RESEARCH CENTRE

Inria Paris Centre at Sorbonne University

IN PARTNERSHIP WITH:

CNRS, INSERM, Sorbonne Université

2024

ACTIVITY REPORT

Project-Team

NERV

Systems neuroengineering to model and interface brain networks

IN COLLABORATION WITH: Institut du Cerveau et de la Moelle Epinière

DOMAIN

Digital Health, Biology and Earth

THEME

Computational Neuroscience and Medicine

Inria

Contents

Project-Team NERV

Creation of the Project-Team: 2023 October 01

Keywords

Computer sciences and digital sciences

A5.1.4. – Brain-computer interfaces, physiological computing

A5.2. – Data visualization

A5.9. – Signal processing

A6.1. – Methods in mathematical modeling

A6.4.3. – Observability and Controlability

A8.8. – Network science

A9.3. – Signal analysis

Other research topics and application domains

B1.2. – Neuroscience and cognitive science

B2.1. – Well being

B2.2. – Physiology and diseases

B2.5. – Handicap and personal assistances

B2.6. – Biological and medical imaging

B5.10. – Biotechnology

B9.5. – Sciences

1 Team members, visitors, external collaborators

Research Scientists

- Fabrizio de Vico Fallani [Team leader, INRIA, Senior Researcher]
- Mario Chavez [CNRS, Senior Researcher]
- Marie-Constance Corsi [INRIA, Researcher]

Faculty Member

- Laurent Bougrain [UL, Associate Professor Delegation, from Sep 2024]

Post-Doctoral Fellows

- Diego Candia Rivera [ICM, Post-Doctoral Fellow, until Oct 2024]
- Juliana Gonzalez Astudillo [INRIA, until Apr 2024]

PhD Students

- Bruno Aristimunha Pinto [INRIA, Co-supervised]
- Camile Bousfiha [Inserm, Co-supervised]
- Lili Cretaigne [SORBONNE UNIVERSITE]
- Cassandra Dumas [ICM, Co-supervised]
- Marc Fiammante [SORBONNE UNIVERSITE]
- Martin Guillemaud [SORBONNE UNIVERSITE]
- Alice Longhena [SORBONNE UNIVERSITE]
- Camilla Mannino [INRIA, Co-supervised]
- Adrien Pontlevy [INRIA, from Oct 2024]
- Wafa Skhiri [INRIA, from Dec 2024]
- Sébastien Velut [UNIV PARIS SACLAY, Co-supervised]

Technical Staff

- Arthur Desbois [INRIA, Engineer]
- Laurent Hugueville [CNRS, Engineer, 20%]
- Tristan Venot [INRIA, Engineer]

Interns and Apprentices

- Theo Coulon [INSERM, from Mar 2024 until Aug 2024]
- Bintou Soumaoro [ICM, Apprentice, from Sep 2024]
- Aurelien Stumpf Mascles [ICM, Intern, from Apr 2024 until Aug 2024]

Administrative Assistant

- Helene Milome [INRIA]

2 Overall objectives

NERV is an Inria project-team joint with the Paris Brain Institute (ICM) at the Pitié-Salpêtrière hospital (AP-HP) in Paris. NERV was created as a project-team in 2023 and later became team at the Paris Brain Institute (ICM) in 2025. NERV has a joint affiliation to Inria, CNRS, Inserm and Sorbonne University.

NERV is thus located both within a leading neuroscience institute and within a large hospital. This unique position has several advantages: direct contact with neuroscientists and clinicians allows us to foresee the emergence of new problems and opportunities for new methodological developments, provides access to unique datasets and experimental platforms, and eases the transfer of our results to clinical research and clinical practice.

Our broad goal is to consider brain-behavior problems at the intersection of statistical physics, biomedical engineering, and clinical neurosciences, that can be tackled using complex systems theory. To this end, we propose to create a new team focused on **systems neuroengineering**, developing new analytical tools and technologies to image, decode, and modulate the brain in order to comprehend its functions and to repair its dysfunction. Specifically, our team will tackle two main scientific thrusts in the next five years:

1. **Analyzing, modeling and controlling multiscale brain networks**. Our ambition is to better understand the structural and functional organization of the human brain. To this end, we propose new computational frameworks to characterize the spatio-temporal complexity of brain networks from multimodal (e.g. structural or functional) and longitudinal neuroimaging data.

2. **Designing a new generation of noninvasive brain-computer interfaces** (BCIs). There is a critical need to improve the usability of BCIs. Our original approach consists in introducing network methods into the BCI pipeline to better decode the user mental state, model the skill acquisition process, and reinforce mental intention-related brain patterns via neuromodulation.

The methodological and technological developments resulting from these goals, will be mainly applied to brain diseases, in close collaboration with neuroscientists and clinicians, in order to: i) provide new insights into the associated neural reorganizational processes ii) identify network-based biomarkers of disease and outcome and, iii) propose innovative network-based BCI neurorehabilitation strategies.

Thanks to the close interaction with ICM, which physically hosts the NERV team, we aim to play a major role in the complex systems and BCI community by capitalizing on the collaboration with other Inria/ICM teams and clinical units, as well as on technological transfer of our scientific expertise to the development of med-tech products.

3 Research program

The NERV project-team has a two-fold reserch trhust. On one hand, it develops methods from signal processing, complex systems, network science, to model and analyze the interconnected nature of the nervous system. On the other hand, it developes noninvasive brain-computer interfaces to allow humans interacting with the external world using brain activity.

3.1 Analyzing, modeling and controlling multiscale brain networks

3.1.1 Multilayer analysis of multimodal brain networks

As in many other real complex systems, the type of interactions between the regions of a same brain might be of different nature, this giving rise to multiple networks between the same nodes (eg, structural, functional, etc). Despite such one-to-many relationship, common network approaches have been traditionally conceived to analyze and model one single type of connectivity. Our project-team develops novel network approaches to the case of multiple interconnected systems. We specifically focus on the development of methods based on multilayer network theory to fully exploit the rich multimodal nature of brain networks.

3.1.2 Temporal models of dynamic brain networks

Current approaches in network neuroscience assume static or time-invariant network that could not capture dynamical mechanisms, such as the persistence or formation of specific connectivity patterns, which are instead crucial in time-varying networks. Another crucial limitation is that standard approaches are basically data-driven, so that the obtained network indices lack of confidence intervals thus making difficult the generalization of the observed results. NERV proposes to simultaneously overcome these limitations by introducing novel model-based approaches that support statistical inference on the connection mechanisms underlying the observed time-varying networks.

3.1.3 Theoretic controllability of brain networks

Controllability of networks refers to the possibility of driving the current state of a system to a specific final state by means of external control inputs. While encouraging results have been obtained in brain networks this field remains quite largely unexplored. How expensive is to drive brain states? Can brain networks be steered effectively from few nodes? What type of input signal should be used? Our project-team addresses the above questions and provide a more robust framework that can be used to identify intervention strategies facilitating desired behavior (eg, learning, Stroke recovery) and counteracting clinical conditions (eg Alzheimer's disease, epilepsy).

3.1.4 Latent geometry of brain networks

Brain networks are a special type of networks embedded in a physical space, so that geometric network models, taking into account distance as a costly factor in links formation, appear particularly relevant. However, the existence of a possible latent structure behind the observed brain network properties is still poorly understood. Is there a hidden geometry model that can explain the observed connectivity? Our project-team explores non-Euclidean geometries to represent complex brain networks and unveil hidden structural properties of the system in a complementary and coherent way. We apply these models to understand and unveil network mechanisms in brain diseases across multiple scales.

3.2 Designing a new generation of efficient noninvasive BCIs

3.2.1 Enriching the features space of BCIs with multimodal brain network metrics

The research of alternative features for improving BCI performance has been quite limited and rather crude univariate features, such as frequency band power or time point concatenation of the brain signals, have been typically used. However, the information contained in brain signal interactions across multiple physiologically-relevant frequency bands has been surprisingly neglected. NERV aims to improves BCI performance by enriching the feature space by inlcuding brain connectivity and network metrics. The project-team develops and text experimentally these advances in both healthy and diseased subjects.

3.2.2 Informing adaptive BCIs through generative network models of human learning

In a BCI, both the human and the computer are part of the same system. In such co-adaptive environment, it is paramount that the computer could adapt to the physiological nonstationarity of the brain features. However, classification algorithms should adapt in practice when the user is in the loop still need to be clarified. NERV develops new statistical network models to characterize temporally dynamic brain networks. By building these new models, we first identify the dynamic brain network properties that significantly predict with the BCI skill acquisition. Once identified, these features will be used to design innovative BCI architectures that take into account the dynamics associated with the user's learning in an effort to improve the overall performance.

3.2.3 Boosting BCI performance through targeted brain stimulation

While richer brain features and an enhanced understanding of the process of learning itself may enhance BCI accuracy on average, challenges still remain for single individuals. An alternative approach is to draw on recent advances in noninvasive brain stimulation technology, such as transcranial magnetic stimulation (TMS), which can directly influence the brain plasticity by sending an external signal that interfere locally and alter the internal neural dynamics. NERV aims to leverage theoretical network controllability models to experimentally validate the ability of single brain regions to steer target brain areas towards BCI-related spatiotemporal activity. By means of this approach, we aim to identify which brain areas and what type of input signal is needed to favor BCI-related plasticity and improve performance of individual subjects.

3.2.4 Towards multimodal and augmented noninvasive BCIs

While BCI performance has been mainly thought as a classification or features extraction issue, current evidence suggests that many other factors can actually affect the accuracy of the system. Among others, the use of alternative physiological signals (ECG, EMG among others), can influence the motivation of the subjects, their sense of agency and in turn their performance. Our project-team develops complementary approaches based on hybrid signal control and enriched feedbacks, to create immersive and ecological BCI setups in an effort to further ameliorate the BCI performance. This activity also explores a new technology based on optically pumped magnetometers to have more accurate brain signals.

4 Application domains

Our methodological and technological development will be mainly applied to solve neuroscience-related problems that can be tackled using systems-level approaches. In line with the Inria challenges plan, our project-team will contribute to modeling and simulation for digital health. Thanks to the strategic position within ICM, we will also design and perform innovative experimental protocols to gather data in humans and validate our theoretical outcome and tools. To this end, we will capitalize on our long-lasting expertise in experimental data acquisition and protocol validation from national and international ethical committees (eg, NIH, CPP, CNRS, Inserm, Coerle). In addition, we can rely on a unique access to large cohorts of patients (eg, INSIGHT cohort for Alzheimer's patients, stroke and epileptic patients from the clinical units at the hospital) which can significantly contribute to the statistical value of our discoveries.

4.1 Network-based biomarkers of brain diseases

Accumulating evidence indicates that the symptoms of a neurological disease are often associated with an abnormal organization of the connections in the brain. Network science and complex systems theory provide therefore natural tools to analyze and model brain diseases as well as to identify pathological reorganizational mechanisms. Our project-team will specifically focus on:

- **Stroke** is a medical condition in which parts of the brain die due to blood supply cut-offs, thus leading to motor-cognitive impairments associated with the dead zone. Predicting the impact of a brain damage and the ability of patients to restore their lost functions is a major issue in stroke neuroscience. Because the brain is an interconnected system, stroke damages -which are local- will also have effects on the rest of the network and induce global reconfiguration processes. By introducing original analytical and modeling tools, we aim to better understand neural plasticity after stroke and derive brain network signatures of functional recovery at individual level. To this end, we already collaborate with the Stroke Unit at the Pitie-Salpetriere Hospital (PU-PH C Rosso) and with P Bartolomeo (INSERM DR) who is a renowned expert in clinical neuroscience at ICM.

  While the NERV team will focus on stroke, it will continue the ongoing collaborations to terminate projects related to:

- **Epilepsy** is a group of neurological disorders characterized by recurrent epileptic seizures that can vary from brief undetectable instants to long periods of vigorous shaking due to abnormal electrical activity in the brain. Detecting epileptic seizures, predicting their appearance, and identifying the best pharmacological treatment for each patient, are the crucial questions, both from a basic and practical perspective. We address these questions by adopting an original point of view based on network science in an effort to better understand the role of the underlying brain network in the generation and propagation of the seizure, to identify more precise biomarkers. To this end, we can count on consolidated collaborations with the Epilepsy Unit at the Pitie-Salpetriere Hospital (PU-PH V Navarro) and with V Dinkelacker (MCU-PH) at the Hautepierre Hospital, in Strasbourg.

- **Neurodegeneration** is caused by the progressive loss of structure or function of neurons, which leads to a range of cognitive and motor impairments, from mild to severe, and eventually to death. Most of research currently focuses on predicting as soon as possible those individuals who will develop the disease, so as to adopt the best therapeutics and slow the disease progression. By adopting a network perspective, we aim to understand the abnormal reorganizational connection processes behind the disease and provide alternative biomarkers that can be integrated with existing ones (eg atrophy, behavioral, metabolic) to improve the accuracy prediction. To this end, we already collaborate with the ARAMIS team and with the Experimental Neurosurgery team at ICM (Parkinson, B Lau CRNS and C Karachi MCU-PH) and we have long-lasting collaborations with the Institut de la memoire et de l Alzheimer (IM2A) at the Pitie-Salpetriere hospital (PU-PH Prof B Dubois).

4.2 Improving BCI efficiency for clinical applications

Enhancing the accuracy of the BCI performance not only has a fundamental interest, but it also has practical consequences. Better decoding the user's mental intent means better understanding the underlying neural process and transform it in more reliable external commands. Our project-team aims to unlock BCI clinical applications by specifically unveiling new network connectivity features of brain functioning. We'll specifically focus on:

- **Neuromotor rehabilitation** aims to aid recovery from a nervous system injury (eg, stroke, Parkinson) and to minimize/compensate for motor alterations resulting from it. Identifying the best rehabilitation strategy for each patient is a major challenge as it significantly affects the quality of recovery. By developing high-performance BCI prototypes we aim to introduce innovative intervention strategies that ease the neuromotor recovery process through noninvasive neurofeedback experimental protocols. To this end, we already collaborate with the Experimental Neurosurgery team at ICM for the application to Parkinson's subjects (ANR Betapark) and we are in the process of establishing new collaborations, within the ERC BCINET, with important stroke neurorehabilitation units at the Pitie-Salpetriere Hospital (P Pradat, AP-HP) and at the Saint-Maurice Hospital (F Colle, AP-HP).

  While the NERV team will focus on Neuromotor rehabilitation, it will continue the ongoing collaboration to terminate projects related to:

- **Brain monitoring** aims to detect events associated with mental states that emerge from background ongoing brain activity (eg, stress or epileptic dynamics). The accuracy of their detection is crucial to decide and execute the most appropriate action from the computer. Our project-team aims to fine-tune and optimize the innovative BCI prototypes for real-time target applications. To this end, we already have collaborated with Air Liquide Medical Systems and the Pitié-Salpêtrière Hospital (Intensive Care Units, PU-PH T Similowski, M Raux), for the development of an EEG-based BCI which detects respiratory discomforts in ventilated patients (patent WO 2013/164462). Also, we have consolidated collaborations with the start-up Mybraintech (ICM spin-off) to develop portable BCIs for predicting mental stress (CIFRE partnership), and with IBM-France and Armand-Troussaud hospital (MD-PH AI Vermersch) to develop EEG-based aid diagnostics tool for predicting newborn hypoxia.

- **Assistive technology** is used to increase or maintain the functional capabilities of disabled people (eg, wheelchairs, prostheses). Assistive BCIs represent therefore a promising tool for allowing users to control external devices directly with their brain. Although our project-team is more focused on rehabilitative BCIs, the development of high-performance BCIs can unlock assistive BCI applications, too. To this end, we have recently started a collaboration with the ISIR lab (LIP6) for the design of a multimodal BCI prototype that controls a robotic arm and grab objects in a 3D space (PhD T Venot). We next aim to integrate augmented reality and enriched feedbacks (virtual hands) to render more ecological environments and improve the sense of agency of patients.

5 Highlights of the year

5.1 Awards

- D Candia-Rivera awarded the Marie Sklodowska-Curie Postdoc fellowship
- M Fiammante received the PhD Felix Prize for Innovation by Central Supelec

6 New software, platforms, open data

6.1 New software

6.1.1 HappyFeat

Keywords: BCI, Connectivity, Brain-Computer Interface, Classification, GUI (Graphical User Interface), Signal processing, Biomedical data

Scientific Description: Two main use-cases are targeted: - Using MI in a clinical setting (e.g. stroke rehabilitation), by greatly reducing the risks of mistakes during the offline analysis and the time needed to perform this step, quickly bridging the gap between EEG data acquisition and online BCI usage.

- Exploring new, alternative metrics for discriminating between mental states. To this aim, prototypes for prospective methods need to be validated on signal databases, before moving on to experimental conditions. HappyFeat helps bridging this gap, and provides a framework in which such methods can be tested, after implementation.

The targetted audience is therefore on the one hand clinicians, neurophysiologists and neuroscientists who want to use BCI in their programs, but also the research community in BCI, brain networks, and functional connectivity.

Functional Description: Brain Computer Interfaces (BCI) has a strong potential in clinical applications such as post-stroke rehabilitation. However, in such constrained contexts, obtaining satisfactory performances from a BCI system can be a challenging task, mainly due to the need for fine-tuning the classification algorithm used to distinguish between mental tasks. Training the classification algorithm with adequately selected features obtained from spectral analysis or other alternative metrics is crucial.

HappyFeat is a software assistant for feature extraction and selection in BCI. It proposes a trial-and-error oriented workflow, where experimenters can extract, visualize and select features of interest for training as many times as needed, in a short time, until a satisfying classification training accuracy is reached.

Every operation from signal loading and feature extraction to classifier training is handled from a unified, dashboard-like GUI, removing the need to use different softwares for data acquisition, feature analysis, classifier training and online classification, and to manage data formatting across the different environments.

Along with the commonly used Power Spectral Density (PSD), HappyFeat enables to work with Functional Connectivity, allowing to use novel network-based approaches based on recent research.

HappyFeat uses OpenViBE in the background for the extraction and training parts, as a fast and efficient processing engine, taking advantage of its optimized C++ implementation of signal processing methods. The generation and manipulation of use-case scenarios is entirely automated via scripts and templates, removing the inherent risk of mistakes in a time constrained environment.

HappyFeat puts the emphasis on reproducibility, by keeping track of all manipulations (EEG sessions file lists, signal processing, classification attempts) and allowing to save, load and export previous work.

Release Contributions: - AutoFeat: Automatic training feature selection mechanism. - "Combination training". - Online BCI scenario generation - "Advanced Mode" options (replay mode). - Basic tests & github action automation. - Experimental One-class MI classification pipeline - Dependencies update - Various bugfixes

URL: https://github.com/Inria-NERV/happyFeat

Publication: hal-03842568v1

Contact: Arthur Desbois

Participants: Arthur Desbois, Marie-Constance Corsi, Fabrizio De Vico Fallani

6.1.2 VIZAJ

Name: A free online interactive software for visualizing spatial networks

Keywords: Complex Systems, Data visualization

Functional Description: In many fields of science and technology we are confronted with complex networks. Making sense of these networks often require the ability to visualize and explore their intermingled structure consisting of nodes and links. To facilitate the identification of significant connectivity patterns, many methods have been developed based on the rearrangement of the nodes so as to avoid link criss-cross. However, real networks are often embedded in a geometrical space and the nodes code for an intrinsic physical feature of the system that one might want to preserve. For these spatial networks, it is therefore crucial to find alternative strategies operating on the links and not on the nodes. Here, we introduce Vizaj a javascript web application to render spatial networks based on optimized geometrical criteria that reshape the link profiles. While optimized for 3D networks, Vizaj can also be used for 2D networks and offers the possibility to interactively customize the visualization via several controlling parameters, including network filtering and the effect of internode distance on the link trajectories. Vizaj is further equipped with additional options allowing to improve the final aesthetics, such as the color/size of both nodes and links, zooming/rotating/translating, and superimposing external objects. Vizaj is an open-source software which can be freely downloaded and updated via a github repository. Here, we provide a detailed description of its main features and algorithms together with a guide on how to use it. Finally, we validate its potential on several synthetic and real spatial networks from infrastructural to biological systems. We hope that Vizaj will help scientists and practitioners to make sense of complex networks and provide aesthetic while informative visualizations.

URL: https://bci-net.github.io/vizaj/

Publication: hal-03837671v2

Contact: Fabrizio De Vico Fallani

6.2 New platforms

6.2.1 Noninvasive brain-computer interfaces (BCI)

Participants: Marie-Constance Corsi, Arthur Desbois, Tristan Venot, Laurent Bougrain, Laurent Hugueville, Fabrizio De Vico Fallani *(Correspondant)*.

NERV coordinates the research and development activity of the Brain-Computer Interface (BCI) platform at the Centre EEG/MEG of the neuroimaging core facility of the ICM. The R&D activity consists in assembling, testing different hardware, software developments to ensure the highest reliability and performance, as well as to test innovative technological solutions. Several projects, including our NETBCI NIH/ANR and ATTACK Big-brain theory funded projects, as well as experiments by different researchers of the Institute (ANR BETAPARK Project), and the BCINET ERC Consolidator grant (F De Vico Fallani) are currently being run.

The BCI experimental platform is closely linked to the development of the Happyfeat software by our engineer A. Desbois (see Software section). HappyFeat is part of a larger INRIA BCI software suite together with OpenVibe (HYBRID team) and BCIVizApp (CHRONOS Temporal). HappyFeat allows to easily intergate new functionalities based on our methodological development on brain connectivity networks and integrates efficient graphical user interfaces for easy use by clinicians.

7 New results

7.1 Node-layer duality in networked systems

Participants: Charley Presigny, Marie-Constance Corsi, Fabrizio de Vico Fallani *(Correspondant)*.

Real-world networks typically exhibit several aspects, or layers, of interactions among their nodes. By permuting the role of the nodes and the layers, we establish a new criterion to construct the dual of a network. This approach allows to examine connectivity from either a node-centric or layer-centric viewpoint. Through rigorous analytical methods and extensive simulations, we demonstrate that nodewise and layerwise connectivity measure different but related aspects of the same system. Leveraging node-layer duality provides complementary insights, enabling a deeper comprehension of diverse networks across social science, technology and biology. Taken together, these findings reveal previously unappreciated features of complex systems and provide a fresh tool for delving into their structure and dynamics.

More details in [25].

7.2 Exploration-exploitation paradigm for networked biological systems

Participants: Vito Dichio, Fabrizio de Vico Fallani *(Correspondant)*.

The stochastic exploration of the configuration space and the exploitation of functional states underlie many biological processes. The evolutionary dynamics stands out as a remarkable example. Here, we introduce a novel formalism that mimics evolution and encodes a general exploration-exploitation dynamics for biological networks. We apply it to the brain wiring problem, focusing on the maturation of that of the nematode Caenorhabditis elegans. We demonstrate that a parsimonious maxent description of the adult brain combined with our framework is able to track down the entire developmental trajectory.

More details in [18].

7.3 Low-dimensional controllability of brain networks

Participants: Remy Ben Messaoud, Camile Bousfiha, Marie-Constance Corsi, Mario Chavez, Fabrizio de Vico Fallani *(Correspondant)*.

Identifying the driver nodes of a network has crucial implications in biological systems from unveiling causal interactions to informing effective intervention strategies. Despite recent advances in network control theory, results remain inaccurate as the number of drivers becomes too small compared to the network size, thus limiting the concrete usability in many real-life applications. To overcome this issue, we introduced a framework that integrates principles from spectral graph theory and output controllability to project the network state into a smaller topological space formed by the Laplacian network structure. Through extensive simulations on synthetic and real networks, we showed that a relatively low number of projected components can significantly improve the control accuracy. By introducing a new low-dimensional controllability metric we experimentally validated our method on N = 6134 human connectomes obtained from the UK-biobank cohort. Results revealed previously unappreciated influential brain regions, enabled to draw directed maps between differently specialized cerebral systems, and yielded new insights into hemispheric lateralization. Taken together, our results offered a theoretically grounded solution to deal with network controllability and provided insights into the causal interactions of the human brain.

More details in [3].

7.4 Detecting local perturbations of networks in a latent hyperbolic embedding space

Participants: Alice Longhena, Martin Guillemaud, Mario Chavez *(Correspondant)*
.

This paper introduces two novel scores for detecting local perturbations in networks. For this, we consider a non-Euclidean representation of networks, namely, their embedding onto the Poincaré disk model of hyperbolic geometry. We numerically evaluate the performances of these scores for the detection and localization of perturbations on homogeneous and heterogeneous network models. To illustrate our approach, we study latent geometric representations of real brain networks to identify and quantify the impact of epilepsy surgery on brain regions. Results suggest that our approach can provide a powerful tool for representing and analyzing changes in brain networks following surgical intervention, marking the first application of geometric network embedding in epilepsy research.

More details in [23].

7.5 A framework for quantifying the coupling between brain connectivity and heartbeat dynamics: Insights into the disrupted network physiology in Parkinson's disease

Participants: Diego Candia-Rivera *(Correspondant)*, Mario Chavez, Fabrizio de Vico Fallani.

Parkinson's disease (PD) often shows disrupted brain connectivity and autonomic dysfunctions, progressing alongside with motor and cognitive decline. Recently, PD has been linked to a reduced sensitivity to cardiac inputs, that is, cardiac interoception. Altogether, those signs suggest that PD causes an altered brain–heart connection whose mechanisms remain unclear. Our study aimed to explore the large-scale network disruptions and the neurophysiology of disrupted interoceptive mechanisms in PD. We focused on examining the alterations in brain–heart coupling in PD and their potential connection to motor symptoms. We developed a proof-of-concept method to quantify relationships between the co-fluctuations of brain connectivity and cardiac sympathetic and parasympathetic activities. We quantified the brain–heart couplings from electroencephalogram and electrocardiogram recordings from PD patients on and off dopaminergic medication, as well as in healthy individuals at rest. Our results show that the couplings of fluctuating alpha and gamma connectivity with cardiac sympathetic dynamics are reduced in PD patients, as compared to healthy individuals. Furthermore, we show that PD patients under dopamine medication recover part of the brain–heart coupling, in proportion with the reduced motor symptoms. Our proposal offers a promising approach to unveil the physiopathology of PD and promoting the development of new evaluation methods for the early stages of the disease.

More details in [11].

7.6 Measures and Models of Brain-Heart Interactions

Participants: Diego Candia-Rivera *(Correspondant)*, Mario Chavez, Fabrizio de Vico Fallani.

The exploration of brain-heart interactions within various paradigms, including affective computing, human-computer interfaces, and sensorimotor evaluation, stands as a significant milestone in biomarker development and neuroscientific research. A range of techniques, spanning from molecular to behavioral approaches, has been proposed to measure these interactions. Different frameworks use signal processing techniques, from the estimation of brain responses to individual heartbeats to higher-order dynamics linking cardiac inputs to changes in brain organization. This review provides an overview to the most notable signal processing strategies currently used for measuring and modeling brain-heart interactions. It discusses their usability and highlights the main challenges that need to be addressed for future methodological developments. Current methodologies have deepened our understanding of the impact of neural disruptions on brain-heart interactions, solidifying it as a biomarker for evaluation of the physiological state of the nervous system and holding immense potential for disease stratification. The vast outlook of these methods becomes apparent specially in neurological and psychiatric disorders. As we tackle new methodological challenges, gaining a more profound understanding of how these interactions operate, we anticipate further insights into the role of peripheral neurons and the environmental input from the rest of the body in shaping brain functioning.

More details in [10].

7.7 Neuronal avalanches in temporal lobe epilepsy as a noninvasive diagnostic tool investigating large scale brain dynamics

Participants: Marie-Constance Corsi *(Correspondant)*.

The epilepsy diagnosis still represents a complex process, with misdiagnosis reaching 40%. We aimed at building an automatable workflow, helping the clinicians in the diagnosis of temporal lobe epilepsy (TLE). We hypothesized that neuronal avalanches (NA) represent a feature better encapsulating the rich brain dynamics compared to classically used functional connectivity measures (Imaginary Coherence; ImCoh). We analyzed large-scale activation bursts (NA) from source estimation of resting-state electroencephalography. Using a support vector machine, we reached a classification accuracy of TLE versus controls of 0.86 and an area under the curve of 0.93. The use of NA features increase by around 16% the accuracy of diagnosis prediction compared to ImCoh. Classification accuracy increased with larger signal duration, reaching a plateau at 5 min of recording. To summarize, NA represents an interpretable feature for an automated epilepsy identification, being related with intrinsic neuronal timescales of pathology-relevant regions.

More details in [16].

7.8 Measuring neuronal avalanches to inform brain-computer interfaces

Participants: Marie-Constance Corsi *(Correspondant)*, Laurent Hugueville, Fabrizio de Vico Fallani.

Large-scale interactions among multiple brain regions manifest as bursts of activations called neuronal avalanches, which reconfigure according to the task at hand and, hence, might constitute natural candidates to design brain-computer interfaces (BCIs). To test this hypothesis, we used source-reconstructed magneto/electroencephalography during resting state and a motor imagery task performed within a BCI protocol. To track the probability that an avalanche would spread across any two regions, we built an avalanche transition matrix (ATM) and demonstrated that the edges whose transition probabilities significantly differed between conditions hinged selectively on premotor regions in all subjects. Furthermore, we showed that the topology of the ATMs allows task-decoding above the current gold standard. Hence, our results suggest that neuronal avalanches might capture interpretable differences between tasks that can be used to inform brain-computer interfaces.

More details in [15].

7.9 Intentional binding for noninvasive BCI control

Participants: Tristan Venot, Arthur Desbois, Marie-Constance Corsi, Laurent Hugueville, Fabrizio de Vico Fallani *(Correspondant)*.

Noninvasive brain–computer interfaces (BCIs) allow to interact with the external environment by naturally bypassing the musculoskeletal system. Making BCIs efficient and accurate is paramount to improve the reliability of real-life and clinical applications, from open-loop device control to closed-loop neurorehabilitation. Approach. By promoting sense of agency and embodiment, realistic setups including multimodal channels of communication, such as eye-gaze, and robotic prostheses aim to improve BCI performance. However, how the mental imagery command should be integrated in those hybrid systems so as to ensure the best interaction is still poorly understood. To address this question, we performed a hybrid EEG-based BCI training involving healthy volunteers enrolled in a reach-and-grasp action operated by a robotic arm. Main results. Showed that the hand grasping motor imagery timing significantly affects the BCI accuracy evolution as well as the spatiotemporal brain dynamics. Larger accuracy improvement was obtained when motor imagery is performed just after the robot reaching, as compared to before or during the movement. The proximity with the subsequent robot grasping favored intentional binding, led to stronger motor-related brain activity, and primed the ability of sensorimotor areas to integrate information from regions implicated in higher-order cognitive functions. Significance. Taken together, these findings provided fresh evidence about the effects of intentional binding on human behavior and cortical network dynamics that can be exploited to design a new generation of efficient brain-machine interfaces.

More details in [26].

7.10 HappyFeat—An interactive and efficient BCI framework for clinical applications

Participants: Arthur Desbois, Tristan Venot, Fabrizio de Vico Fallani, Marie-Constance Corsi *(Correspondant)*.

Brain-Computer Interface (BCI) systems allow to perform actions by translating brain activity into commands. Such systems require training a classification algorithm to discriminate between mental states, using specific features from the brain signals. This step is crucial and presents specific constraints in clinical contexts. HappyFeat is an open-source software making BCI experiments easier in such contexts: effortlessly extracting and selecting adequate features for training, in a single GUI. Novel features based on Functional Connectivity can be used, allowing graph-oriented approaches. We describe HappyFeat's mechanisms, showing its performances in typical use cases, and showcasing how to compare different types of features.

More details in [17].

8 Bilateral contracts and grants with industry

8.1 Bilateral contracts with industry

8.1.1 CIFRE PhD - Reliev Technology

Participants: Mario Chavez *(Correspondant)*.

Partner : Startup Reliev Technology (Nantes)

Description : This project aims at developing a non-invasive multimodal system for predicting the risk of epileptic seizures, based on artificial intelligence, which will be integrated into a continuous monitoring system in patients allowing the acquisition in ambulatory mode.

Coordinator : M Chavez

Duration : 3 years

9 Partnerships and cooperations

9.1 International initiatives

9.1.1 Participation in other International Programs

FACE Foundation - FR.US partnership

Participants: Marie-Constance Corsi *(Correspondant)*.

Project title: Biophysical modeling to inform Brain-Computer Interface learning mechanisms

Partner: University of California, San Francisco (UCSF)

Duration: 2 years

Amount: 20 keuros

Coordinator: Marie-Constance Corsi

Summary: Brain-Computer Interface (BCI), that translates brain activity into commands for communication and control, is a promising tool for patients who suffer from neuromuscular pathologies or lesions. Nevertheless, it fails to detect intents in 30% of the BCI users, even after several weeks of training. To circumvent it, it is crucial to better understand the mechanisms underlying the BCI training. In this project, we aim at using the spectral graph model (SGM) developed by the US project leader's lab to identify biophysical changes occurring while controlling a BCI. SGM captures the relationship between brain structure and brain function with a reduced number of interpretable parameters. We will apply SGM to a longitudinal BCI dataset collected by the French project leader. We will fully explore the potentiality of this approach to identify biophysical markers that inform the neural mechanisms underlying the BCI training. Such insights could pave the way to tailored BCI training programs.

Kyushu Institute of Technology (Kyutech)

Participants: Laurent Bougrain.

Title: Kyutech

Partner Institution(s):
- Kyushu Institute of Technology, Japan
- University of Lorraine, France

Date/Duration: Sept. 1 2023 - Aug. 31 2025

Additionnal info/keywords: A PHC sakura project has been jointly submitted on *Brain synchronization during physical exercices guided by an avatar for elderly person care.*

9.2 International research visitors

9.2.1 Visits of international scientists

Other international visits to the team

Kosei Shibata

Status (PhD)

Kyushu Institute of Technology (Kyutech)

Country: Japan

Mobility program/type of mobility: lecture

Andrea Santoro

Status (post-Doc)

Institution of origin: EPFL

Country: Switzerland

Mobility program/type of mobility: lecture

Alessandra Corso

Status (PhD)

Institution of origin: Catania University

Country: Italy

Mobility program/type of mobility: research stay

Gian Marco Duma

Status (researcher)

Institution of origin: Scientific Institute E. Medea

Country: Italy

Mobility program/type of mobility: lecture

Steven Rico

Status (M2 student)

Institution of origin: Universidad Industrial de Santander

Country: Colombia

Mobility program/type of mobility: ERASMUS

Isabella Ioveno

Status (M2 student)

Institution of origin: Padova University

Country: Italy

Mobility program/type of mobility: ERASMUS

9.3 European initiatives

9.3.1 Horizon Europe

MCMS NETCORE

Participants: Diego Candia-Rivera *(Correspondant)*.

Project title: Biomarkers of the interplay between brain networks and cardiac dynamics for the evaluation of non-invasive brain-computer interfaces

Duration: 2024 - 2026

Amount: 212k€

Coordinator: Diego Candia-Rivera

Other partners: ICM

Summary: Brain-computer interfaces (BCI) hold promise in the restoration of lost sensorimotor abilities after stroke, a leading cause of disability. Yet, their effectiveness varies because BCI typically need to be customized for each patient. Our innovative methodology focuses on the brain-heart interplay and combines network science and biomedical signal processing to estimate interactions between these two systems in the context of motor imagery. We will explore various approaches, such as generative data methods, multi-layer networks, higher-order dependencies, and deducing potential causal interactions from physiologically informed neural models. Our ultimate goal is to pave the way for future biomedical breakthroughs in the emerging field of brain-heart interplay. Through these efforts, NETCORE strives to enhance the potential of BCI in aiding brain-injured patients and showing the potential of studying brain-heart interplay in healthcare and neuroscientific research.

9.3.2 H2020 projects

ERC-COG BCINET

Participants: Fabrizio de Vico Fallani *(Correspondant)*.

BCINET project on cordis.europa.eu

Title: Non-invasive decoding of brain communication patterns to ease motor restoration after stroke

Duration: 2020 - 2026

Coordinator: Fabrizio De Vico Fallani

Other partners: Inria

Summary: Brain-computer interfaces (BCIs), bypassing the skeletomuscular system, are particularly promising for assisting paralyzed people in control and communication, but also for boosting neuromotor rehabilitation. Despite their potential, the societal impact of BCIs is dramatically limited by the poor usability in real-life applications. Critically, one of the main limitations is implicitly assuming that the user's intent could be decoded by examining the activity of single brain areas. The grand challenge of this project is to develop a novel generation of BCIs that integrate the user's brain network information for enhancing accuracy and usability. Based on this approach, we will experiment innovative BCI prototypes to restore the lost motor functions in patients suffering from stroke. This project relies on a unifying framework that analyses and models brain networks by means of analytical tools derived from graph theory and complex systems science. This project can significantly improve BCI usability as well as determining how brain lesions compromise brain functioning and which solutions are most effective to unlock motor restoration after stroke.

9.4 National initiatives

ANR-PRC BETPARK

Participants: Mario Chavez, Fabrizio De Vico Fallani *(Correspondant)*.

Project title: Neurofeedback for Parkinson's disease

Duration: 2021 - 2025

Amount: 712k€

Coordinator: Nathalie George

Other partners: CNRS CCLE; ICM

Summary: Parkinson's disease (PD) is a complex neurodegenerative disease caused by death of midbrain dopaminergic neurons. This calls for better understanding the pathophysiology of PD in order to pave the way to new non-pharmacological and non-invasive treatment options for PD. We propose to use neurofeedback (NF) to test whether PD patients can learn to self-regulate their brain activity to reduce pathological neural activity and thereby motor symptoms. We will leverage NF to target regulation of pathological beta band (8-35 Hz) oscillations, and we will characterize training-induced changes in cortical network activity and their relationship with symptom severity. Our goal is to provide direct evidence of the functional role of beta rhythms in the pathophysiology of PD while assessing NF as a new non-pharmacological and non-invasive tool for ameliorating PD motor symptoms.

ANR-PRC MEO

Participants: Laurent Hugueville *(Correspondant)*.

Project title: Overcome SQUID and alkali OPM limitations for Epilepsy: 4He OPMs

Duration: 2022 - 2025

Amount: 639k€

Coordinator: Francesca Bonini

Other partners: MAG4Health,CRNL,INS,APHM, ICM

Summary: The main objective of this highly interdisciplinary and collaborative project is to demonstrate that innovative optically pumped magnetometers (OPM) using helium-4 (4HeOPM) can overcome the limitations of SQUID and alkali OPM sensors to monitor brain activity in epileptic patients including children and to perform long-term recording of epileptic seizures. Innovative optically pumped magnetometers (OPMs) using helium-4 (4HeOPM) have been developed by Mag4Health, which operate at room temperature. These sensors can be placed near the scalp and have a wider dynamic range and bandwidth more suitable for detecting epileptic activities. Our aim is to demonstrate their capability to overcome the limitations of commercially available MEG systems (sMEGs) as well as prototype alkaline OPM, thus opening new horizons for the non-invasive pre-surgical evaluation of epilepsy including recording of seizure onset.

9.4.1 ANR

Grasp-IT, ANR PRCE CES 33 (interaction, robotics)

Title: Design and evaluation of a tangible and haptic brain-computer interface for upper limb rehabilitation after stroke

Duration: Jan2020-July2024

Coordinator: Laurent Bougrain (LORIA/NeuroRhythms)

Partners:
- LORIA (Lorraine Research Laboratory in Computer Science and its Applications)
- Center for research Inria Rennes - Bretagne Atlantique
- Center for research Inria Sophia Antipolis - Méditerranée
- IRR UGECAM-NE centre Lay Saint Christophe
- CHU Rennes / Physical Medicine and Rehabilitation Service
- CHU Toulouse
- SARL ALCHIMIES

Loria contact: Laurent Bougrain

Summary: This project aims to recover upper limb control improving the kinesthetic motor imagery (KMI) generation of post-stroke patients using a tangible and haptic interface within a gamified Brain-Computer Interface (BCI) training environment. (i) This innovative KMI-based BCI will integrate complementary modalities of interactions such as tangible and haptic interactions in a 3D printable flexible orthosis. We propose to design and test usability (including efficacy towards the stimulation of the motor cortex) and acceptability of this multimodal BCI. (ii) The GRASP-IT project proposes to design and integrate a gamified non-immersive virtual environment to interact with. This multimodal solution should provide a more meaningful, engaging and compelling stroke rehabilitation training program based on KMI production. (iii) In the end, the project will integrate and evaluate neurofeedbacks, within the gamified multimodal BCI in an ambitious clinical evaluation with 75 hemiplegic patients in 3 different rehabilitation centers in France. The GRASP-IT project represents a challenge for the industrial 3D printing field. The materials of the 3D printable orthosis, allowing the integration of haptic-tangible interfaces, will come from a joint R&D work performed by the companies Alchimies and Open Edge.

Projetc website: https://graspit.loria.fr

BCI4IA, ANR PRC CES 19 (Technologies for health)

Title: a New BCI Paradigm To Detect Intraoperative Awareness During General Anesthesia

Duration: Jan2023-Dec2026

Coordinator: Claude Meistelman (CHRU Nancy)

Partners:
- CIC regional university hospital of Nancy
- LORIA
- Center for research Inria Bordeaux - Sud-Ouest
- Anesthesia and intensive care unit/CHU-Brugmann, Belgium (unfunded)
- Laboratory of Neurophysiology and Movement Biomechanics/Université Libre de Bruxelles, Belgium (unfunded)

Loria contact: Laurent Bougrain

Summary: The BCI4IA project aims to design a brain-computer interface to enable reliable general anesthesia (GA) monitoring, in particular to detect intraoperative awareness. Currently, there is no satisfactory solution to do so whereas it causes severe post-traumatic stress disorder. "I couldn't breathe, I couldn't move or open my eyes, or even tell the doctors I wasn't asleep." This testimony shows that a patient's first reaction during an intraoperative awareness is usually to move to alert the medical staff. Unfortunately, during most surgery, the patient is curarized, which causes neuromuscular block and prevents any movement. To prevent intraoperative awareness, we propose to study motor brain activity under GA using electroencephalography (EEG) to detect markers of motor intention (MI) combined with general brain markers of consciousness. We will analyze a combination of MI markers (relative powers, connectivity) under the propofol anesthetics, with a brain-computer interface based on median nerve stimulation to amplify them. Doing so will also require to design new machine learning algorithms based on one-class (rest class) EEG classification, since no EEG examples of the patient's MI under GA are available to calibrate the BCI. Our preliminary results are very promising to bring an original solution to this problem which causes serious traumas.

Projetc website: https://project.inria.fr/anrbci4ia/

AI Cluster PrAIrie-PSAI

Participants: Fabrizio De Vico Fallani *(Correspondant)*.

Project title: Paris School of AIfor Epilepsy: 4He OPMs

Duration: Since 2024

Amount: 75M€

Coordinator: Isabelle Ryl

Other partners: PSL,CNRS,Paris Cite, Inria, Pasteur

Summary: As AI confirms its role as a disruptive technology and its impact on all sectors of society, the PRAIRIE - Paris School of AI project is positioned as a catalyst for innovation and research in AI, with the ambition of becoming the world leader that France needs to remain competitive on the international stage. Winner of the IA Cluster call for 75 million, it brings together the same players who, since 2019, have made the 3IA PRAIRIE Institute a success and established it on the world stage as a leading player in Artificial Intelligence (AI) research and training. Taking full advantage of this momentum, PRAIRIE-PSAI will broaden the positioning of the 3IA PRAIRIE Institute, by federating the interdisciplinary research and training initiatives of its partners. The strength of the consortium is unique in this respect.

9.5 Public policy support

France 2030 - AI convergence

Participants: Mario Chavez, Marc Fiammante *(Correspondant)*.

Project title: Newborn Neurodigital

Duration: 1 year

Coordinator: M Fiammante

Summary: This project, in collaboration with the Armand Trousseau Hospital (Paris), aims at improving the assessment of possible brain lesions in children born at term in a context of perinatal asphyxia, thus making it possible to improve the precision of the indication for the initiation of hypothermia. The practical objective is to enable the development of a diagnostic aid tool, based on EEG, in intensive care and neonatology.

10 Dissemination

10.1 Promoting scientific activities

10.1.1 Scientific events: organisation

General chair, scientific chair

- L Bougrain, Cortico 2024, Nancy, France

Member of the organizing committees

- F de Vico Fallani, Network Neuroscience workshop, Quebec City, Canada
- L Bougrain, BCI meeting 2025 workshop on exploring the clinical integration of BCI technology in general anesthesia monitoring, Banff, Canada
- L Bougrain: Neuroergonomics 2024 conference, organizer of the "Get started with OpenViBE" workshop, Bordeaux, France
- L Bougrain: Neuroergonomics 2024 conference, organizer of the "OpenViBE for wannabe experts" workshop, Bordeaux, France
- M.-C. Corsi: CuttingEEGX, chair of the "Evolving methods" symposium, Virtual
- M.-C. Corsi: BIOMAG 2024, chair of the "Alternative functional connectivity estimators and their real-life application" symposium, Sydney, Australia
- M.-C. Corsi: 9th Graz BCI conference, organizer of the "Designing Brain-Computer Interfaces, from theory to real-life scenarios" workshop, Graz, Austria
- M.-C. Corsi: Computational neuroscience meeting, organizer of the "Virtual Brains: From data to modeling and back" workshop, Natal, Brazil
- M.-C. Corsi: Neuroergonomics 2024 conference, organizer of the "Designing Brain-Computer Interfaces, from theory to real-life scenarios" workshop, Bordeaux, France
- M.-C. Corsi: WIRED, tutor during "iEEG data processing" Fieldtrip workshop, Paris, France

10.1.2 Scientific events: selection

Chair of conference program committees

- L Bougrain, Cortico 2024, Nancy, France

Member of the conference program committees

- F de Vico Fallani, Network Neuroscience workshop, Quebec City, Canada
- F de Vico Fallani, NETSCI conference, Quebec City, Canada
- F de Vico Fallani, COMPLEX NETWORKS conference, Instanbul, Turkey
- F de Vico Fallani, COMPLENET conference, Exeter, UK
- M.-C. Corsi, Neuroergonomics 2024, Bordeaux, France

Reviewer

- F de Vico Fallani: Network Neuroscience workshop, NETSCI, COMPLEX NETWORKS, COMPLENET
- L Bougrain: IEEE Virtual Reality 2025, Cortico 2024
- M.-C. Corsi: Neuroergonomics 2024, Cortico 2024

10.1.3 Journal

Member of the editorial boards

- F de Vico Fallani: PLoS One, Brain Topography
- M.-C. Corsi: PLOS ONE

Reviewer - reviewing activities

- F de Vico Fallani: PLoS Computational Biology, Phys Rev A, Reviews in Biomedical Engineer, Nature Communications, Nature Communications Biology
- M-C Corsi: eNeuro, NeuroImage: Clinical, Brain Topography, Brain Connectivity, Journal of Neural Engineering, IEEE Transactions on Biomedical Engineering, Frontiers in Human Neuroscience, Frontiers in Neuroergonomics, Scientific Reports, PLOSONE, Sensors, Int. Journal of Neural Systems, Brain-Computer Interfaces, Epilepsy Open, IOP Biomed. Phys. Eng. Express, Electronics
- D Candia-Rivera: Clinical Neurophysiology, Consciousness and Cognition, Neuropsychologia, Neuroscience and Biobehavioral Reviews, IBRO Neuroscience Reports, eBiomedicine, Brain Structure and Function, Neuroinformatics, Journal of Open Research Software
- M Chavez: Physical Review E, Brain Communications, PLoS Computation Biology, Chaos
- L. Bougrain: Brain Topography

10.1.4 Invited talks

- F de Vico Fallani, Plenary speaker, Neurospin Institute, Saclay, France
- F de Vico Fallani, Plenary speaker, Institute of Science and Technology - YSS, Wien, Austria
- F de Vico Fallani, Session speaker, American Physical Society(APS) March Meeting, Minneapolis, US
- F de Vico Fallani, Session speaker, SIAM Applied Linear Algebra conference, Paris, France

- D Candia-Rivera, Session speaker, European Soc. Cognitive and Affective Neuroscience, Ghent, Belgium
- D Candia-Rivera, Session speaker, Body Brain Waves Conference, Salerno, Italy
- L Bougrain: Invited speaker, Designing non-invasive Brain-Computer Interfaces, Jun. 24 2024, Lab-STICC, Brest
- L Bougrain: Session speaker, Inria Scientific days disability, loss of autonomy & digital, Hôpital Hôtel-Dieu, Paris
- L Bougrain: Session speaker, Digital and health on neurology, Presidence of the univ. of Lorraine, Nancy
- M.-C. Corsi: Session speaker, BIOMAG 2024, Sydney, Australia
- M.-C. Corsi: Session speaker, 1st EBRAINS workshop, Marseille, France
- M.-C. Corsi: Using non-invasive closed-loop systems: insights from machine and users centrered approaches, MIND seminar, Saclay, France
- M.-C. Corsi: Inria Scientific days disability, loss of autonomy & digital, Paris, France
- M Chavez: Invited speaker, BrainModes 2024, Bilbao Spain

10.1.5 Leadership within the scientific community

- F de Vico Fallani, Representative member of the steering committee for the European infrastructure EBRAINS
- Laurent Bougrain and M.-C. Corsi are members of the Board of Directors of the scientific society CORTICO for the promotion of Brain-Computer Interfaces in France.

10.1.6 Scientific expertise

- M.-C. Corsi: reviewing for the ANR PRME call
- M.-C. Corsi: reviewing for the INCA grant for the clinical neuroscience institute of Rennes

10.1.7 Research administration

- F de Vico Fallani, Member of the Bureau du Comité de Projets (CP) of the Inria Paris Center
- F de Vico Fallani, Ad-hoc member of the Comite Evaluation Scientifique (CES) of the Inria Paris Center
- L Hugueville, Expert member of IT deparment of ICM, Paris
- L Hugueville, Expert member of RnD Unit of ICM, Paris

10.2 Teaching - Supervision - Juries

- T Venot, Master M2 MAPIMED, Sorbonne University, Networks and BCI module (3h), France, Paris
- M Chavez, CENIR course, ICM, Complex networks module (3h), France, Paris
- M.-C. Corsi, CENIR course, ICM, Brain-Computer Interface (2h), Paris, France
- M.-C. Corsi, DU IA Santé, Univ. Paris Cité, Introduction to Brain-Computer Interfaces (1h), Paris, France

- M.-C. Corsi, Master Computational Neuroscience and Neuroengineering (CNN), Univ. Paris-Saclay, Network science for understanding Brain-Computer Interfaces (3h), Saclay, France
- M.-C. Corsi, Master Mathématiques Vision Apprentissage (MVA), ENS Saclay, Imagerie fonctionnelle cérébrale et interface cerveau machine (9h), Saclay, France
- L Hugueville, Master M2 BIP/MAPIMED, MEG and EEG (3h), Sorbonne University, Paris
- L Hugueville, M2 Neurosciences du Mouvement, UE Recueil et Analyse des Signaux Neurophysiologiques (2h), Université Paris Est Créteil
- L Hugueville, M1 Biologie intégrative et physiologie (BIP), Atelier Technologique "Plateforme ingénierie" (1h30), Sorbonne Université
- L Hugueville, D.I.U. MORPHOLOGIE ET IMAGERIE, Acquisition et traitements des données fonctionnelles MEG/EEG 2h, Sorbonne University
- L Hugueville, Master de Sciences et Technologie (BIP), Bases physiologiques de la neuro-imagerie cognitive (1h30), Sorbonne University
- L Hugueville, Cours du CENIR : Introduction MEG-EEG (1h30) + Preprocessing MEG-EEG (1h30), ICM, Paris

10.2.1 Supervision

- PhD Wafa Skhiri, Higher-order interactions for brain-computer interfaces, 2024-, Advisor: F de Vico Fallani
- PhD Adrien Pontlevy, Emergent properties in neural networks, 2024-, Advisor: F de Vico Fallani
- PhD Camile Bousfiha, Noninvasive BCIs for stroke recovery, 2023-, Advisors: F de Vico Fallani, Paolo Bartolomeo
- PhD Camilla Mannino, Neuronal avalanches to improve Brain-Computer Interfaces, 2023-, Advisors: M.-C. Corsi, M. Chavez
- PhD Cassandra Dumas, Characterization of the spatial signatures of beta sensorimotor rhythms for the neurofeedback, 2024-, Advisors: M.-C. Corsi, N. George
- PhD Bruno Aristimunha, Learning structure in electroencephalogram using deep learning, 2023-, Advisors: M.-C. Corsi, S. Chevallier
- PhD Sébastien Velut, Variability inter-user in passive and active BCI, 2023-, Advisors: M.-C. Corsi, S. Chevallier, F. Dehais
- PhD Lili Crétaigne, Développement d'un système météo de prédiction de risques des crises d'épilepsie à partir de signaux périphériques, 2024- , Advisor: M Chavez
- PhD Marc Fiammante, Analyse automatique du signal EEG pour l'évaluation diagnostique de lésions cérébrales chez le nouveau-né à terme dans un contexte d'asphyxie périnatale, 2022- , Advisor: M Chavez
- PhD Martin Guillemaud, Latent geometries of epileptic brain networks as biomarkers for seizures forecasting and outcome of surgery, 2022- , Advisor: M Chavez
- PhD Alice Longhena, Characterisation of multiscale geometry in brain networks, 2021- , Advisor: M Chavez

10.2.2 Juries

- F De Vico Fallani, Examiner, HDR committee of Jeremie Mattout (INSERM), Lyon, France
- F De Vico Fallani, Reviewer, PhD committee of Alexis Benichou (Paris PSL), Paris, France
- F De Vico Fallani, Reviewer, PhD committee of Giacomo Barzon (Padua University), Padua, Italy
- M.-C. Corsi, Examiner, PhD committee of Luna Angelini (Nancy University), Nancy, France
- M.-C. Corsi, Examiner, PhD committee of Juan Jesus Torre Tresols (ISAE-SUPAERO), Toulouse, France
- M.-C. Corsi, Examiner, PhD committee of Igor Carrara (Inria), Sophia Antipolis, France
- M.-C. Corsi, admission jury member, CRCN Inria
- M.-C. Corsi, jury member, Assistant professor recruitment procedure - University of Paris-Saclay (COS, section 27)
- M Chavez, Examiner, HDR committee of Mrs Nisrine Jrad, Université Catholique de l'Ouest, Angers, France
- M Chavez, Reviewer, PhD committee of Mrs Tala Abdalah, Université d'Angers, France
- M Chavez, Reviewer, PhD committee of Mrs Apolline Mellot, Université de Saclay, France
- M Chavez, Reviewer, PhD committee of Mrs Maedeh Khalilian, Université d'Angers, France

10.3 Popularization

10.3.1 Specific official responsibilities in science outreach structures

- M.-C. Corsi: member of the organizing committee of the France Brain Bee (Olympiades de Neurosciences)

10.3.2 Productions (articles, videos, podcasts, serious games, ...)

- F de Vico Fallani, Speaker, Art-Basel Breakfast, Pavillon Ledoyen, Paris, France .

10.3.3 Participation in Live events

- F de Vico Fallani, Moderator, Live panel discussion on Network neuroscience, Accelnet Program, US .

10.3.4 Others science outreach relevant activities

- M.-C. Corsi: "The science of Brain-Computer Interface", Forum TERATEC, Paris, France
- M.-C. Corsi: presentation of the career path and the research projects to high school students for the Olympiades de Neurosciences
- M. Fiammante, participation to the 2024 ICM's campaign for donators subject to the Capital Real Estate Tax (IFI).

11 Scientific production

11.1 Major publications

[1] V. Dichio and F. de Vico Fallani. 'Exploration-exploitation paradigm for networked biological systems'. In: *Physical Review Letters* (1st Mar. 2024). DOI: 10.1103/PhysRevLett.132.098402. URL: https://hal.science/hal-04404220.

[2] C. Presigny, M.-C. Corsi and F. de Vico Fallani. 'Node-layer duality in networked systems'. In: *Nature Communications* (18th July 2024). DOI: 10.1038/s41467-024-50176-5. URL: https://inria.hal.science/hal-04163895.

11.2 Publications of the year

International journals

[3] R. Ben Messaoud, V. L. Du, B. C. Kaufmann, B. Couvy-Duchesne, L. Migliaccio, P. Bartolomeo, M. Chavez and F. de Vico Fallani. 'Low-dimensional controllability of brain networks'. In: *PLoS Computational Biology* (2024). URL: https://hal.science/hal-04302540 (cit. on p. 10).

[4] S. Benghanem, T. Sharshar, M. Gavaret, F. Dumas, J.-L. Diehl, N. Brechot, F. Picard, D. Candia-rivera, M.-P. Le, F. Pène, A. Cariou and B. Hermann. 'Heart rate variability for neuro-prognostication after CA: Insight from the Parisian registry'. In: *Resuscitation* 202 (13th Oct. 2024), p. 110294. DOI: 10.1016/j.resuscitation.2024.110294. URL: https://hal.science/hal-04855382.

[5] T. Bieth, M. Ovando-Tellez, A. Lopez-Persem, B. Garcin, L. Hugueville, K. Lehongre, R. Levy, N. George and E. Volle. 'Time course of EEG power during creative problem-solving with insight or remote thinking'. In: *Human Brain Mapping* 45.1 (2024), e26547. DOI: 10.1002/hbm.26547. URL: https://cnrs.hal.science/hal-04331846.

[6] Q. Calonge, F. Le Gac, M. Chavez, A. Degremont, C. Quantin, F. Tubach, S. Tezenas Du Montcel and V. Navarro. 'Burden of Status Epilepticus: prognosis and cost driving factors, insight from a nationwide retrospective cohort study of the French health insurance database'. In: *Journal of Neurology* (23rd Aug. 2024). DOI: 10.1007/s00415-024-12589-6. URL: https://hal.sorbonne-universite.fr/hal-04701239.

[7] D. Candia-Rivera, M. Chavez and F. De Vico Fallani. 'Measures of the coupling between fluctuating brain network organization and heartbeat dynamics'. In: *Network Neuroscience* 8.2 (1st July 2024), pp. 557–575. DOI: 10.1162/netn_a_00369. URL: https://hal.sorbonne-universite.fr/hal-04632701.

[8] D. Candia-Rivera, T. Engelen, M. Babo-Rebelo and P. C. Salamone. 'Interoception, network physiology and the emergence of bodily self-awareness'. In: *Neuroscience and Biobehavioral Reviews* 165 (Oct. 2024), p. 105864. DOI: 10.1016/j.neubiorev.2024.105864. URL: https://hal.science/hal-04816392.

[9] D. Candia-Rivera, F. de Vico Fallani, R. Boehme and P. Salamone. 'Linking heartbeats with the cortical network dynamics involved in self-social touch distinction'. In: *Communications Biology* (15th May 2024). DOI: 10.1101/2024.05.15.594340. URL: https://hal.science/hal-04881993. In press.

[10] D. Candia-rivera, L. Faes, F. de Vico Fallani and M. Chavez. 'Measures and Models of Brain-Heart Interactions'. In: *IEEE Reviews in Biomedical Engineering* (2024). URL: https://hal.science/hal-04881986. In press (cit. on p. 11).

[11] D. Candia-rivera, M. Vidailhet, M. Chavez and F. De Vico Fallani. 'A framework for quantifying the coupling between brain connectivity and heartbeat dynamics: Insights into the disrupted network physiology in Parkinson's disease'. In: *Human Brain Mapping* 45.5 (23rd Mar. 2024), e26668. DOI: 10.1002/hbm.26668. URL: https://hal.sorbonne-universite.fr/hal-04519321 (cit. on p. 10).

[12] I. Carrara, B. Aristimunha, M.-C. Corsi, R. Y. de Camargo, S. Chevallier and T. Papadopoulo. 'Geometric Neural Network based on Phase Space for BCI decoding'. In: *Journal of Neural Engineering* (18th Oct. 2024). DOI: 10.1088/1741-2552/ad88a2. URL: https://inria.hal.science/hal-04500580.

[13] V. Catrambone, D. Candia-rivera and G. Valenza. 'Intracortical brain-heart interplay: An EEG model source study of sympathovagal changes'. In: *Human Brain Mapping* 45.6 (24th Apr. 2024). DOI: 10.1002/hbm.26677. URL: https://hal.science/hal-04855245.

[14] T. Cattai, G. Scarano, M.-C. Corsi, F. de Vico Fallani and S. Colonnese. 'Community Detection from Multiple Observations: from Product Graph Model to Brain Applications'. In: *IEEE Transactions on Signal and Information Processing over Networks* (2024). URL: https://hal.science/hal-04854823. In press.

[15] M.-C. Corsi, P. Sorrentino, D. P. Schwartz, N. George, L. L. Gollo, S. Chevallier, L. Hugueville, A. E. Kahn, S. Dupont, D. S. Bassett, V. Jirsa and F. de Vico Fallani. 'Measuring Neuronal Avalanches to inform Brain-Computer Interfaces'. In: *iScience* 27.1 (2024), p. 108734. DOI: 10.1016/j.isci.2023.108734. URL: https://inria.hal.science/hal-04345847 (cit. on p. 12).

[16] M.-C. Corsi, E. Troisi Lopez, P. Sorrentino, S. Cuozzo, A. Danieli, P. Bonanni and G. M. Duma. 'Neuronal avalanches in temporal lobe epilepsy as a noninvasive diagnostic tool investigating large scale brain dynamics'. In: *Scientific Reports* 14.1 (18th June 2024), p. 14039. DOI: 10.1038/s41598-024-64870-3. URL: https://inria.hal.science/hal-04618262 (cit. on p. 11).

[17] A. Desbois, T. Venot, F. de Vico Fallani and M.-C. Corsi. 'HappyFeat—An interactive and efficient BCI framework for clinical applications'. In: *Software Impacts* 19 (2024), p. 100610. DOI: 10.1016/j.simpa.2023.100610. URL: https://hal.science/hal-04343247 (cit. on p. 12).

[18] V. Dichio and F. de Vico Fallani. 'Exploration-exploitation paradigm for networked biological systems'. In: *Physical Review Letters* (1st Mar. 2024). DOI: 10.1103/PhysRevLett.132.098402. URL: https://hal.science/hal-04404220 (cit. on p. 9).

[19] C. Dussard, L. Pillette, C. Dumas, É. Pierrieau, L. Hugueville, B. Lau, C. Jeunet-Kelway and N. George. 'Influence of feedback transparency on motor imagery neurofeedback performance: the contribution of agency'. In: *Journal of Neural Engineering* 21 (25th Sept. 2024), p. 056029. DOI: 10.1088/1741-2552/ad7f88. URL: https://hal.science/hal-04718663.

[20] F. Hauw, J. Gonzalez-Astudillo, F. De Vico Fallani and L. Cohen. 'Increased core-periphery connectivity in ticker-tape synesthetes'. In: *Brain - A Journal of Neurology* 147.5 (3rd May 2024), e34–e36. DOI: 10.1093/brain/awae001. URL: https://hal.science/hal-04854482.

[21] B. Hermann, D. Candia-rivera, T. Sharshar, M. Gavaret, J.-l. Diehl, A. Cariou and S. Benghanem. 'Aberrant brain–heart coupling is associated with the severity of post cardiac arrest brain injury'. In: *Annals of Clinical and Translational Neurology* 11.4 (2024), pp. 866–882. DOI: 10.1002/acn3.52000. URL: https://hal.science/hal-04412605. In press.

[22] L. Jamal, L. Michelant, S. Delanaud, L. Hugueville, P. Mazet, P. Lévêque, T. Baz, V. Bach and B. Selmaoui. 'Autonomous nervous system responses to environmental-level exposure to 5G's first deployed band (3.5 GHz) in healthy human volunteers'. In: *Experimental Physiology* (15th Oct. 2024), Online ahead of print. DOI: 10.1113/EP092083. URL: https://u-picardie.hal.science/hal-04740870.

[23] A. Longhena, M. Guillemaud and M. Chavez. 'Detecting local perturbations of networks in a latent hyperbolic embedding space'. In: *Chaos: An Interdisciplinary Journal of Nonlinear Science* 34.6 (5th June 2024), p. 063117. DOI: 10.1063/5.0199546. URL: https://hal.science/hal-04609862 (cit. on p. 10).

[24] X. Navarro-Sune, M. Raux, A. Hudson, T. Similowski and M. Chavez. 'Cycle-frequency content EEG analysis improves the assessment of respiratory-related cortical activity'. In: *Physiological Measurement* 45.9 (16th Sept. 2024), p. 095003. DOI: 10.1088/1361-6579/ad74d7. URL: https://hal.science/hal-04877015.

[25] C. Presigny, M.-C. Corsi and F. de Vico Fallani. 'Node-layer duality in networked systems'. In: *Nature Communications* (18th July 2024). DOI: 10.1038/s41467-024-50176-5. URL: https://inria.hal.science/hal-04163895 (cit. on p. 9).

[26] T. Venot, A. Desbois, M. C. Corsi, L. Hugueville, L. Saint-Bauzel and F. De Vico Fallani. 'Intentional binding for noninvasive BCI control'. In: *Journal of Neural Engineering* 21.4 (2024), p. 046026. DOI: 10.1088/1741-2552/ad628c. URL: https://inria.hal.science/hal-04244638 (cit. on p. 12).

[27] D. Ziri, L. Hugueville, C. Olivier, P. Boulinguez, H. Gunasekaran, B. Lau, M.-l. Welter and N. George. 'Inhibitory control of gait initiation in humans: An electroencephalography study'. In: *Psychophysiology* 61.11 (10th July 2024), e14647. DOI: 10.1111/psyp.14647. URL: https://hal.science/hal-04751938.

International peer-reviewed conferences

[28] D. Candia-rivera and M. Chavez. 'Freezing of gait in Parkinson's disease increases sympathetic and parasympathetic indices'. In: ESGCO 2024 - 13th Conference of the European Study Group on Cardiovascular Oscillations. Saragosse, Spain: IEEE, 23rd Oct. 2024. DOI: 10.1109/ESGCO63003.2024.10767055. URL: https://hal.science/hal-04813803.

[29] D. Candia-rivera and M. Chavez. 'Tracking the physiological responses in sleep apnea using robust cardiac sympathetic activity estimation'. In: 20ESGCO 2024 - 13th Conference of the European Study Group on Cardiovascular Oscillations. Zaragoza, Spain: IEEE, 23rd Oct. 2024. DOI: 10.1109/ESGCO63003.2024.10766963. URL: https://hal.science/hal-04813786.

[30] T. Cattai, C. Caporali, M.-C. Corsi and S. Colonese. 'Introducing the modularity graph: an application to brain functional networks'. In: EUSIPCO 2024 - 32nd European conference on signal processing. Lyon, France, 26th Aug. 2024. URL: https://inria.hal.science/hal-04895016.

[31] M.-C. Corsi. 'A theory-driven approach to data analysis: practical applications: CNS2024 workshop - Virtual Brains: From data to modeling and back'. In: 33rd Annual Computational Neuroscience Meeting. Natal, Brazil, 20th July 2024. URL: https://inria.hal.science/hal-04701039.

[32] A. Longhena, M. Guillemaud and M. Chavez. 'Detecting local perturbations of networks in a latent hyperbolic embedding space'. In: COMPLEX NETWORKS 2024 - 13th International Conference on Complex Networks and Their Applications. Istanbul, Turkey, 10th Dec. 2024. URL: https://hal.science/hal-04891978.

[33] C. Mannino, P. Sorrentino, M. Chavez and M.-C. Corsi. 'Neuronal avalanches for eeg-based motor imagery BCI'. In: *9th Graz Brain-Computer Interface Conference 2024*. 9th Graz Brain-Computer Interface Conference 2024. Graz, Austria: Verlag der Technischen Universität Graz, 2024, p. 98. DOI: 10.3217/978-3-99161-014-4-018. URL: https://hal.science/hal-04698548.

[34] S. Velut, S. Chevallier, M.-C. Corsi and F. Dehais. 'Deep Riemannian Neural Architectures for Domain Adaptation in Burst cVEP-based Brain Computer Interface'. In: ESANN 2024 - 32nd European Symposium on Artificial Neural Networks, Computational Intelligence and Machine Learning. Bruges, Belgium: Ciaco - i6doc.com, 3rd Oct. 2024, pp. 571–576. DOI: 10.14428/esann/2024.ES2024-112. URL: https://hal.science/hal-04720928.

[35] T. Venot, A. Desbois and F. de Vico Fallani. 'Dynamic brain networks in motor imagery-based BCI'. In: Graz BCI Conference. Graz, Austria: Verlag der Technischen Universität Graz, 2024. DOI: 10.3217/978-3-99161-014-4-031. URL: https://inria.hal.science/hal-04854131.

[36] F. de Vico Fallani and T. Rolland. 'How many connections can you read?' In: NetSci 2024 - International School and Conference on Network Science. Quebec City, Canada, 16th June 2024. URL: https://hal.science/hal-04890759.

Conferences without proceedings

[37] M.-C. Corsi. 'Using models for classification: real-life applications: Alternative functional connectivity estimators and their real-life application symposium'. In: BIOMAG 2024 - 23rd International Conference on Biomagnetism. Sydney, Australia, 26th Aug. 2024. URL: https://inria.hal.science/hal-04701100.

[38] M.-C. Corsi and A. Desbois. 'What are BCIs, and how do they work? How to ease the reproducibility in BCI?: Designing Brain-Computer Interfaces, from theory to real-life scenarios workshop'. In: *All the materials presented during the workshop are available here:https://github.com/AsteroidShrub/NEC24-DesigningBCI-Workshop*. 5th International Neuroergonomics Conference. Bordeaux, France, 8th July 2024. URL: https://inria.hal.science/hal-04701062.

[39] A. Desbois. '"Designing Brain-Computer Interfaces with Open-Source Tools: from theory to real-life scenarios": Happyfeat: HappyFeat: an interactive and efficient BCI framework for clinical applications'. In: 5th International Neuroergonomics Conference. Bordeaux, France, 8th July 2024. URL: https://inria.hal.science/hal-04854431.

[40] A. Desbois. 'Workshop: "Designing Brain-Computer Interfaces, from theory to real-life scenarios" - HappyFeat: HappyFeat: an interactive and efficient BCI framework for clinical applications'. In: 9th Graz Brain-Computer Interface Conference 2024. Graz, Austria, 9th Sept. 2024. URL: https://inria.hal.science/hal-04854478.

Reports & preprints

[41] M. Fiammante, A.-I. Vermersch, M. Vidailhet and M. Chavez. *A simple EEG-based decision tool for neonatal therapeutic hypothermia in hypoxic-ischemic encephalopathy*. 2024. URL: https://hal.science/hal-04877027.

[42] J. Gonzalez-Astudillo and F. de Vico Fallani. *Feature interpretability in BCIs: exploring the role of network lateralization*. 2024. URL: https://hal.science/hal-04854817.

[43] M. Guillemaud, L. Cousyn, V. Navarro and M. Chavez. *Hyperbolic embedding of brain networks as a tool for epileptic seizures forecasting*. 2024. URL: https://hal.science/hal-04877141.

[44] M. Guillemaud, A. Longhena, L. Cousyn, V. Frazzini, B. Mathon, V. Navarro and M. Chavez. *Hyperbolic embedding of brain networks can predict the surgery outcome in temporal lobe epilepsy*. 2024. URL: https://hal.science/hal-04877126.

[45] A. Longhena, M. Guillemaud, F. d. V. Fallani, R. L. Migliaccio and M. Chavez. *Hyperbolic embedding of brain networks detects regions disrupted by neurodegeneration in Alzheimer's disease*. 2024. URL: https://hal.science/hal-04884605.

[46] F. de Vico Fallani and T. Rolland. *Economical representation of spatial networks*. 2024. URL: https://hal.science/hal-04854830.

Other scientific publications

[47] B. Aristimunha, T. Moreau, S. Chevallier, R. Y. de Camargo and M.-C. Corsi. 'What is the best model for decoding neurophysiological signals? Depends on how you evaluate'. In: CNS 2024 - 33rd Annual Computational Neuroscience Meeting. Natal, Brazil, 20th July 2024. URL: https://inria.hal.science/hal-04743845.

[48] M.-C. Corsi, P. Sorrentino, D. P. Schwartz, N. George, L. L. Gollo, S. Chevallier, A. E. Kahn, S. Dupont, D. S. Bassett, V. Jirsa and F. de Vico Fallani. 'Neuronal avalanches as potential features for Brain-Computer Interfaces'. In: OHBM 2024 - Organization for Human Brain Mapping. Vol. 4. 1. Seoul, South Korea, 28th June 2024. URL: https://inria.hal.science/hal-04701010.

[49] M. Guillemaud, L. Cousyn, V. Navarro and M. Chavez. 'Epileptic seizure prediction with hyperbolic embedding of EEG connectivity networks'. In: EEC 2024 - 15th European Epilepsy Congress. Rome, Italy, 7th Sept. 2024. URL: https://hal.science/hal-04892088.

[50] M. Guillemaud, L. Cousyn, V. Navarro and M. Chavez. 'Les réseaux cérébraux de connectivité comme biomarqueurs pour prédire les résultats de la chirurgie de l'épilepsie'. In: JFE 2024 - 26èmes journées Française de l'épilepsie. Marseille, France, 8th Oct. 2024. URL: https://hal.science/hal-04892105.

[51] M. Guillemaud, A. Longhena and M. Chavez. 'Detection of network connectivity perturbations based on their embedding in a latent hyperbolic space'. In: Netsci 2024 - International School and Conference on Network Science. Québec City, Canada, 16th June 2024. URL: https://hal.science/hal-04891962.

[52] C. Mannino, M. Chavez, P. Sorrentino and M.-C. Corsi. 'Neuronal avalanches for EEG-based motor imagery BCI: robustness of classification performance & validity of feature selection'. In: Journées CORTICO 2024. Nancy, France, 22nd May 2024. URL: https://hal.science/hal-04621936.

[53] C. Mannino, P. Sorrentino, M. Chavez and M.-C. Corsi. 'The potential of neural avalanches to design innovative sensorimotor-based brain-computer interface'. In: NCM 2024 - Neural Control of Movement, 33° Annual meeting. Dubrovnik, Croatia, 15th Apr. 2024. URL: https://hal.science/hal-04621883.

[54] T. Venot, C. Bousfiha, F. de Vico Fallani and M.-C. Corsi. 'Investigating evolution of features in Brain Computer Interface experimentation for robustness'. In: SFN 2024 - Annual meeting of the Society for Neuroscience. Chicago (IL), United States, 5th Oct. 2024. URL: https://hal.science/hal-04890567.

[55] T. Venot, A. Desbois and F. de Vico Fallani. *Temporal dynamics of networks in MI BCI*. 22nd May 2024. URL: https://hal.science/hal-04890613.

[56] P. Verma and M.-C. Corsi. 'Biophysical modeling to inform performance in motor imagery-based Brain Computer Interfaces'. In: BIOMAG 2024 - 23rd International Conference on Biomagnetism. Sydney, Australia, 26th Aug. 2024. URL: https://inria.hal.science/hal-04701082.

[57] P. Verma and M.-C. Corsi. 'Biophysical modeling to inform performance in motor imagery-based Brain-Computer Interfaces'. In: CNS 2024 - 33rd Annual Computational Neuroscience Meeting. Natal, Brazil, 20th July 2024. URL: https://inria.hal.science/hal-04701021.