SS	Erasmus MC	Chris de Zeeuw	2023	December	
A Systematic Review of Direct Outputs from the Cerebellum to the Brainstem and Diencephalon in Mammals	WP 1 Neuroscience	Journal article	Public	Novello M, Bosman LWJ, **De Zeeuw CI.**	Erasmus MC	Chris de Zeeuw	2023	December	
NeuroDots: From Single-Target to Brain-Network Modulation: Why and What Is Needed?	WP 3 Neurotechnology hardware	Journal article	Public	Dirk De Ridder, Muhammad Ali Siddiqi, Justin Dauwels, **Wouter A. Serdijn, Christos Strydis**	TU Delft	Wouter Serdijn	2024	January	Y

Disynaptic Inhibitory Cerebellar Control Over Caudal Medial Accessory Olive	WP 1 Neuroscience	Journal article	Public	Willem S. van Hoogstraten, Marit C. C. Lute, Zhiqiang Liu, Robin Broersen, **Luca Mangili**, Lieke Kros, Zhenyu Gao, Xiaolu Wang, Arn M. J. M. van den Maagdenberg, **Chris I. De Zeeuw**	Erasmus MC	Luca Mangili	2024	January	Y
A Dynamical Systems Approach to Optimal Foraging.	WP 2 Computational methods	Preprint	Public	**Siddharth Chaturvedi, Ahmed El-Gazzar, Marcel van Gerven**	Radboud University	Siddharth Chaturvedi	2024	January	Y
Meeting Summary of The NYO3 5th NO-Age/AD Meeting and the 1st Norway–UK Joint Meeting on Aging and Dementia: Recent Progress on the Mechanisms and Interventional Strategies	WP 1 Neuroscience	Journal article	Public	H. Wang, ... **Chris de Zeeuw** (Total 38 authors)	Erasmus MC	Chris de Zeeuw	2024	January	
Flexible Polymer Electrodes for Stable Prosthetic Visual Perception in Mice	WP 1 Neuroscience	Journal article	Public	Corinne Orlemann, Christian Boehler, Roxana N. Kooijmans, Bingshuo Li, Maria Asplund, **Pieter R. Roelfsema**	NIN	Pieter Roelfsema	2024	February	
2024 Nederlanse Hersenolympiade: DBI2 junior researchers contributed to the event.	NA	Workshop, event, conference	Public	**Sjoerd Murris, Elena Offenberg, Fleur Zeldenrust**	NIN, UMC Utrecht	Fleur Zeldenrust	2024	February	Y
Different Purkinje cell pathologies cause specific patterns of progressive gait ataxia in mice	WP 1 Neuroscience	Journal article	Public	Dick Jaarsma, Maria B. Birkisdóttir, Randy van Vossen, Demi W.G.D. Oomen, Oussama Akhiyat, Wilbert P. Vermeij, Sebastiaan K.E. Koekkoek, **Chris I. De Zeeuw**, Laurens W.J. Bosman	Erasmus MC	Chris de Zeeuw	2024	March	
Open source tool: A fully differentiable and biologically plausible simulation of cortical prosthetic vision, which can be used for end-to-end optimization.	WP 1 Neuroscience	Code	Public	P. Roelfseman lab	NIN	Pieter Roelfsema	2024	March	
Impact of enriched environment on motor performance and learning in mice	WP 1 Neuroscience	Journal article	Public	S. Dijkhuizen, L. M. C. Van Ginneken, A. H. C. IJpelaar, S. K. E. Koekkoek, **C. I. De Zeeuw**, H. J. Boele	Erasmus MC	Chris de Zeeuw	2024	March	
Universal Differential Equations as a Common Modeling Language for Neuroscience	WP 2 Computational methods	Preprint	Public	**Ahmed El-Gazzar, Marcel van Gerven**	Radboud University	Ahmed El-Gazzar	2024	March	Y

Synthesizing EEG Signals from Event-Related Potential Paradigms with Conditional Diffusion Models	WP 2 Computational methods	Preprint	Public	Guido Klein, Pierre Guetschel, Gianluigi Silvestri, **Michael Tangermann**	Radboud University	Michael Tangermann	2024	March	
A role for the cerebellum in motor-triggered alleviation of anxiety	WP 1 Neuroscience	Journal article	Public	Xiao-Yang Zhang, Wen-Xia Wu, Li-Ping Shen, Miao-Jin Ji, Peng-Fei Zhao, Lei Yu, Jun Yin, Shu-Tao Xie, Yun-Yong Xie, Yang-Xun Zhang, Hong-Zhao Li, Qi-Peng Zhang, Chao Yan, Fei Wang, **Chris I. De Zeeuw**, Jian-Jun Wang, Jing-Ning Zhu	Erasmus MC	Chris de Zeeuw	2024	April	
Analytical Characterization of Epileptic Dynamics in a Bistable System	WP 2 Computational methods	Preprint	Public	**Y. Qin, A. El-Gazzar, M. van Gerven**	Radboud University	Yuzhen Qin	2024	April	Y
Mesoscale simulations predict the role of synergistic cerebellar plasticity during classical eyeblink conditioning	WP 1 Neuroscience	Journal article	Public	Alice Geminiani, Claudia Casellato, Henk-Jan Boele, Alessandra Pedrocchi, **Chris I. De Zeeuw**, Egidio D'Angelo	Erasmus MC	Chris de Zeeuw	2024	April	
Approximate UMAP allows for high-rate online visualization of high-dimensional data streams	WP 2 Computational methods	Preprint	Public	Peter Wassenaar, Pierre Guetschel, **Michael Tangermann**	Radboud University	Michael Tangermann	2024	April	
ExaFlexHH: an exascale-ready, flexible multi-FPGA library for biologically plausible brain simulations	WP 1 Neuroscience	Journal article	Public	Rene Miedema, **Christos Strydis**	Erasmus MC	Christos Strydis	2024	April	
Recurrent neural networks that learn multi-step visual routines with reinforcement learning	WP 1 Neuroscience	Journal article	Public	Sami Mollard, Catherine Wacongne, Sander M. Bohte, **Pieter R. Roelfsema**	NIN	Pieter Roelfsema	2024	April	
Plasticity mechanisms of genetically distinct Purkinje cells	WP 1 Neuroscience	Journal article	Public	Stijn Voerman, Robin Broersen, Sigrid M. A. Swagemakers, **Chris I. De Zeeuw,** Peter J. van der Spek	Erasmus MC	Chris de Zeeuw	2024	May	
Brain2GAN: Feature-disentangled neural encoding and decoding of visual perception in the primate brain	WP 2 Computational methods	Journal article	Public	Thirza Dado, Paolo Papale, Antonio Lozano, Lynn Le, Feng Wang, **Marcel van Gerven, Pieter Roelfsema**, Yağmur Güçlütürk, **Umut Güçlü**	Radboud University	Marcel van Gerven	2024	May	
An integrative, multiscale view on neural theories of consciousness	WP 1 Neuroscience	Journal article	Public	Johan F. Storm, P. Christiaan Klink, Jaan Aru, Walter Senn, Rainer Goebel, Andrea Pigorini, Pietro Avanzini, Wim Vanduffel, **Pieter R.**	NIN, UvA	Pieter Roelfsema	2024	May	

				Roelfsema, Marcello Massimini, Matthew E. Larkum, **Cyriel M.A. Pennartz**					
Exploring new territory: Calibration-free decoding for c-VEP BCI	WP 2 Computational methods	Preprint	Public	J. Thielen, J. Sosulski, **M. Tangermann**	Radboud University	Michael Tangermann	2024	May	
Review of Deep Representation Learning Techniques for Brain-Computer Interfaces and Recommendations	WP 2 Computational methods	Preprint	Public	Pierre Guetschel, Sara Ahmadi, **Michael Tangermann**	Radboud University	Michael Tangermann	2024	May	
Comparison of electrical microstimulation artifact removal methods for high-channel-count prostheses	WP 1 Neuroscience	Journal article	Public	Feng Wang, Xing Chen, **Pieter R. Roelfsema**	NIN	Pieter Roelfsema	2024	May	
Tricking AI chips into simulating the human brain: A detailed performance analysis	WP 3 Neurotechnology hardware	Journal article	Public	Lennart P.L. Landsmeer, Max C.W. Engelen, Rene Miedema, **Christos Strydis**	Erasmus MC	Christos Strydis	2024	May	
Gradient-free training of recurrent neural networks using random perturbations	WP 2 Computational methods	Journal article	Public	J. Fernandez, **Sander Keemink, Marcel van Gerven**	Radboud University	Sander Keemink	2024	July	
Purkinje cell models: past, present and future	WP 1 Neuroscience	Journal article	Public	Elías Mateo Fernández Santoro, Arun Karim, Pascal Warnaar, **Chris I. De Zeeuw,** Aleksandra Badura, Mario Negrello	Erasmus MC	Chris de Zeeuw	2024	July	
Distinct feedforward and feedback pathways for cell-type specific attention effects	WP 1 Neuroscience	Journal article	Public	Georgios Spyropoulos, Marius Schneider, Jochem van Kempen, Marc Alwin Gieselmann, Alexander Thiele, **Martin Vinck**	Radboud University	Martin Vinck	2024	July	
Cerebellar encoding of prior knowledge of temporal statistics	WP 2 Computational methods	Preprint	Public	Julius Koppen, Marit Runge, Lucas Bayones, **Ilse Klinkhamer, Devika Narain**	Erasmus MC	Devika Narain	2024	August	Y
Fast implicit and slow explicit learning of temporal context in cortico-cerebellar loops	WP 2 Computational methods	Preprint	Public	**Luca Mangli**, Charlotte Wissing, **Devika Narain**	Erasmus MC	Luca Mangili	2024	August	Y
Pronouns reactivate conceptual representations in human hippocampal neurons	WP 1 Neuroscience	Journal article	Public	D. E. Dijksterhuis, M. W. Self, J. K. Possel, J. C. Peters, E. C. W. van Straaten, S. Idema, J. C. Baaijen, S. M. A. van der Salm, E. J. Aarnoutse, N. C. E. van Klink, P. van Eijsden,	NIN	Pieter Roelfsema	2024	September	

				S. Hanslmayr, R. Chelvarajah, F. Roux, L. D. Kolibius, V. Sawlani, D. T. Rollings, S. Dehaene, **P. R. Roelfsema**					
Cross-species single-cell spatial transcriptomic atlases of the cerebellar cortex	WP 1 Neuroscience	Journal article	Public	S. Hao, … Chris de Zeeuw (total 82 authors)	Erasmus MC	Chris de Zeeuw	2024	September	
Uncertainty analysis of tissue conductivities in temporal interference stimulation based on polynomial chaos expansion	WP 3 Neurotechnology hardware	Poster	Public	**Paria Mansourinezhad, Maarten Paulides, Rob Mestrom**	TU Eindhoven	Paria Mansourinezhad	2024	April	Y
Uncertainty analysis of brain tissue conductivities in Temporal Interference (TI) stimulation	WP 3 Neurotechnology hardware	Poster	Public	**Paria Mansourinezhad, Rob Mestrom, Maarten Paulides**	TU Eindhoven	Paria Mansourinezhad	2023	November	Y
Transfer-Free Fabrication and Characterisation of Transparent Multilayer CVD Graphene MEAs for In-Vitro Optogenetic Applications	WP 3 Neurotechnology hardware	Conference paper	Public	Gonzalo León González, Shanliang Deng, Sten Vollebregt, **Vasiliki Giagka**	TU Delft	Vasiliki Giagka	2024	June	
AMD Open Hardware Competition Winner: "Decoding the Seizure Storm: Leveraging the ACAP Heterogeneity for Large-Scale Neural-Mass Brain Modeling	WP 2 Computational methods	Conference paper	Public	Amirreza Movahedin, **Christos Strydis (supervisor)**	TU Delft	Christos Strydis	2024	July	
Oscillations in an artificial neural network convert competing inputs into a temporal code	WP 2 Computational methods	Journal article	Public	Katharina Duecker, Marco Idiart, **Marcel van Gerven,** Ole Jensen	Radboud University	Marcel van gerven	2024	September	
Vibrational Control of Complex Networks	WP 2 Computational methods	Preprint	Public	**Yuzhen Qin**, Fabio Pasqualetti, Danielle S. Bassett, **Marcel van Gerven**	Radboud University	Yuzhen Qin	2024	August	
Modeling and Detection of Critical Slowing Down in Epileptic Dynamics	WP 2 Computational methods	Preprint	Public	**Yuzhen Qin, Marcel van Gerven**	Radboud University	Yuzhen Qin	2024	November	
Closed-Form Control With Spike Coding Networks	WP 2 Computational methods	Journal article	Public	Filip S. Slijkhuis, **Sander W. Keemink**, Pablo Lanillos	Radboud University	Sander Keemink	2024	September	
Distributed representations of prediction error signals across the cortical hierarchy are synergistic	WP 1 Neuroscience	Journal article	Public	Frank Gelens, Juho Äijälä, Louis Roberts, Misako Komatsu, **Cem Uran**, Michael A. Jensen, Kai J. Miller, Robin A. A. Ince, Max Garagnani,	Radboud University	Cem Uran	2024	May	Y

				Martin Vinck & Andres Canales-Johnson					

Appendix D. Financial Overview

Financial overview in Year 2 (Oct 2023 - Sep 2024)

Table 10 Year 2 Total budget overview (unit k EUR)

		Planned budget (k EUR)			
Year	Period	Personnel	Non-personnel	Total requested	Co-funding
Y 1	Oct 2022-Sep 2023	€ 1,066.83	€ 716.09	€ 1,782.92	€ 671.13
Y 2	Oct 2023-Sep 2024	€ 2,195.88	€ 555.79	€ 2,751.67	€ 549.19
	Total	€ 3,262.71	€ 1,271.88	€ 4,534.59	€ 1,220.32

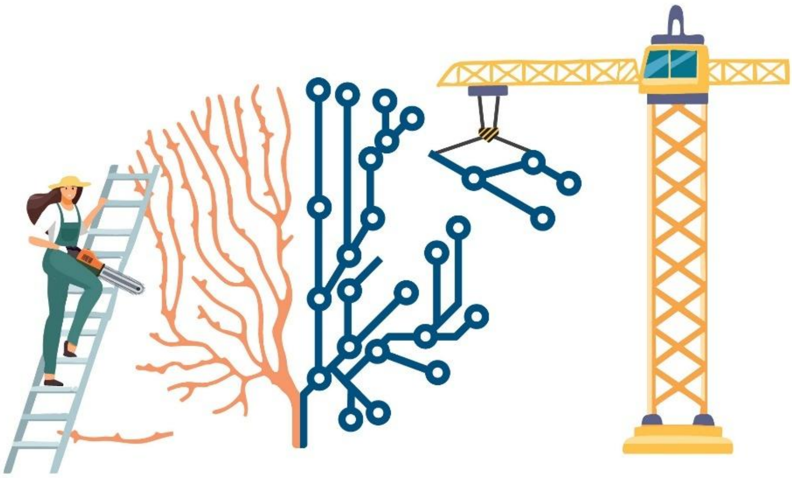
Table 11 Year 2 Total tranche fee distributed to partners (unit kEUR)

Year	Period	Tranche fee distributed to partners	Inflation correction	Total subsidy (Tranche + inflation correction)
Y 1	Oct 2022-Sep 2023	€ 2,225.95	€ 74.35	€ 2,300.30
Y 2	Oct 2023-Sep 2024	€ 2,465.32	€ 247.60	€ 2,712.91
	Total	€ 4,691.27	€ 321.95	€ 5,013.22

Table 12 Year 2 Total costs and delta (unit kEUR)

		Actual costs		**Total actual costs**	**Delta**
Year	Period	Actual personnel costs	Actual non-personnel costs		Total subsidy (Table 12) - Total actual costs
Y 1	Oct 2022-Sep 2023	€ 622.30	€ 135.02	€ 757.32	€ 1,542.98
Y 2	Oct 2023-Sep 2024	€ 1,851.36	€ 287.46	€ 2,138.83	€ 574.09
	Total	€ 2,473.66	€ 422.49	€ 2,896.15	€ 2,117.07

Though most DBI^2 positions are filled, hiring has not yet been completed, which is still causing a gap between the total distributed tranche fee and the actual costs incurred. Consortium is aiming to complete the hiring for Phase 1 by 2025.



Ever-changing, ever-pruning brain

Credit: Dr Guido Meijer – DBI² Affiliated Researcher