UMR IRISA

Activity Report 2025

Team EMPENN

Neuroimaging: Methods and Applications

Joint team with Centre Inria de l'Université de Rennes

D6 – Signal, Image, Language

Université de Rennes | rennes | INSA INSTITUT NATIONAL DES SCIENCES APPLIQUÉES RENNES | cnrs | Inria | Inserm | CentraleSupélec | IMT Atlantique Bretagne-Pays de la Loire École Mines-Télécom | Université Bretagne Sud ubs

Project-Team EMPENN

Creation of the Project-Team: 2019 January 01

Keywords

Computer sciences and digital sciences

A3.1.2. – Data management, quering and storage
A3.1.3. – Distributed data
A3.1.7. – Open data
A3.1.8. – Big data (production, storage, transfer)
A3.2.4. – Semantic Web
A3.3.3. – Big data analysis
A5.1.4. – Brain-computer interfaces, physiological computing
A5.2. – Data visualization
A5.3.2. – Sparse modeling and image representation
A5.3.3. – Pattern recognition
A5.3.4. – Registration
A5.9.2. – Estimation, modeling
A5.9.4. – Signal processing over graphs
A6.2.3. – Probabilistic methods
A6.2.4. – Statistical methods
A6.3.3. – Data processing
A6.3.4. – Model reduction
A9.2. – Machine learning
A9.2.1. – Supervised learning
A9.2.2. – Unsupervised learning
A9.2.3. – Reinforcement learning
A9.2.4. – Optimization and learning
A9.2.6. – Neural networks
A9.2.8. – Deep learning
A9.3. – Signal processing
A9.12.1. – Object recognition
A9.12.6. – Object localization

Other research topics and application domains

B1.2. – Neuroscience and cognitive science

B1.2.1. – Understanding and simulation of the brain and the nervous system

B1.2.2. – Cognitive science

B2.1. – Well being

B2.2.2. – Nervous system and endocrinology

B2.2.6. – Neurodegenerative diseases

B2.5.1. – Sensorimotor disabilities

B2.5.2. – Cognitive disabilities

B2.6.1. – Brain imaging

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1 Team members, visitors, external collaborators

Research Scientists

- Emmanuel Caruyer [CNRS, Researcher, HDR]
- Julie Coloigner [CNRS, Researcher, HDR]
- Benoit Combes [INRIA, Researcher]
- Claire Cury [INRIA, Researcher]
- Fanny Dégeilh [INSERM, Researcher, HDR]
- Camille Maumet [INRIA, Researcher, HDR]

Faculty Members

- Pierre Maurel [Team leader, UNIV RENNES, Professor, HDR]
- Jean-Marie Batail [UNIV RENNES, Professor, HDR]
- Isabelle Bonan [UNIV RENNES, Professor, HDR]
- Gilles Edan [UNIV RENNES, Emeritus, HDR]
- Jean-Christophe Ferré [UNIV RENNES, Professor, HDR]
- Francesca Galassi [UNIV RENNES, Associate Professor]
- Jean-Yves Gauvrit [UNIV RENNES, Professor, HDR]
- Anne Kerbrat [UNIV RENNES, Professor, HDR]
- Gabriel Robert [UNIV RENNES, Professor, HDR]

Post-Doctoral Fellows

- Nathan Decaux [INCR, Post-Doctoral Fellow, from Feb 2025]
- Julie Fournier [INRIA, Post-Doctoral Fellow, from Oct 2025]
- Julie Fournier [INCR, Post-Doctoral Fellow, until Sep 2025]
- Mathieu Labrunie [INRIA, Post-Doctoral Fellow, from Dec 2025]
- Anne Lise Marais [INRIA, Post-Doctoral Fellow, until Apr 2025]
- Camille Muller [UNIV RENNES, Post-Doctoral Fellow, until Jul 2025]

PhD Students

- Melvin Selim Atay [INRIA]
- Constance Bocquillon [UNIV RENNES, until Nov 2025]
- Lisa Borgmann [UNIV RENNES, from Dec 2025]
- Valentine Chouquet [INRIA]
- Sebastien Dam [INRIA, until Oct 2025]
- Carlo Ferritto [CNRS]

- Mathys Georgeais [UNIV RENNES]
- Malo Gicquel [INRIA]
- Maud Guillen [CHRU RENNES , until Aug 2025]
- Nolwenn Jegou [INRIA]
- Carla Joud [UNIV RENNES, until Oct 2025]
- Gracia Khoury [INRIA, from Sep 2025]
- Mathilde Liffran [UNIV RENNES]
- Youwan Mahe [SIEMENS IND.SOFTWARE, CIFRE]
- Youenn Merel Jourdan [INRIA]
- Marie Poirier [UNIV RENNES, until Nov 2025]
- Benjamin Prigent [INRIA]
- Adele Savalle [INRIA]
- Gregoire Ville [INRIA]
- Ricky Walsh [UNIV RENNES, until Oct 2025]

Technical Staff

- Gwenael Ambrosino-Ielpo [INRIA, Engineer, until Nov 2025]
- Elise Bannier [CHRU RENNES, Engineer, HDR]
- Boris Clenet [INRIA, Engineer]
- Isabelle Corouge [UNIV RENNES, Engineer]
- Pierre-Henri Dauvergne [INRIA, Engineer]
- Quentin Duché [UNIV RENNES, Engineer]
- Malo Gaubert [CHRU RENNES, Engineer]
- Guewen Hubert [INRIA, Engineer]
- Dorian Le Quilleuc [INRIA, Engineer, from Dec 2025]
- Cédric Meurée [INRIA, Engineer]
- Louis Pade [INRIA, Engineer, from Mar 2025]
- Mathis Piquet [INRIA, Engineer]
- Alexandre Pron [INRIA, Engineer, until Jun 2025]
- Gwendal Soisnard [INRIA, Engineer, until Mar 2025]
- Benjamin Streichenberger [INRIA, Engineer]

Interns and Apprentices

- Celia Bouvier [INRIA, Intern, from Mar 2025 until Aug 2025]
- Andjela Dimitrijevic [UNIV MONTREAL, Intern, from Feb 2025 until Mar 2025]
- Rodolphe Fenech [INRIA, Intern, until Jul 2025]
- Anne-Gaelle Geffroy [INRIA, Intern, until Jul 2025]
- Maxime Jardin [UNIV RENNES, Intern, from May 2025 until Jun 2025]
- Yann Kerverdo [INRIA, Intern, from Jun 2025 until Aug 2025]
- Kieran Le Mouel [INRIA, Intern, from Jun 2025 until Aug 2025]
- Juliane Le Treis [UNIV RENNES, Intern, from May 2025 until Jun 2025]
- Maurane Omnes [INRIA, Intern, from May 2025 until Jun 2025]
- Sonia Tifrea [CHRU RENNES, Intern, until Jul 2025]

Administrative Assistant

- Armelle Mozziconacci [CNRS]

Visiting Scientists

- Alessandro Di Matteo [Univ Aquila , from Feb 2025 until Jun 2025]
- Andjela Dimitrijevic [UNIV MONTREAL, until Feb 2025]

External Collaborators

- Pierre-Yves Jonin [CHRU RENNES]
- Stéphanie Leplaideur [CHRU RENNES]
- Camille Muller [UNIV TOULOUSE I, from Nov 2025]

2 Overall objectives

The research team Empenn ("Brain" in Breton language) ERL U1228 is co-affiliated with Inria, Inserm (National Institute for Health and Scientific Research), CNRS (Informatics), and the University of Rennes. It is a team of IRISA/UMR CNRS 6074. Empenn is located in Rennes, on the medical and scientific campus. It succeeded in 2019 to the "VisAGeS" team, created in 2006 by Inria. As for "VisAGeS", Empenn holds the accreditation number U1228, renewed by Inserm in 2022 and for a period of 6 years, after an evaluation conducted by the HCERES and Inserm.

Thanks to this unique partnership, Empenn's ambition is to establish a multidisciplinary team of researchers in information sciences and medicine. Our medium and long term objective is to introduce our fundamental research into clinical practice, while maintaining the excellence of our methodological research.

Our goal is to foster research in medical imaging, neuroinformatics and population cohorts. In particular, the Empenn team aims at the detection and development of imaging biomarkers for brain diseases and focuses its efforts on transferring this research to the clinic and clinical neuroscience in general. More specifically, the objective of Empenn is to propose new statistical and computational methods, and to measure and model morphological, structural and functional states of the brain to better diagnose, monitor and treat mental, neurological and substance use disorders. We propose to combine advanced instrumental devices and novel computational models to provide advanced diagnostic, therapeutic, and neurorehabilitation solutions for some of the major developing and aging brain disorders.

Generic and challenging research topics in this broad area include finding new ways to compare models and data, aid in decision making and interpretation, and develop feedback. These activities are carried out in close collaboration with the Neurinfo imaging platform *in vivo*, which is an essential environment for the experimental implementation of our research on ambitious clinical research projects and the development of new clinical applications.

3 Research program

3.1 Glossary

- **Magnetic Resonance Imaging**
  - MR - Magnetic Resonance
  - MRI - Magnetic Resonance Imaging
  - fMRI - Functional Magnetic Resonance Imaging
  - DWI - Diffusion-Weighted Imaging
  - ASL - Arterial Spin Labeling
- **Other modalities**
  - PET - Positron Emission Tomography
  - EEG - Eletroencephalograpy
  - NIRS - Near InfraRed Spectroscopy
- **Medical terminology**
  - MS - Multiple Sclerosis
  - TBI - Traumatic Brain Injury
- **Methodological terminology**
  - GLM - General Linear Model
  - MCM - Multi-compartment models
  - NF - Neurofeedback

3.2 Scientific Foundations

The scientific foundations of our team concern the design and development of new computational solutions for biological images, signals and measurements. Our goal is to develop a better understanding of the normal and pathological brain, at different scales.

This includes imaging brain pathologies in order to better understand pathological behavior from the organ level to the cellular level, and even to the molecular level (PET-MR imaging), and modeling of large groups of normal and pathological individuals (cohorts) from image descriptors. It also addresses the challenge of the discovery of episodic findings (i.e., rare events in large volumes of images and data), data mining and knowledge discovery from image descriptors, validation and certification of new drugs from imaging features, and, more generally, the integration of neuroimaging into neuroinformatics by promoting and supporting virtual organizations of biomedical actors using e-health technologies.

As shown in Figure 1, the research activities of the Empenn team closely link observations and models through the integration of clinical and multiscale data, and phenotypes (cellular, and later molecular, with

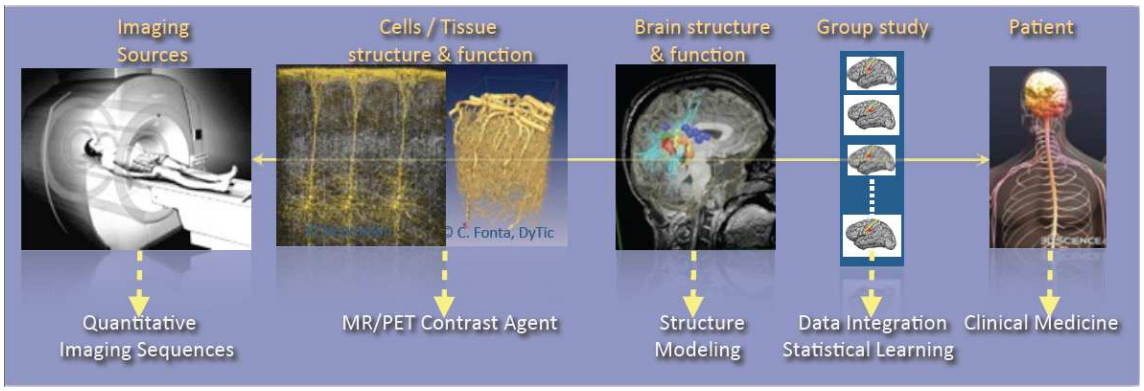


Figure 1: The major overall scientific foundation of the team concerns the integration of data from the imaging source to the patient at different scales: from the cellular or molecular level describing the structure and function, to the functional and structural level of brain structures and regions, to the population level for the modelling of group patterns and the learning of group or individual imaging markers.

structural or connectivity patterns in the first stage). Our ambition is to build personalized models of central nervous system organs and pathologies, and to compare these models with clinical research studies in order to establish a quantitative diagnosis, prevent the progression of diseases and provide new digital recovery strategies, while combining all these research areas with clinical validation. This approach is developed within a translational framework, where the data integration process to build the models is informed by specific clinical studies, and where the models are assessed regarding prospective clinical trials for diagnosis and therapy planning. All of these research activities are conducted in close collaboration with the Neurinfo platform, which benefited in 2018 from a new high-end 3T MRI system dedicated to research (3T Prisma™ system from Siemens), and through the development in the coming years of multimodal hybrid imaging (from the currently available EEG-MRI, to EEG-NIRS and PET-MRI in the future).

In this context, some of our major developments and newly arising issues and challenges include:

- The generation of new descriptors to study brain structure and function (e.g. the combination of variations in brain perfusion with and without a contrast agent; changes in brain structure in relation to normal, pathological, functional or connectivity patterns; or the modeling of brain state during cognitive stimulation using neurofeedback).
- The integration of additional spatiotemporal and hybrid imaging sequences covering a larger range of observations, from the molecular level to the organ level, via the cellular level (arterial spin labeling, diffusion MRI, MR relaxometry, MR cell labeling imaging, EEG-MRI functional imaging, EEG-NIRS-MRI).
- The creation of computational models through the data fusion of multimodal MR images, structural and functional image descriptors from group studies of normal and/or pathological subjects.
- The evaluation of these models in relation to acute pathologies, especially for the study of degenerative, psychiatric, traumatic or developmental brain diseases (primarily multiple sclerosis, stroke, traumatic brain injury (TBI) and depression, but applicable with a potential additional impact to epilepsy, Parkinson's disease, dementia, post-traumatic stress disorder, etc.) within a translational framework.

In terms of new major methodological challenges, we address the development of models and algorithms to reconstruct, analyze and transform the images, and to manage the mass of data to store, distribute and "semanticize" (i.e. provide a logical division of the model's components according to their meaning). As such, we expect to make methodological contributions in the fields of model inference; statistical analysis and modeling; the application of sparse representation (compressed sensing and dictionary learning) and machine learning (supervised/unsupervised classification and discrete model learning); data fusion (multimodal integration, registration, patch analysis, etc.); high-dimensional optimization; data integration; and brain-computer interfaces. As a team at the frontier between the digital sciences and clinical research in

neuroscience, we do not claim to provide theoretical breakthroughs in these domains but rather to provide significant advances in using these algorithms through to the advanced applications we intend to address. In addition, we believe that by providing these significant advances using this set of algorithms, we will also contribute to exhibiting new theoretical problems that will fuel the domains of theoretical computer sciences and applied mathematics.

In summary, we expect to address the following major challenges:

- Developing new information processing methods able to detect imaging biomarkers in the context of mental, neurological, and substance use disorders.
- Providing new computational solutions for our target applications, allowing a more appropriate representation of data for image analysis and the detection of biomarkers specific to a form or grade of pathology, or specific to a population of subjects.
- Providing, for our target applications, new patient-adapted connectivity atlases for the study and characterization of diseases from quantitative MRI.
- Providing, for our target applications, new analytical models of dynamic regional perfusion, and deriving indices of dynamic brain local perfusion from normal and pathological populations.
- Investigating whether the theragnostics paradigm of rehabilitation from hybrid neurofeedback can be effective in some behavioral and disability pathologies.

These major advances are primarily developed and validated in the context of several priority applications in which we expect to play a leading role: multiple sclerosis, stroke rehabilitation, and the study and treatment of depression.

3.3 Research axes

Figure 2 summarizes the scientific organization of the research team through three basic research topics in information sciences: Population Imaging (see 3.3.1), Detection and Learning (see 3.3.2), and Quantitative Imaging (see 3.3.3) and three translational axes on central nervous system diseases: Behavior, Neuro-inflammation and Recovery (see section 4).

3.3.1 Population imaging

One major objective of neuroimaging researchers and clinicians is to be able to stratify brain imaging data in order to derive new and more specific population models. In practice, this requires to set up large-scale experiments that, due to the lack of resources and capabilities to recruit locally subjects who meet specific inclusion criteria, motivates the need for sharing the load.

However, building and using multi-site large-scale resources pose specific challenges to deal with the huge quantity of data produced and their diversity. Empenn focuses on two challenges in particular:

- Providing computational environments for the computation and use of imaging biomarkers in the targeted brain diseases, a solution to be used by radiologists and neurologists/psychiatrists for the clinical follow-up of a large patient population.
- Modeling analytic variability of image processing pipelines to better understand and predict the behaviour of imaging biomarker detection solutions and improve reproducibility and productivity in clinical neuroimaging research.

3.3.2 Detection and learning

We intend to make significant contributions with major impacts in learning coupling models between functional recordings during neurofeedback procedures. These advances will provide a breakthrough in brain-computer interfaces for rehabilitation protocols. Our aim is to:

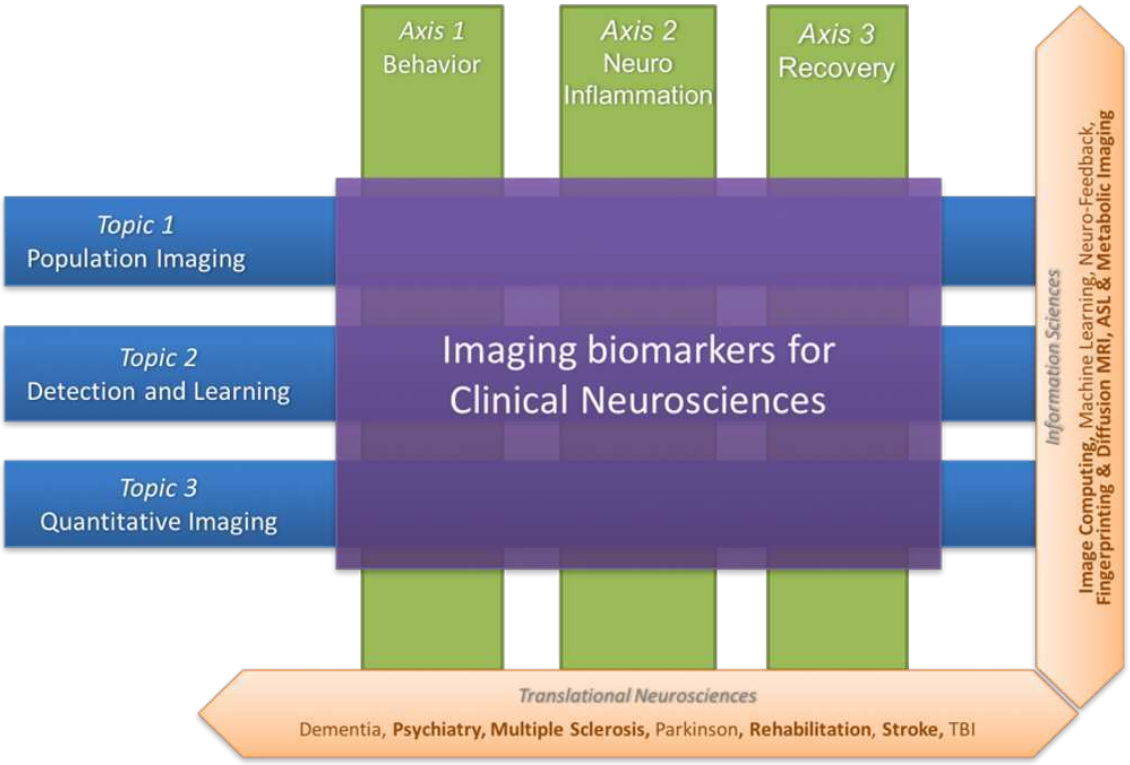


Figure 2: Scientific organization of the research team through three basic research topics in information sciences (Population Imaging, Detection and Learning, and Quantitative Imaging) and three translational axes on central nervous system diseases (Behavior, Neuro-inflammation and Recovery). These projects intersect around the core scientific objective of the team: “Imaging Biomarkers for Clinical Neurosciences".

- Our research employs data-driven approaches, encompassing machine learning and deep learning, to enhance the detection and segmentation of abnormal patterns in medical images. Our primary focus is on multiple sclerosis (MS) and, more recently, on stroke. The findings from our studies indicate promising outcomes in automated tools for accurate disease activity assessment and lesion segmentation within large MRI databases. Special attention is given to the integration of multimodal information and the utilization of labeled and unlabeled data. As we progress, our aim is to adapt these methods to address a broader range of neurological diseases, including epilepsy, tumors, etc., in both neonate and adult brains. This research contributes to advancing diagnostic tools and methodologies in the field of medical imaging.
- Develop solutions for combining brain state measurements from multimodal sensors or sequences (e.g. fMRI, ASL, EEG, NIRS, etc.) with applications in the spatiotemporal reconstruction of brain activity from MRI-EEG or the combined detection of the endogenous hemodynamic and resting state network of the brain from ASL and NIRS. Over the longer term, the advent of new hybrid brain imaging sensors (e.g. PET-MRI) will require these methods to be extended to a larger spectrum of information combining structural, morphological, metabolic, electrophysiological and cellular/molecular information (e.g. through the use of specific ligands/nanocarriers).

3.3.3 Quantitative imaging

The Empenn research group focuses on the development of several quantitative techniques in magnetic resonance imaging of the brain. These methods allow for characterization of both the function and the structure of the brain with high precision. Arterial spin labelling (ASL) is a contrast agent-free imaging technique which labels arterial blood water as an endogenous tracer for perfusion and can measure resting-state cerebral blood flow. We are interested in estimating multiparametric hemodynamics using ASL, such as combined cerebral blood flow and arterial transit times, and derive statistical descriptors to represent significant differences between groups. In addition to quantitative perfusion parameters, our contributions on tissue compartment imaging aim at delineating neural circuits and characterize their microstructure properties, using both diffusion MRI and relaxometry. In diffusion MRI, arbitrary gradient waveforms were shown to exhibit higher sensitivity to microstructure parameters than standard pulsed gradients. We work on the optimization of sampling protocols in this domain, with the objective to propose sequences compatible with in vivo acquisition. Complementary to diffusion MRI, we develop methods for the reconstruction of myelin-bound, extra-axonal and cerebrospinal fluid water using multi-compartment modelling of the T2-relaxometry signal. We combine these techniques with tractography to identify trajectories of pathologies associated to the evolution of these microstructural parameters along specific fiber bundles in the brain white matter. Finally, we are also focusing on assessing the characteristics (repeatability, reproducibility and sensitivity) of several quantitative metrics variability (e.g. MTR, T1 relaxometry) in the spinal cord of patients with MS.

3.3.4 Translational research

The three translational axes focus on the central nervous system and are presented in details in the following section.

4 Application domains

The team develops three translational research axes focused on the central nervous system: Behavior (see 4.1) Neuro-inflammation (see 4.2) and Recovery (see 4.3).

4.1 Behavior

Advances in the field of in vivo imaging offer new opportunities for addressing the management of resistant affective disorders and their consequences (suicide risk and socio-professional impact), and the management of spatial cognition disorders after stroke and their consequences (postural perturbations and the loss of autonomy). Our objective, and the main challenge in this context, is to introduce medical image computing

methods to the multidisciplinary field of behavioral disorders (cognitive disorders, particularly spatial and postural control disorders or anterograde memory impairment, mood disorders, notably resistant depression, schizophrenic disorders, pervasive developmental disorders, attention disorders, etc.) in order to gain a better understanding of the pathology and devise innovative therapeutic approaches.

We also expect to become a major player in the future and make important contributions with significant impacts, primarily in drug-resistant depression in young and old populations. In particular, we expect to provide new image-related metrics combining perfusion, metabolism and microstructural information regarding the brain in order to better characterize pathologies, provide prospective evolution values and potentially provide new brain stimulation targets that could be used in neurofeedback rehabilitation protocols or other types of brain stimulation procedures.

We aim to provide new imaging markers of mental diseases, especially in the context of mood disorders. The new biomarkers are derived from the metabolic (ASL and later ASL+PET) point of view as well as from the microstructural point of view (multicompartment diffusion MRI and relaxometry). Similarly, we expect to exhibit imaging biomarker regularities combining metabolic and structural information. Over the longer term, we expect these biomarkers to be the target of neurofeedback rehabilitation procedures. Also, over the longer term, we expect to supplement the MRI markers with molecular markers coming from new PET tracers, especially those associated with serotonin intake, at one time point or during a rehabilitation protocol under hybrid PET-EEG-MRI neurofeedback procedures.

4.2 Neuroinflammation

Some of the major ongoing research issues regarding neuroimaging of neuro-inflammatory diseases concern the definition of new biomarkers to track the development of the pathology using high- dimensional data (e.g. nD+t MRI). This includes the use of white matter-specific imaging, such as magnetization transfer MRI, relaxometry and diffusion-weighted imaging (DW-MRI). Our objective is (1) to develop information-processing tools to tag the spatiotemporal evolutions of Multiple Sclerosis patterns at the brain parenchyma and spinal cord levels from their different signatures (inflammatory cells visible with USPIO or Gd contrast agents on MRI, persistent black holes, eloquent regional atrophy and microstructure signatures); and (2) to test these new tools on new imaging cohorts. In this respect, we for instance conduct studies on brain and spinal cord imaging, continuing on from the PHRC multicentric EMISEP project (PI: G. Edan), as it is very likely that lesions in the spine will directly affect the ambulatory ability of the patient (and thereby the clinical scores). In order to extend this experiment to a larger MS population, based on our expertise from the OFSEP cohort, we also plan to improve the MS therapeutic decision process notably through the RHU PRIMUS (PRojection In MUltiple Sclerosis) project (PI: G. Edan). Our goal is to develop and assess a standardized monitoring tool that provides a robust, long-term computerized MRI follow-up that will become the gold standard in clinical practice for therapeutic decisions in MS treatment. As part of this project, Empenn will share its expertise in data management systems (Shanoir and FLI-IAM), automatic processing tools (through the medInria and Anima software repositories) to extract quantitative indices from the images and the assessment of the added-value of promising quantitative sequences.

4.3 Recovery

Mental and neurological disorders are the leading cause of years lived with a disability. Treatment-resistant depression affects approximately 2% of the European population. Meanwhile, in the case of brain disorders, almost 1.5 million Europeans (15 million people worldwide) suffer a stroke event each year. Current recovery methods for brain disorders and traumatic brain injuries remain limited, preventing many from achieving full recuperation. We propose to address the issue of brain recovery by introducing new advances from recent breakthroughs in computational medical imaging, data processing and human-machine interfaces, and demonstrate how these new concepts can be used, in particular for the treatment of stroke and major depressive disorders.

We ambition to combine advanced instrumental devices (hybrid EEG, NIRS and MRI platforms), with new hybrid brain computer interface paradigms and new computational models to provide neurofeedback-based therapeutic and neuro-rehabilitation paradigms in some of the major mental and neurological disorders of the developmental and aging brain.

Neurofeedback involves using a brain-computer interface that provides an individual with real-time biofeedback about his or her brain activity in the form of sensory feedback. It enables individuals to learn to better control their brain activity, which can be measured in real time using various non-invasive sensors as described above. Although EEG is currently the only modality used by clinical practitioners in that context, it lacks specificity due to its low spatial resolution. Dynamic research into fMRI-neurofeedback has held promise for treating depression, chronic pain and stroke, since it offers the prospect of real-time imagery of the activity in deep brain structures with high spatial resolution. However, the low temporal resolution and high cost of fMRI-neurofeedback has hampered the development of many applications. We believe that the future belongs to hybrid responses that combine multimodal sensors and intend to demonstrate this in the Empenn project.

5 Social and environmental responsibility

- **Participation to gender-equality**
  - Nolwenn Jégou, Camille Maumet: member of the women-men equality group at Inria Rennes / IRISA.
  - Nolwenn Jégou, leader of the women-men equality reading group at Inria Rennes / IRISA.
  - Elise Bannier: member of the Pairing Committee for the mentoring program of Inria Rennes / IRISA.
  - Fanny Dégeilh, Camille Maumet: mentor for the mentoring program of Inria Rennes / IRISA.

6 Highlights of the year

6.1 Awards

- Youwan Mahé was awarded National Laureate of the Star'Thèse programme, a national initiative supporting the entrepreneurial valorisation of doctoral research.
- Valentine Chouquet was awarded "Prix de la Créativité" - Star'Thèse Rennes (May 2025)
- Carlo Ferritto was awarded the “EURASIP EUSIPCO 2025 Student Travel Grant” (750€).
- Valentine Chouquet, Youwan Mahé were awarded GDR iasis CNRS Travel Grant (2000€)
- Valentine Chouquet, Youwan Mahé, Benjamin Prigent were awarded Doctoral School of Brittany Travel Grant (2400€)
- Valentine Chouquet was awarded Mitacs Globalink Travel Grant (6000$ CAD)

6.2 Promotions

- Isabelle Corouge was promoted to the rank of "ingénieur de recherche hors classe".

7 Latest software developments, platforms, open data

7.1 Latest software developments

7.1.1 Anima

Keywords: Medical imaging, Neuroimaging, Image processing

Scientific Description: Anima is a set of libraries and tools developed by the team as a common repository of research algorithms. As of now, it contains tools for image registration, statistical analysis (group comparison, patient to group comparison), diffusion imaging (model estimation, tractography, etc.), quantitative MRI processing (quantitative relaxation times estimation, MR simulation), image denoising and filtering, and segmentation tools. All of these tools are based on stable libraries (ITK, VTK), making it simple to maintain.

Functional Description: Anima is a set of libraries and tools in command line mode for processing and analysing medical images.

URL: https://anima.irisa.fr

Contact: Julie Coloigner

Participant: 8 anonymous participants

7.1.2 MedINRIA

Keywords: Visualization, DWI, Health, Segmentation, Medical imaging

Scientific Description: MedInria aims at creating an easily extensible platform for the distribution of research algorithms developed at Inria for medical image processing. This project has been funded by the D2T (ADT MedInria-NT) in 2010, renewed in 2012. A fast-track ADT was awarded in 2017 to transition the software core to more recent dependencies and study the possibility of a consortium creation.The Empenn team leads this Inria national project and participates in the development of the common core architecture and features of the software as well as in the development of specific plugins for the team's algorithm.

Functional Description: medInria is a free software platform dedicated to medical data visualization and processing.

URL: https://med.inria.fr

Contact: Florent Leray

Participant: 2 anonymous participants

Partners: HARVARD Medical School, IHU - LIRYC, NIH

7.1.3 autoMRI

Keywords: FMRI, MRI, ASL, FASL, SPM, Automation

Scientific Description: This software is highly configurable in order to fit a wide range of needs. Pre-processing includes segmentation of anatomical data, as well as co-registration, spatial normalization and atlas building of all data types. The analysis pipelines perform either within-group analysis or between-group or one subject-versus-group comparison, and produce statistical maps of regions with significant differences. These pipelines can be applied to structural data to exhibit patterns of atrophy or lesions, to ASL (both pulsed or pseudo-continuous sequences) data to detect perfusion abnormalities, to functional data - either BOLD or ASL - to outline brain activations related to block or event-related paradigms. New functionalities have been implemented to facilitate the management and processing of data coming from complex projects.

Functional Description: AutoMRI is based on MATLAB and the SPM12 toolbox and provides complete pipelines to pre-process and analyze various types of images (anatomical, functional, perfusion).

URL: https://team.inria.fr/visages/software/

Contact: Isabelle Corouge

Participant: 6 anonymous participants

7.1.4 ShanoirUploader

Name: ShanoirUploader (SHAring NeurOImaging Resources Uploader)

Keywords: Webservices, PACS, Medical imaging, Neuroimaging, DICOM, Health, Biology, Java, Shanoir

Scientific Description: ShanoirUploader is a desktop application on base of JavaWebStart (JWS). The application can be downloaded and installed using an internet browser. It interacts with a PACS to query and retrieve the data stored on it. After this ShanoirUploader sends the data to a Shanoir server instance in order to import these data. This application bypasses the situation, that in most of the clinical network infrastructures a server to server connection is complicated to set up between the PACS and a Shanoir server instance.

Functional Description: ShanoirUploader is a Java desktop application that transfers data securely between a PACS and a Shanoir server instance (e.g., within a hospital). It uses either a DICOM query/retrieve connection or a local CD/DVD access to search and access images from a local PACS or the local CD/DVD. After having retrieved the data, the DICOM files are locally anonymized and then uploaded to the Shanoir server. A possible integration of a hash creation application for patient identifiers is provided as well. The primary goals of that application are to enable mass data transfers between different remote server instances and therefore reduce the waiting time of the users, when importing data into Shanoir. Most of the time during import is spent with data transfers.

URL: https://github.com/fli-iam/shanoir-ng/wiki/ShanoirUploader

Contact: Michael Kain

Participant: 5 anonymous participants

7.1.5 Shanoir-NG

Name: Shanoir (SHAring iN vivO Imaging Resources)

Keyword: Medical imaging

Functional Description: Shanoir (SHAring iN vivO Imaging Resources) is an open-source web platform designed to share, archive, search and visualize medical imaging data. It provides an user-friendly secure web access and offers an intuitive workflow to facilitate the collecting and retrieving of imaging data from multiple sources. Quality control can be applied on imported data. Mass data can be downloaded in multiple ways, via the web interface and via a Python script.

It supports the following formats: DICOM classic/enhanced (MR, CT, PT, NM), BIDS, processed datasets (NIfTI), Bruker, EEG(BrainVision/EDF).

Shanoir comes along many features such as pseudonymization of data (based on DICOM standard profiles), support for multi-centric clinical studies on subjects. Shanoir offers an ontology-based data organization (OntoNeuroLOG). Among other things, this facilitates the reuse of data and metadata, the integration of processed data and provides traceability trough an evolutionary approach. Shanoir allows researchers, clinicians, PhD students and engineers to undertake quality research projects with an emphasis on remote collaboration. Data user agreements (DUA) can be configured by study to be accepted by each accessing users and access requests can be initated to study administrators.

Release Contributions: - New tree view - New version of OHIF, with annotations and segmentations - Mass processing integration with VIP - Java 21 - Spring Boot 3.2

URL: https://github.com/fli-iam/shanoir-ng

Contact: Michael Kain

Participant: 7 anonymous participants

7.1.6 LongiSeg4MS

Name: Longitudinal Segmentation For Multiple Sclerosis

Keywords: 3D, Brain MRI, Deep learning, Detection

Functional Description: LongiSeg4MS is an automatic new multiple sclerosis (MS) lesion detection tool based on longitudinal data and using deep learning. The system uses FLAIR, T1 or T2 modalities, or a combination of those. The input is 2, 4 or 6 images (2 FLAIR, 2 FLAIR and 2 T1, etc.), a set of modalities for each time point, and outputs a segmentation map describing the location of new MS lesions.

URL: https://gitlab.inria.fr/amasson/longiseg4ms

Contact: Arthur Masson

Partner: OFSEP

7.1.7 Anima medInria plugins

Keywords: IRM, Medical imaging, Diffusion imaging

Functional Description: Plugins for the medInria software based on the open source software Anima developed in the Visages / Empenn team. These plugins are interfaces between anima and medinria allowing to use Anima functionalities within the clinical user interface provided by medInria. The current functionalities included in the plugins are right now: image registration, denoising, quantitative imaging (relaxometry), and model estimation and visualization from diffusion imaging.

URL: https://github.com/medInria/medInria-visages

Contact: Florent Leray

Participant: 4 anonymous participants

7.1.8 MS_SC_lesions_seg_t2_stir

Keywords: Segmentation, Multimodality, Python, Docker, MRI

Functional Description: The software provides segmentation of multiple sclerosis lesions from a pair of T2-weighted and STIR MRI images of the spinal cord.

Contact: Benoit Combes

7.1.9 MS_SC_lesions_seg

Keywords: Segmentation, MRI, Multiple Sclerosis

Functional Description: The software provides segmentation of multiple sclerosis lesions in T2-weighted MRI images of patients' spinal cords.

Contact: Benoit Combes

7.1.10 NARPS Open Pipelines

Name: NARPS Open Pipelines

Keywords: Functional MRI, FMRI, Variability, Statistical analysis, Reproducibility

Scientific Description: A codebase reproducing the 70 pipelines of the NARPS study (Botvinik-Nezer et al., 2020) shared as an open resource for the community.

NARPS Open Pipelines is developed in the Empenn team by Boris Clénet, Elodie Germani, Jeremy Lefort-Besnard and Camille Maumet with contributions by Rémi Gau. In addition, this project was presented and received contributions during multiple hackathons, for a complete list see: https://github.com/Inria-Empenn/narps_open_pipelines?tab=readme-ov-file#credits

Functional Description: We believe the NARPS Open Pipelines codebase will help analysing and understanding variability of fMRI analysis workflows, hence participating in the reproducible research movement.

URL: https://github.com/Inria-Empenn/narps_open_pipelines

Publication: hal-04286609

Contact: Camille Maumet

Participant: 5 anonymous participants

Partner: Région Bretagne

7.1.11 shanoir downloader

Name: Shanoir Downloader

Keywords: Medical imaging, Data management, Big data, Python

Scientific Description: Shanoir Downloader enables large volumes of imaging data stored on the Shanoir software platform to be downloaded via a python interface. Data can be retrieved in DICOM or NIFTI formats. The integrity of downloaded data is verified. Shanoir Downloader also enables downloaded data to be pseudonymised and organised according to the BIDS standard.

Functional Description: Shanoir Downloader enables large volumes of imaging data stored on the Shanoir software platform to be downloaded via a python interface. Data can be retrieved in DICOM or NIFTI formats. The integrity of downloaded data is verified. Shanoir Downloader also enables downloaded data to be pseudonymised and organised according to the BIDS standard.

News of the Year: In the context of the FAIR data access principles, appropriate support for the BIDS data standard based on the heudiconv software has been implemented, support for distributed data management and versioning has also been included via the datalad software. Finally, a deletion of large volumes of data stored on Shanoir was also implemented in order to consolidate the existing databases of the Shanoir platform.

URL: https://github.com/Inria-Empenn/shanoir_downloader

Contact: Michael Kain

Participant: 6 anonymous participants

7.2 New platforms

7.2.1 The Neurinfo Platform

Participants: Elise Bannier, Emmanuel Caruyer, Isabelle Corouge, Quentin Duché, Jean-Christophe Ferré, Jean-Yves Gauvrit.

Empenn is the founding actor of an experimental research platform which was installed in August 2009 at the University Hospital of Rennes. The University of Rennes, Inria, CNRS for the academic side, and the University Hospital of Rennes and the Cancer Institute “Eugene Marquis” for the clinical side, are partners of this neuroinformatics platform called Neurinfo (Neurinfo website). Concerning the Neurinfo Platform, the activity domain is a continuum between methodological and technological research built around specific clinical research projects. On the medical field, the translational research domain mainly concerns medical imaging and more specifically the clinical neurosciences. Among them are multiple sclerosis, epilepsy, neurodegenerative, neurodevelopmental and psychiatric diseases, surgical procedures of brain lesions, neuro-oncology and radiotherapy planning. Beyond these central nervous system applications, the platform is also open to alternative applications. Neurinfo ambitions to support the emergence of research projects based on their level of innovation, their pluri-disciplinarity and their ability to foster collaborations between different actors (public and private research entities, different medical specialties, different scientific profiles). In this context, a research 3T MRI system (Siemens Verio) was acquired in summer 2009 in order to develop the clinical research in the domain of morphological, functional, structural and cellular in-vivo imaging. A new 3T Siemens Prisma MRI scanner was installed at the Neuroinfo platform in February 2018 and a major upgrade towards a 3T CIMA.x (Siemens) with high-performance gradients is planned for January 2026. In 2014, an equipment for simultaneous recording of EEG and MRI images was acquired from Brain Product. In 2015, a mock scanner for experimental set-up was acquired as well as a High Performance Computing environment made of one large computing cluster and a data center that is shared and operated by the Inria center and IRISA (UMR CNRS 6074). The data center (up to 150 TB) is dedicated to host imaging data produced by the Neurinfo platform, but also by other research partners that share their protocols on the Neurinfo neuroinformatics system (currently more than 90 sites). In 2019, an MRI and EEG-compatible fNIRS system was acquired through a co-funding from the INS2I institute of CNRS and FEDER. At the end of 2019, GIS IBISA awarded the Neurinfo platform with a complementary funding that will be dedicated to supplement the current system with additional sensors (from 8x8 optodes to 16x16 optodes). In 2022, the Regional Council of Britanny funding was renewed to provide engineer support for another year to develop and integrate this new imaging system.

7.3 Open data

7.3.1 The ms-multi-spine challenge

Participants: Benoit Combès, Anne Kerbrat, Cédric Meurée, Gwendal Soisnard, Louis Padé
.

Benoit Combès and Anne Kerbrat organized the ms-multi-spine MICCAI challenge [63]. This challenge results from the joint motivation of the OFSEP (French registry on multiple sclerosis aiming at gathering, for research purposes, imaging data, clinical data and biological samples from the French population of multiple sclerosis subjects), FLI (France Life Imaging, devoted to setup a national distributed e-infrastructure to manage and process medical imaging data) and Empenn research team. These particular efforts were directed towards bringing attention to the spinal cord multiple sclerosis lesion segmentation and to its specific methodological setting. Indeed, in clinical practice, it is highly recommended to acquire at least two sequences among a set of available ones for the detection of spinal cords, without specific guidelines to date. In practice, depending on the center and context, any combination of existing MR sequences can be provided. This challenge therefore represents a concrete and paradigmatic case of missing modalities setting where, depending on the case, some modalities may be missing both at inference or training time. To the best of our knowledge, such clinical datasets are still rarely available in medical imaging. More generally, to date, the medical imaging community concentrated its efforts toward the detection/segmentation of the lesions in brain MRI but spinal cord lesions remain a topic much less studied. In this challenge, we provided a set of 100 segmented cases with different combinations of sequences among sagittal T2w, sagittal PSIR, sagittal STIR and 3d MPRAGE to the participants, that were asked to propose a segmentation method being able to deal with any of the following combinations (sagittal T2w, sagittal PSIR), (sagittal T2w, sagittal STIR), (sagittal T2w, 3d MP2RAGE) and (sagittal T2w, sagittal STIR, 3D MP2RAGE). The performances of the

methods were then assessed using a dedicated testing set. The training and testing data sets were manually annotated using a principled process involving 5 experts for each case. All pipelines were submitted in the form of a docker and integrated to the VIP platform and participants were not involved in the evaluation on the test set data. The dataset can be requested on Shanoir and we hope it will contribute to unlock new solutions to improve spinal cord lesion segmentation methods.

7.3.2 HCP Multi-Pipeline: a derived dataset to investigate analytical variability in fMRI

Participants: Elodie Germani, Pierre Maurel, Camille Maumet.

Results of functional Magnetic Resonance Imaging (fMRI) studies can be impacted by many sources of variability, including different sampling strategies for the participants, different acquisition protocols and materials, but also different analytical choices in the processing of the fMRI data. While variability across participants or acquisition instruments has been extensively studied in the neuroimaging literature, the root causes of analytical variability remain an open question. Here, we share the HCP Multi-Pipeline dataset, which provides the resulting statistic maps for 24 typical fMRI pipelines on 1,080 participants of the HCP Young Adult dataset. We share both individual and group results for 1,000 groups of 50 participants over 5 motor contrasts. We hope this large dataset, covering a wide range of analysis conditions, will provide new opportunities to study analytical variability in fMRI [30]. This work was done in collaboration with Elisa Fromont (Lacodam team).

8 New results

8.1 Basic research

8.1.1 Population imaging

Population imaging is fundamental when it comes to evaluate clinical biomarkers. In this section we summarise our contributions over the last year to this theme.

Statistical Inference for Same Data Meta-Analysis in Neuroimaging Multiverse Analyzes

Participants: Jeremy Lefort-Besnard, Camille Maumet.

Researchers using task-fMRI data have access to a wide range of analysis tools to model brain activity. If not accounted for properly, this plethora of analytical approaches can lead to an inflated rate of false positives and contribute to the irreproducibility of neuroimaging findings. Multiverse analyses are a way to systematically explore pipeline variations on a given dataset. We focus on the setting where multiple statistic maps are produced as an output of a set of analyses originating from a single dataset. However, having multiple outputs for the same research question – corresponding to different analytical approaches – makes it especially challenging to draw conclusions and interpret the findings. Meta-analysis is a natural approach to extract consensus inferences from these maps, yet the traditional assumption of independence amongst input datasets does not hold here. In this work we consider a suite of methods to conduct meta-analysis in the multiverse setting, which we call same data meta-analysis (SDMA), accounting for inter-pipeline dependence among the results. First, we assessed the validity of theses methods in simulations. Then we tested them on the multiverse outputs of two real world multiverse analyses: “NARPS”, a multiverse study originating from the same dataset analyzed by 70 different teams, and “HCP Young Adult”, a more homogeneous multiverse analysis using 24 different pipelines analyzed by the same team. Our findings demonstrate the validity of our proposed SDMA models under inter-pipeline dependence, and provide an array of options, with different levels of relevance, for the analysis of multiverse outputs [36]. This work was done in collaboration with Prof. Thomas Nichols (Oxford Uni., UK).

Mitigating analytical variability in fMRI results with style transfer

Participants: Elodie Germani, Camille Maumet.

We propose a novel approach to improve the reproducibility of neuroimaging results by converting statistic maps across different functional MRI pipelines. We make the assumption that pipelines used to compute fMRI statistic maps can be considered as a style component and we propose to use different generative models, among which, Generative Adversarial Networks (GAN) and Diffusion Models (DM) to convert statistic maps across different pipelines. We explore the performance of multiple GAN frameworks, and design a new DM framework for unsupervised multi-domain style transfer. We constrain the generation of 3D fMRI statistic maps using the latent space of an auxiliary classifier that distinguishes statistic maps from different pipelines and extend traditional sampling techniques used in DM to improve the transition performance. Our experiments demonstrate that our proposed methods are successful: pipelines can indeed be transferred as a style component, providing an important source of data augmentation for future medical studies [45]. This work was done in collaboration with Elisa Fromont (Lacodam team).

On the validity of fMRI mega-analyses using data processed with different pipelines

Participants: Elodie Germani, Xavier Rolland, Pierre Maurel, Camille Maumet.

In neuroimaging and functional Magnetic Resonance Imaging (fMRI), many derived data are made openly available in public databases. These can be re-used to increase sample sizes in studies and thus, improve robustness. In fMRI studies, raw data are first preprocessed using a given analysis pipeline to obtain subject-level contrast maps, which are then combined into a group analysis. Typically, the subject-level analysis pipeline is identical for all participants. However, derived data shared on public databases often come from different workflows, which can lead to different results. Here, we investigate how this analytical variability, if not accounted for, can induce false positive detections in mega-analyses combining subject-level contrast maps processed with different pipelines. We use the HCP multi-pipeline dataset, containing contrast maps for N=1,080 participants of the HCP Young-Adult dataset, whose raw data were processed and analyzed with 24 different pipelines. We performed between-groups analyses with contrast maps from different pipelines in each group and estimated the rates of pipeline-induced detections. We show that, if not accounted for, analytical variability can lead to inflated false positive rates in studies combining data from different pipelines [31].

Extending the Brain Imaging Data Structure specification to provenance metadata

Participants: Boris Clénet, Camille Maumet.

Interpreting and comparing scientific results as well as enabling reusable data and analysis output require understanding provenance, i.e. how data were generated and processed. To be useful, the provenance must be comprehensive, understandable, easily communicated, and captured in a machine accessible form. We presented a recent extension of the Brain Imaging Data Structure (BIDS) that aims at describing the provenance of a dataset. This extension was designed as a combination of ergonomics and computability in order to help neuroscientists parsing human readable yet computer generated provenance records. This work [49] was done in collaboration with Yaroslav Halchenko (Dartmouth, USA), BIDS-Prov contributors, and Satrajit Ghosh (MIT, USA).

Which infrastructure can I use to share human neuroimaging data? Recommendations for EU researchers based on a survey and literature review

Participants: Lefort-Besnard Jérémy, Pron Alexandre, Camille Maumet.

The ability to share research data publicly is crucial for enhancing statistical power, improving the quality of results, and ensuring the generalizability of findings. Despite the widespread availability of web-based tools and collaborative opportunities, sharing human neuroimaging data remains challenging for researchers based in the European Union (EU) due to various obstacles. In particular, many of the infrastructures available to share brain imaging data do not comply with the General Data Protection Rule (GDPR) which is applicable in the EU for all data that come from human participants. To investigate the awareness and utilization of data sharing platforms, we conducted a global survey targeting neuroimaging researchers. Our findings showed that amongst the 81 respondents, less than 50% were familiar with an infrastructure designed for EU researchers and about 20% had already shared data. Respondents also identified several key challenges, including legal compliance and privacy concerns, resource and infrastructure limitations, ethical considerations, institutional barriers, and awareness gaps. These results underscore the critical need to better publicize data sharing platforms that may be used by EU researchers. Here, we compiled a comprehensive list of infrastructures suitable for EU researchers to share brain imaging datasets from human participants. This work [37] was done in collaboration with members of the GLIMR European COST Action.

Large-scale exploration of analytical variability in task-fMRI Software Pipelines

Participants: Youenn Merel Jourdan, Camille Maumet.

Neuroimaging pipelines are characterized by a wide range of tools, parameters, and configuration choices. Such flexibility, while enabling diverse scientific inquiries, gives rise to analytical variability: different pipeline variants can lead to different outcomes. We leveraged methods from software engineering to systematically explore analytical variability from preprocessing up to group analysis in a multi-task fMRI dataset. We studied various candidate proxy ground truths and computed Spearman correlations as a quantitative metric of the performance of each pipeline, and used a decision tree learning approach to inspect variability. We separated variability of interest (differences observed across valid results) from unwanted variability (differences linked to pipelines producing unacceptable or low quality results) while minimizing the required amount of visual quality control. We evaluated the sensitivity of our method to the choice of (proxy) ground truth, both in terms of predictive accuracy and in the identification of important features, and identified the parameters that had the strongest impact on the final (valid) result. Our first results [58, 73] outline the challenge of choosing and validating a referential to assess our understanding of variability in the absence of ground truth. This work was done in collaboration with Mathieu Acher of the DiverSE team.

Quantifying the researcher degrees of freedom in FMRI preprocessing

Participants: Melvin Selim Atay, Boris Clénet, Elise Bannier, Camille Maumet.

At every step of the processing of task-fMRI data, researchers have to make multiple decisions: from deciding on software and their versions to choosing parameters and their values. Such variations in the pipelines have been shown to give rise to differences in experimental results, leading to so-called *analytical variability* and hindering reproducibility. In this work [64], our aim is to investigate the task-fMRI parameter space. First we counted the number of possible preprocessing options in each software package. Second, we analyzed the parameter preferences of scientists by retrieving and interrogating open-source codes. We targeted three

widely-used neuroimaging software packages: AFNI, FSL, and SPM. Using GitHub, we created a codebase containing a total of 3000 code files from 93, 157, and 312 unique repositories for AFNI, FSL, and SPM, respectively. We observed fundamental differences between software in terms of pipeline steps, number of parameters available, and parameter values chosen by researchers. We detected variations in the default values per parameter for each software as well as different researcher preferences.

fNIRS reproducibility varies with data quality, analysis pipelines, and researcher experience

Participants: Élise Bannier, Emmanuel Caruyer, Isabelle Corouge, Nolwenn Jégou.

As data analysis pipelines grow more complex in brain imaging research, understanding how methodological choices affect results is essential for ensuring reproducibility and transparency. This is especially relevant for functional Near-Infrared Spectroscopy (fNIRS), a rapidly growing technique for assessing brain function in naturalistic settings and across the lifespan, yet one that still lacks standardized analysis approaches. In this context, we participated in the fNIRS Reproducibility Study Hub (FRESH) initiative, as one of the 38 research teams worldwide invited to independently analyze the same two fNIRS datasets. Despite using different pipelines, nearly 80% of teams agreed on group-level results, particularly when hypotheses were strongly supported by literature. Teams with higher self-reported analysis confidence, which correlated with years of fNIRS experience, showed greater agreement. At the individual level, agreement was lower but improved with better data quality. The main sources of variability were related to how poor-quality data were handled, how responses were modeled, and how statistical analyses were conducted. These findings suggest that while flexible analytical tools are valuable, clearer methodological and reporting standards could greatly enhance reproducibility. By identifying key drivers of variability, this study highlights current challenges and offers direction for improving transparency and reliability in fNIRS research [42]. This FRESH challenge was promoted by the OpenFNIRS initiative (https://openfnirs.org/) and organized by the steering committee composed of R. Luke, Macquarie University, Australia; R. Mesquita, University of Campinas, Brazil; M Yücel, Boston University, USA and A. von Lühmann, Technische Universität (TU) Berlin, Germany.

Urban environment in early-life and brain morphology in preadolescents

Participants: Elise Bannier.

Rapid urbanization leads to increased exposure to air pollution, limited greenness, and denser built environments. However, evidence on how these urban factors influence brain development remains limited. We investigated associations between urban characteristics during pregnancy and childhood and brain morphology in preadolescence. The study included 2895 children from the Dutch Generation R Study, with replication in 92 children from the French PELAGIE cohort. Twelve built environment and four urban natural space indicators were estimated at residential addresses during pregnancy and childhood. Brain outcomes included cortical gray matter, cerebral white matter, cerebellum, corpus callosum, subcortical structures volumes, cortical thickness, and surface area assessed at 9-12 years. We applied multi-exposure regression models with data-driven variable selection and assessed mediation by air pollution and road-traffic noise, adjusting for confounders. In Generation R, higher NDVI during pregnancy was associated with smaller cortical gray matter volume (-5132 mm3; 95 percent CI: -8611, -1652), and higher facility richness with larger nucleus accumbens volume. During childhood, higher distance to blue space was associated with larger cortical gray matter volume, and higher transport land use with smaller hippocampus. No mediation by air pollution or road-traffic noise was observed. In PELAGIE, associations were consistent but not statistically significant. Cortical thickness was associated with several built environment indicators during childhood, and surrounding greenness was linked to smaller surface area in specific cortical regions. Our findings suggest that early-life exposure to urban environments may influence brain morphology, with distinct contributions from green space, blue space, and built environment factors [16]. This work was lead by Anne-Claire Binter.

Evaluating lesion-specific preprocessing pipelines for rs-fMRI in stroke patients: Impact on functional connectivity and behavioral prediction

Participants: Julie Coloigner, Pierre Maurel.

Functional magnetic resonance imaging (fMRI) is essential for studying brain function and connectivity. Resting- state fMRI, which captures spontaneous brain activity without task requirements, is particularly suited for individuals with post- stroke impairments. However, the inherent noise and artifacts in fMRI signals can compromise analysis accuracy, especially in stroke patients with complex neurological conditions. Currently, there is no consensus on the best preprocessing approach for stroke fMRI data. In this study, we design and evaluate three preprocessing pipelines: a standard pipeline, an enhanced pipeline that accounts for lesions when computing tissue masks, and a stroke- specific pipeline that incorporates independent component analysis to address lesion- driven artifacts. These pipelines are assessed for their effectiveness in reducing spurious connectivity and improving the prediction of behavioral outcomes on a large stroke dataset. Using metrics such as connectivity mean strength and functional connectivity contrast, our results indicate that the stroke- specific pipeline significantly reduces spurious connectivity without impacting behavioral predictions. These findings underscore the need for tailored preprocessing strategies in stroke fMRI research to enhance the reliability and accuracy of connectivity measures. In addition, we make the stroke- specific pipeline accessible by designing an open- source tool (fMRIStroke), in order to ensure replicability of our results and to contribute to best practices [34]. In collaboration with Alix Lamouroux, Giulia Lioi and Nicolas Farrugia from the BRAIn Team, Lab-STICC, IMT Atlantique.

Data-driven identification of functional network changes in Neurofeedback stroke rehabilitation: A clinical validation of network-based statistics

Participants: Julie Coloigner, Pierre Maurel, Isabelle Bonan.

Functional connectivity (FC) analysis is crucial for understanding neuroplasticity in stroke rehabilitation. Neurofeedback (NF) training has shown promise in facilitating recovery, but its whole-brain effects remain poorly understood due to limitations in traditional FC analysis methods. Many studies rely on region-of-interest (ROI)-based approaches, which restrict analysis to predefined regions, or whole-brain mass univariate tests, which suffer from the multiple comparisons problem. In this study, we apply Network-Based Statistics (NBS), a graphtheoretic signal processing approach, to identify data-driven FC changes following NF-based stroke rehabilitation. Using fMRI data, we detected two significant network components: one within the somatomotor network, reflecting expected motor recovery processes, and another within the default mode network (DMN), highlighting broader neuroplasticity effects. Our findings validate NBS as a robust tool for unbiased, whole-brain connectivity analysis, offering new insights into the distributed impact of NF training in stroke rehabilitation [46]. In collaboration with Alix Lamouroux, Giulia Lioi and Nicolas Farrugia from the BRAIn Team, Lab-STICC, IMT Atlantique.

8.1.2 Detection and learning

In this section, we summarize our recent contributions to information extraction and learning from medical imaging and neurophysiological data.

LesionSCynth: A simple parametric lesion synthesis method to improve spinal cord lesion segmentation in low-data scenarios

Participants: Ricky Walsh, Anne Kerbrat, Francesca Galassi, Benoit Combès.

Detecting multiple sclerosis (MS) lesions in spinal cord MRI is a critical yet challenging task due to the small size of lesions, imaging artifacts, and the limited availability of manually annotated datasets. Although deep learning-based segmentation methods have shown promising results, their performance strongly depends on the amount of annotated training data, which is costly and time-consuming to obtain in clinical settings. In this work, we proposed LesionSCynth, a simple parametric framework for synthesizing hyperintense MS lesions in spinal cord MRI to address low-data training scenarios. The method was designed based on an analysis of the intensity distributions of real lesions in sagittal T2-weighted acquisitions and generates realistic synthetic lesions that can be seamlessly inserted into healthy spinal cord images. These synthetic data were used to augment small annotated datasets during training. Segmentation models trained on a combination of LesionSCynth-generated lesions and 17 real acquisitions achieved improved performance compared to models trained on real data alone, as measured by the Free-response Receiver Operating Characteristic (FROC) score (0.52 vs. 0.46). These results demonstrate that parametric lesion synthesis can effectively reduce the annotation burden while improving segmentation performance in low-data scenarios. This work was published in Imaging Neuroscience [74]. This work was done in collaboration with Prabhjot Kaur, Davood Karimi, and Simon K. Warfield (Computational Radiology Laboratory, Boston Children's Hospital and Harvard Medical School, Boston, MA, United States).

Late fusion for multi-sequence MS lesion segmentation in spinal cord MRI

Participants: Ricky Walsh, Francesca Galassi, Benoit Combès.

Identifying lesions in spinal cord MRI is a key challenge for the diagnosis and prognosis of multiple sclerosis (MS), notably due to the small size of the cord, image artifacts, and high inter-rater variability. Current clinical guidelines recommend using multiple MRI sequences with complementary contrasts, but this heterogeneity introduces a frequent missing-modality problem, where some sequences may be unavailable at training or inference time. Previous work addressing this issue using intermediate fusion strategies showed limited performance at inference. In this contribution, we proposed a late fusion approach for multi-sequence MS lesion segmentation in spinal cord MRI. Our method relied on a publicly available deep learning segmentation model to generate initial lesion probability maps. We then summarized predicted probabilities and intensity information across the available MRI sequences for each detected lesion candidate. A classification model was subsequently trained to discriminate true positive from false positive detections. This strategy allowed us to leverage the diversity and robustness of a large pre-trained model while adapting predictions to the specific characteristics of the challenge dataset and accounting for sequence-specific information. This work was presented as part of the MS-Multi-Spine challenge, MICCAI 2025 [63].

Multi-sequence learning for multiple sclerosis lesion segmentation in spinal cord MRI

Participants: Ricky Walsh, Malo Gaubert, Cédric Meurée, Burhan Rashid Hussein, Anne Kerbrat, Benoit Combès, Francesca Galassi.

Automated tools to detect multiple sclerosis (MS) lesions in spinal cord MRI have so far mainly relied on single MR sequences processed by deep learning models. In this work, we were the first to investigate a multi-sequence learning approach for MS lesion segmentation in spinal cord MRI, and proposed a method to address key issues inherent to multi-sequence spinal cord data, including differing fields of view, inter-sequence misalignment, and missing sequences at training and inference time. To handle the missing-modality problem, we evaluated a simple strategy consisting in replacing missing latent features with the mean of the features computed from the available sequences. This approach led to improved segmentation performance even in the single-sequence inference setting, compared with models trained directly on that single sequence. Our experiments further provided insights into this seemingly counter-intuitive result, showing that both the encoder and decoder benefited from the variability introduced by the multi-sequence setting. This work was published in the proceedings of MICCAI 2024 and presented at the French Conference on Artificial Intelligence for Biomedical Imaging (IABM 2025) [90] and in collaboration with Romain Casey.

Evaluation of a deep learning segmentation tool to help detect spinal cord lesions from combined T2 and STIR acquisitions in people with multiple sclerosis

Participants: Baptiste Lodé, Burhan Rashid Hussein, Cédric Meurée, Ricky Walsh, Malo Gaubert, Francesca Galassi, Jean-Christophe Ferré, Gilles Edan, Benoit Combès, Anne Kerbrat.

In this work, we developed a deep learning tool to detect MS spinal cord lesions using combined sagittal T2-weighted and STIR acquisitions from the French MS registry imaging database (OFSEP), leveraging retrospective data acquired on a large variety of scanners (40 different systems). We then conducted a multi-reader retrospective study (December 2023 to June 2024) to assess whether the tool could improve clinical performance in lesion detection. Twenty clinicians (radiologists and neurologists) reviewed cervical and thoracic spinal cord MRI from 50 MS patients, with and without assistance from the tool, separated by a washout period. A reference standard was established by three experts using all available imaging information (including additional sequences such as axial acquisitions when available and follow-up scans). With tool assistance, clinicians achieved a significant increase in sensitivity (78% vs 73%, $p<0.001$), while precision did not significantly change on average. Importantly, performance and agreement varied widely across readers, highlighting both the difficulty of the task and the potential value of standardized assistance tools in clinical practice. This work was published in *European Radiology* [38].

Deep learning and multi-modal MRI for the segmentation of sub-acute and chronic stroke lesions

Participants: Alessandro Di Matteo, Youwan Mahé, Stéphanie S. Leplaideur, Isabelle Bonan, Elise Bannier, Francesca Galassi.

Stroke is a leading cause of morbidity and mortality worldwide. Accurate segmentation of post-stroke lesions on MRI is crucial to assess brain damage and inform rehabilitation, yet manual delineation is time-consuming and prone to error, motivating automated solutions. In this work, we investigated how deep learning and multimodal MRI can improve automated segmentation of sub-acute and chronic stroke lesions. A single-modality baseline was trained on the public ATLAS v2.0 dataset (655 T1-weighted scans) using the nnU-Net v2 framework and evaluated on an independent clinical cohort of 45 stroke patients with paired T1-weighted and FLAIR MRI. On this internal dataset, we conducted a systematic ablation study comparing (i) direct transfer of the ATLAS baseline, (ii) fine-tuning using T1-weighted images only, and (iii) fusion of T1-weighted and FLAIR inputs using early, mid, and late fusion strategies. Overall, incorporating FLAIR information improved lesion delineation compared to single-modality models, highlighting the benefit of multimodal learning to better capture lesion appearance variability across post-stroke stages. This work was published in *Pattern Recognition Letters* [23] and presented at the French Conference on Artificial Intelligence for Biomedical Imaging (IABM 2025) [56].

Stroke lesion segmentation in clinical workflows: a modular, lightweight, and deployment-ready tool

Participants: Florent Leray, Youwan Mahé, Stéphanie Leplaideur, Francesca Galassi.

Deep learning frameworks such as nnU-Net achieve state-of-the-art performance for post-stroke lesion segmentation, but clinical deployment remains challenging due to heavy dependencies and monolithic pipelines. In this work, we introduce *StrokeSeg*, a modular and lightweight framework that translates research-grade nnU-Net stroke lesion segmentation models into deployable tools for clinical research workflows. The pipeline is refactored into three independent stages: (i) preprocessing based on the Anima toolbox with BIDS-compliant outputs, (ii) inference using ONNX Runtime with Float16 quantisation, reducing model size by approximately 50%, and (iii) postprocessing producing probability maps and binary masks with configurable thresholding and optional MNI-space outputs. *StrokeSeg* provides both graphical and

command-line interfaces and is distributed as Python scripts and as a standalone Windows executable, enabling execution on typical clinical workstations without manual environment configuration. On a held-out set of 300 sub-acute and chronic stroke subjects, the ONNX implementation achieved numerical equivalence with the original PyTorch pipeline, demonstrating that high-performing segmentation pipelines can be transformed into portable, clinically usable tools without compromising accuracy. This work has been submitted to the ISBI 2026 conference and accepted at IABM 2026 [70].

Unsupervised Detection of Post-Stroke Brain Abnormalities

Participants: Youwan Mahé, Elise Bannier, Stéphanie Leplaideur, Francesca Galassi.

Post-stroke MRI not only delineates focal lesions but also reveals secondary structural changes, such as atrophy and ventricular enlargement. These abnormalities, increasingly recognised as imaging biomarkers of recovery and outcome, remain poorly captured by supervised segmentation methods. We evaluated REFLECT, a flow-based generative model, for unsupervised detection of both focal and non-lesional abnormalities in post-stroke patients. Using dual-expert central-slice annotations on ATLAS data, performance was assessed at the object level with Free-Response ROC analysis for anomaly maps. Two models were trained on lesion-free slices from stroke patients (ATLAS) and on healthy controls (IXI) to test the effect of training data. On ATLAS test subjects, the IXI-trained model achieved higher lesion segmentation (Dice = 0.37 vs 0.27) and improved sensitivity to non-lesional abnormalities (FROC = 0.62 vs 0.43). Training on fully healthy anatomy improved the modelling of normal variability, enabling broader and more reliable detection of structural abnormalities. This work is available as a preprint on HAL [72]. We also released a systematic scoping review synthesizing recent advances in unsupervised deep generative models for anomaly detection in neuroimaging. The review maps the methodological landscape (model families, training strategies, evaluation protocols, and datasets) and discusses common limitations affecting comparability and clinical translation, including heterogeneous ground truths, inconsistent metrics, and sensitivity to acquisition and preprocessing variability. This work is available as a preprint on HAL [71]. This work was done in collaboration with Elisa Fromont (MALT team).

Integrating Functional and Structural Brain Connectomes: a novel multilayer graphs framework for Alzheimer's disease classification

Participants: Carlo Ferritto, Julie Coloigner.

Multilayer graphs are an emerging tool in connectomics and graph theory, offering a powerful framework to integrate and analyze multiple data modalities. By representing each modality as a separate layer with interconnecting edges, Multilayer graphs capture complex relationships that are often missed in classical unimodal graph analyses. This ability to combine complementary information is particularly valuable in clinical neuroscience, where both functional and structural connectivity provide distinct but related insights into pathophysiology. In this project, we evaluated a novel Multilayer graphs framework to integrate functional MRI and diffusion MRI data for the classification of patients with Alzheimer's disease, mild cognitive impairment, and healthy controls using the Alzheimer's Disease Neuroimaging Initiative database. The novelty of our approach lies in assigning distinct weights to structural and functional layers, optimizing their respective contributions to classification. Results show that our Multilayer graphs framework improves classification accuracy while uncovering key brain regions and subnetworks. This work underscores the potential of multilayer graphs to provide a more comprehensive understanding of how Alzheimer's disease alters brain connectivity, and to enhance the detection of neurodegenerative disorders [44, 53, 54]. This work was done in collaboration with Pierre-Yves Jonin, CHU Rennes and Giulia Lioi, researcher, IMT, Brest.

8.1.3 Quantitative imaging

Quantitative imaging methods can provide access to imaging metrics which can help characterize tissue integrity or neural activity. These methods can be used to assess tissue impairment, lesion severity and follow

disease evolution.

Optimization of Acquisition Schemes Towards a Better Estimation of Microstructure Parameters in Multidimensional Diffusion MRI

Participants: Constance Bocquillon, Isabelle Corouge, Emmanuel Caruyer.

Unlike traditional measurements by diffusion tensor imaging, multidimensional diffusion MRI allows the estimation of additional microstructural parameters such as anisotropy, kurtosis and orientation dispersion. To properly take advantage of this imaging modality and capturing microstructure parameters accurately and efficiently, it is crucial to use a dedicated acquisition scheme. Several models and acquisition representations can be used towards this goal. In this work, we focused on the q-space trajectory imaging, using b-tensor acquisition encoding and the diffusion tensor distribution (DTD) modeling. More specifically, our goal is to develop a framework for the optimization of acquisition scheme based on their ability to properly estimate microstructural parameters of interest. We generated an extensive collection of b-tensor shapes with a fixed number of directions each, from which we efficiently selected an optimized acquisition scheme. In the spirit of fingerprinting, we proposed a dictionary-based approach. The dictionary columns were carefully adapted to the achievable resolution in the parameter space, the parameters of interest being the microscopic anisotropy, the tensor size variance and the orientation parameter. To solve the combinatorial optimization problem of selecting the best subset of b-tensor shapes, we implemented two approximation algorithms: a greedy approach based and a permutation strategy. To assess the performance of our optimization procedure, we computed the estimation error for each parameter. The signal generated from our scheme yielded lower or comparable errors to those of a reference scheme proposed in the literature and designed for this purpose [43]. This work was presented at an international workshop on diffusion MRI [75] and resulted in two oral presentations, one at national level [48] and the other at international level [75].

Repeatability of T1 measurements from MP2RAGE in MS lesions of the brain and cervical spinal cord

Participants: Nolwenn Jégou, Malo Gaubert, Elise Bannier, Anne Kerbrat, Benoit Combès.

MP2RAGE is a fast T1 quantitative MRI sequence offering simultaneous imaging of the brain and cervical spinal cord in 8 minutes. It enables visualization of multiple sclerosis lesions and evaluation of the evolution of microstructural tissue damage, while remaining clinically compatible. This study investigates the variability (scan-rescan) of extracted T1 measurement in brain and cervical spinal cord lesions. [80, 81]

A Riemannian framework for incorporating white matter bundle priors in ODF-based tractography algorithms.

Participants: Julie Coloigner, Emmanuel Caruyer.

Diffusion magnetic resonance imaging (dMRI) tractography is a powerful approach to study brain structural connectivity. However, its reliability in a clinical context is still highly debated. Recent studies have shown that most classical algorithms achieve to recover the majority of the existing true bundles. However, the generated tractograms contain many invalid bundles. This is due to the crossing fibers and bottleneck problems which increase the number of false positives fibers. In this work, we proposed to overpass this limitation with a novel method to guide the algorithms in those challenging regions with prior knowledge of the anatomy. We developed a method of creating and combination of anatomical prior applicable to any orientation distribution function (ODF)-based tractography algorithms. The proposed method captures the track orientation distribution (TOD) from an atlas of segmented fiber bundles and incorporates it during the tracking process, using a Riemannian framework. We tested the prior incorporation method on two

ODF-based state-of-the-art algorithms, iFOD2 and Trekker PTT, on the diffusion-simulated connectivity (DiSCo) dataset and on the Human Connectome project (HCP) data. We showed that our method improves the overall spatial coverage and connectivity of a tractogram on the two datasets, especially in crossing fiber regions. Moreover, the fiber reconstruction may be improved on clinical data, informed by prior extracted on high quality data, and therefore could help in the study of brain anatomy and function [24].

Quantitative susceptibility mapping (QSM) in the cervical spinal cord at 3T

Participants: Benjamin Streichenberger, Quentin Duché, Anne Kerbrat, Elise Bannier.

Quantitative susceptibility mapping (QSM) is a powerful MRI technique that links phase variations to tissue magnetic susceptibility, providing insights into microstructural composition and chronic inflammation. In multiple sclerosis (MS), QSM has shown strong potential for characterizing brain lesions and for assessing chronic inflammation in white matter (WM). Extending QSM to the spinal cord (SC) is essential, as SC lesions are common in MS and strongly influence clinical outcomes.

In 2025, we developed a high-resolution axial protocol for the C3–C5 cervical SC, acquiring two sequences, in-phase (IP) and out-of-phase (OOP), and combining the echoes to estimate the local magnetic field for QSM reconstruction. Imaging the SC remains challenging due to its small size, curvature, and physiological motion, but our approach successfully addressed these issues, providing clear, reliable maps. The high-resolution axial QSM maps clearly delineate gray matter (GM), WM, and lesions in both healthy controls (HC) and MS patients. Initial analyses compared two processing methods: one with water–fat separation (FWS) and one without. Interestingly, the inclusion of fat correction did not substantially improve QSM map quality, indicating that sufficient echo sampling (24 echoes total across IP and OOP sequences) is more critical for accurate field estimation and microstructural contrast. QSM values obtained in the SC were substantially lower than typical brain values, reflecting the SC's distinct tissue composition and lower iron content.

In HC, QSM maps demonstrated excellent delineation of GM and WM, confirming the robustness of high-resolution SC QSM and representing a major technical advance in the field. In MS patients, lesions were identified and classified into three susceptibility types: hypointense, isointense, and hyperintense, suggesting that SC QSM may reveal lesion heterogeneity.

These findings highlight the feasibility and utility of high-resolution SC QSM for studying both healthy and pathological tissue, providing a foundation for future studies on SC microstructure and MS lesion characterization.

Improved Riemannian FOD averaging for fiber bundle priors incorporation in FOD-based tractography algorithms

Participants: Grégoire Ville, Emmanuel Caruyer, Julie Coloigner.

The sensitivity-specificity ratio of tractography can be improved by guiding the algorithms with prior information from anatomy. Previously in our team, an approach was proposed in this direction for Orientation Distribution Function (ODF)-based tractography, where priors are estimated from templates of streamlines and take the form of Track Orientation Distributions. These priors are incorporated voxel wise to ODF thanks to a weighted averaging following a Riemannian framework. In this work, we improved the way to perform this averaging, and generalized it to Fiber Orientation Distributions (FOD) thanks to a normalization step, making the pipeline suitable for FOD-based tractography. Using Human Connectome Project (HCP) data with pre-segmented fiber bundles, we assessed the validity of our contributions both in terms of FOD and tractograms. We notably found, as expected, a better coverage of ground-truth fiber bundles by streamlines [62]

Multi-compartment tractometry approach for white matter neuroinflammation investigation in late-life depression

Participants: Nathan Decaux, Gabriel Robert, Julie Coloigner.

This study uses an advanced tractometry approach to investigate the neurobiological underpinnings of late-life depression (LLD), identifying specific white matter alterations that may serve as novel biomarkers. By employing a multi-compartment model and a refined method to project the associated metrics, this work provides a more realistic understanding of white matter integrity and inflammation in LLD [51].

Quantification by T2 MRI - From plants to the brain

Participants: Benjamin Prigent, Julie Coloigner, Elise Bannier.

T2 relaxometry is the main method used to quantify the myelin fraction in the brain. The most commonly used sequence is CPMG or multi-echo spin echo. However, this sequence can be negatively impacted by stimulated echoes. We propose an exploration of the myelin fraction using T2 relaxometry, with a modified CPMG sequence initially developed for the study of short T2 components in plants. The modified sequence allows an unlimited number of echoes to be collected through the use of non-selective refocusing pulses, also controlling the intensity of the crushers. Alltogether these changes reduce the effect of stimulated echoes. [88]

This project was carried out in collaboration with Marc Lapert (Siemens Healthineers SAS, Courbevoie, France), Erick Jorge Canales-Rodríguez Lausanne (University Hospital (CHUV) | Center for Biomedical Imaging (CIBM), Switzerland), Guylaine Collewet and Maja Musse (UR OPAALE, INRAE, Rennes, France)

Food addiction severity is associated with decreased functional connectivity and responses to palatable food pictures in brain areas involved in emotion and cognitive control

Participants: Elise Bannier, Yann Serrand.

Patients with obesity frequently report impulsivity or loss control of food intake, reflecting the dysfunction of brain regions involved in reward and cognitive control processing related to food addiction (FA). Functional magnetic resonance imaging (fMRI) may help to identify the cognitive processes underlying FA. In patients with obesity, we aimed at identifying (i) fMRI specific responses in brain regions involved in hedonic and motivational processes (striatum), and cognitive control (e.g. prefrontal cortex) according to FA severity; (ii) whether FA severity is related to anxiety and/or depression symptoms. Our results show that brain profiles of patients with obesity are related to FA severity. FA severity is associated with impaired cortico-striatal functional connectivity between brain regions involved in motivation, decision-making and inhibitory control. Interindividual variability in brain responses suggests that dedicated therapeutic strategies might be helpful for obese patients with FA.[18]. This work is lead by collaborators at Inrae, e.g. David Val-Laillet and Nicolas Coquery.

8.2 Translational research

Our goal is also to provide new computational solutions for our target clinical applications (Alzheimer's disease, psychiatry, neurology or public health issues), allowing a more appropriate representation of the data for image analysis and detection of specific biomarkers. In this section, we present the contributions of the last year in the clinical applications of behavior and neuro-inflammation.

8.2.1 Behavior

Multimodal Graph Convolutional Network on Brain Structure and Function in Adolescent Anxiety and Depression

Participants: Sébastien Dam, Jean-Marie Batail, Pierre Maurel, Julie Coloigner.

Multimodal analysis of Magnetic Resonance Imaging (MRI) data enables leveraging complementary information across multiple imaging modalities that may be incomplete when using a single modality. For brain connectivity analysis, graph-based methods, such as graph signal processing, are effective for capturing topological characteristics of the brain structure while incorporating neural activity signals. However, for tasks like group classification, these methods often rely on traditional machine learning algorithms, which may not fully exploit the underlying graph topology. Recently, Graph Convolutional Networks (GCN) have emerged as a powerful tool in brain connectivity research, uncovering complex nonlinear relationships within the data. In [19, 50], we develop a multimodal GCN model to jointly model brain structure and function to classify anxiety and depression in adolescents using the Boston Adolescent Neuroimaging of Depression and Anxiety dataset. The graph's topology is initialized from structural connectivity derived from diffusion MRI, while functional connectivity is incorporated as node features to improve distinction between anxious, depressed patients and healthy controls. Interpretation of key brain regions contributing to classification is enabled through Gradient-weighted Class Activation Mapping, revealing the influence of the frontal and limbic lobes in the diagnosis of the conditions, which aligns with previous findings in the literature. By comparing classification results and the most discriminative features between multimodal and unimodal GCN-based approaches, we demonstrate that our framework improves accuracy in most classification tasks and reveals significant patterns of brain alterations associated with anxiety and depression.

Graph Slepian Framework for Guided Filtering with Application to Neuroimaging

Participants: Sébastien Dam, Julie Coloigner.

Graph signal processing (GSP) has enabled new approaches for jointly analyzing graphs and graph signals. Various classical operations, such as the Fourier transform and filtering, have been extended to this setting, along with more advanced constructs including Slepian functions. The latter provides a basis for bandlimited graph signals that are maximally concentrated in a given subgraph. Here, we propose a novel approach that introduces complex values to encode several subgraphs, enabling a richer analysis of how graph signals are expressed. The motivating application from neuroscience is to jointly analyze brain graphs obtained from diffusion-weighted magnetic resonance imaging (MRI), with brain graph signals from functional MRI. The brain activity measured by the latter is constrained by the underlying brain graph. Complex-valued graph Slepians constructed with prior knowledge from well-known task-positive and - negative functional networks can then reflect how activity is dynamically reorganizing. The feasibility of the approach is demonstrated using synthetic data first, and then applied to data from the Human Connectome Project, revealing patterns of brain network interactions. Results are currently limited to two subgraphs, but future work will explore more extensive graph configurations. Conclusion: Slepian functions offer new ways to decode graph signals lying on top of a graph structure. Significance: This confirms that the proposed method provides a new representation for studying brain activity constrained by the brain's structural connectivity [20].

8.2.2 Neuro-inflammation

Limited added value of systematic spinal cord MRI vs brain MRI alone to classify patients with MS as active or inactive during follow-up

Participants: Malo Gaubert, Elise Bannier, Jean-Christophe Ferré, Benoit Combès, Anne Kerbrat.

The utility of systematic spinal cord (SC) MRI for monitoring disease activity after a multiple sclerosis (MS) diagnosis remains a topic of debate. Objectives: To evaluate the frequency of disease activity when considering brain MRI alone versus both brain and SC MRI and to identify factors associated with the occurrence of new SC lesions. Methods: We conducted a retrospective analysis of clinical and imaging data prospectively collected over 5 years as part of the EMISEP cohort study. A total of 221 intervals (with both brain and spinal cord MRI scans available at 2 consecutive time-points) from 68 patients were analysed. For each interval, brain (3D Fluid-Attenuated Inversion Recovery (FLAIR, axial T2 and axial PD) and SC MRI (sagittal T2 and phase-sensitive inversion recovery, axial T2*w and 3D T1) were reviewed to detect new lesions. Each interval was classified as symptomatic (with relapse) or asymptomatic. The baseline brain and SC lesion numbers were computed. Results: SC MRI activity without clinical relapse and/or brain MRI activity was rare (4 out of 221 intervals, 2%). The occurrence of a new SC lesion was associated with the number of brain lesions at baseline (OR = 1.002 [1.000; 1.0004], p = 0.015) and the occurrence of a new brain lesion during the interval (OR = 1.170 [1.041; 1.314], p = 0.009), but not with the baseline SC lesion number (p = 0.6). Conclusion: These findings support the current guidelines recommending routine disease monitoring with brain MRI alone, even in patients with a high SC lesion load. [33].

Association between structural lesions in the cerebral and pan-medullary motor pathways in people with MS and motor deficits in the lower and upper limbs

Participants: Mathilde Liffran, Malo Gaubert, Elise Bannier, Jean-Christophe Ferré, Benoit Combès, Anne Kerbrat.

Motor impairments are common in people with multiple sclerosis (pwMS), reflecting substantial involvement of the corticospinal tract (CST). However, the extent of motor symptoms varies across patients: some exhibit a pyramidal reflex syndrome without motor deficits, others have motor deficits limited to the lower limbs, while some are affected in both upper and lower limbs. In this study, we hypothesize that CST lesions are more extensive and severe in pwMS with motor impairments in both upper and lower limbs. To test this, we compared three groups of patients: those with a pyramidal syndrome but no motor deficits (Group A), those with motor deficits limited to the lower limbs (Group B), and those with deficits in both the upper and lower limbs (Group C). We included 100 pwMS in a prospective cross-sectional study. Patients were assigned to groups A, B, or C based on their ASIA motor score by limb. CST lesions (LV) were segmented on 3D FLAIR (brain) and axial T2* and T2-weighted images (cervical and thoracic spinal cord (SC)). Quantitative T1 (qT1), calculated from the MP2RAGE sequence, was used to assess lesion severity in the brain and cervical SC. Cortical thickness of the primary motor area and spinal cord cross-sectional area (CSA) were calculated from the brain 3DT1 sequence. Ninety-two pwMS were included in the analysis (A=38, B=31, C=23). No patients in the study had motor disorders limited to the upper limbs. Thus, an upper limb motor deficit was always associated with a lower limb deficit, more pronounced in group C compared to group B. LV was higher in groups B and C than in group A in the brainstem and cervical CST (all p<.001). qT1 was higher only in the cervical CST (all p<.05). LV and qT1 were not significantly different between groups B and C in any CST segment. No significant differences were found between groups for cortical thickness and CSA. In multivariate analysis (LASSO), age, disease duration, LV in the brainstem, and qT1 in the cervical SC distinguished group A from groups B and C. No differentiating factors were identified between groups B and C. Motor deficits were associated with the volume and severity of lesions in the brainstem and cervical CST, highlighting the importance of preventing lesion accumulation to avoid motor disability. Our study suggests that once a certain degree of CST damage is reached, lower limb deficits appear, followed by upper limb motor deficit, with no evidence of further accumulation of focal lesions.

Microstructural Damage and Repair in the Spinal Cord of Patients With Early Multiple Sclerosis and Association With Disability at 5 Years.

Participants: Malo Gaubert, Benoit Combès, Elise Bannier, Masson Arthur, Vivien Caron, Gaëlle Baudron, Jean-Christophe Ferré, Gilles Edan, Anne Kerbrat.

The dynamics of microstructural spinal cord (SC) damage and repair in people with multiple sclerosis (pwMS) and their clinical relevance have yet to be explored. In this projet, we set out to describe patient-specific profiles of microstructural SC damage and change during the first year after MS diagnosis and to investigate their associations with disability and SC atrophy at 5 years. We performed a longitudinal monocentric cohort study among patients with relapsing-remitting MS: first relapse <1 year, no relapse <1 month, and high initial severity on MRI (>9 T2 lesions on brain MRI and/or initial myelitis). pwMS and age-matched healthy controls (HCs) underwent cervical SC magnetization transfer (MT) imaging at baseline and at 1 year for pwMS. Based on HC data, SC MT ratio z-score maps were computed for each person with MS. An index of microstructural damage was calculated as the proportion of voxels classified as normal at baseline and identified as damaged after 1 year. Similarly, an index of repair was also calculated (voxels classified as damaged at baseline and as normal after 1 year). Linear models including these indices and disability or SC cross-sectional area (CSA) change between baseline and 5 years were implemented. Thirty-seven patients and 19 HCs were included. We observed considerable variability in the extent of microstructural SC damage at baseline (0%-58% of SC voxels). We also observed considerable variability in damage and repair indices over 1 year (0%-31% and 0%-20%), with 18 patients showing predominance of damage and 18 predominance of repair. The index of microstructural damage was associated positively with the Expanded Disability Status Scale score ($r = 0.504$, $p = 0.002$) and negatively with CSA change ($r = -0.416$, $p = 0.02$) at 5 years, independent of baseline SC lesion volume. People with early relapsing-remitting MS exhibited heterogeneous profiles of microstructural SC damage and repair. Progression of microstructural damage was associated with disability progression and SC atrophy 5 years later. These results indicate a potential for microstructural repair in the SC to prevent disability progression in pwMS [27]. This work was done in collaboration with Laure Michel, Emmanuelle Lepage, Bruno Stankoff and Benedetta Bodini.

Severity of brain and spinal motor tract lesions in multiple sclerosis using quantitative MRI imaging.

Participants: Malo Gaubert, Alice Dufey, Elise Bannier, Mathilde Liffran, Benoit Combès, Anne Kerbrat.

Motor deficits in people with MS (pwMS) are often asymmetrical, suggesting an important role of focal lesions affecting the corresponding motor pathways. However, the relationship between lesion load and physical disability remains modest. One hypothesis could be that only heavily demyelinated lesions along the cortico-spinal tracts (CST) would be associated with functional consequences. To test this hypothesis, we reconstructed the whole CST from the cortex to the bottom of the spinal cord (SC) and linked its structural damage with its functional consequences by limb as measured clinically (with the American Spinal Injury Association [ASIA] motor score) and electrophysiologically (with the central motor conduction time [CMCT]). We prospectively included 60 relapsing remitting pwMS (having at least one clinical sign of CST damage) and 33 healthy controls. The CST were reconstructed using probabilistic atlases. Lesion volume fraction and myelin content (approximate through magnetization transfer ratio [MTR] and MP2RAGE quantitative T1 [qT1]) were computed by side on the different portions of the CST. Voxelwise MTR z-score maps were computed to detect lesions severely demyelinated (z-score<-1.96 standard deviation) along the whole CST. The analyses included 46 pwMS and 28HC. Forty-five out of 46 pwMS had at least one CST lesion. In the upper limb, CMCT was associated with both cervical lesion load ($p<.001$) and cervical MTR ($p=.02$). In the lower limb, CMCT was associated with cervical lesion load, brain and thoracic MTR (all $p<.002$). No association was found with the ASIA motor score per limb. Twenty six percent of the lesions were classified as severe, preferentially in the cervical CST. In patients with at least one severe lesion,

extra-lesional MTR along the CST was lower than in those without severe lesions (p=.004 and p<.001 for the brain and SC portions, resp.). The presence of a severe lesion in the SC CST was the only explanatory variable associated with an increased risk of having an abnormal CMCT in lower limbs (OR (95%CI): 1.74 (1.4-2.2), p<.001). Main results were replicated with qT1. In this study, we describe different levels of myelin content in lesions along the CST with an association between the severity of the lesions and extra-lesional damage, as well as between the severity of the lesions and the CMCT measurement. These findings suggest an important role of severe lesions along the CST, particularly at the cervical level, beyond simply the lesion load [79], [55]. This work was done in collaboration with Sarah Demortière, Raphaël Chouteau, Laure Michel, Emmanuelle Le Page, Virginie Callot and Bertrand Audoin

8.2.3 Recovery

EEG-fMRI neurofeedback versus motor imagery after stroke, a randomized controlled trial

Participants: Quentin Duché, Elise Bannier, Pierre Maurel, Isabelle Bonan.

Neurofeedback (NF), an advanced technique enabling self-regulation of brain activity, was used to enhance upper limb motor recovery in chronic stroke survivors. A comparison was conducted between the efficacy of NF versus motor imagery (MI) training without feedback. We hypothesized that employing a bimodal EEG-fMRI based NF training approach would ensure precise targeting, and incorporating progressive multi-target feedback would provide a more effective mean to enhance plasticity. Thirty stroke survivors, exhibiting partial upper-limb motor impairment with a Fugl-Meyer Assessment Upper Extremity score (FMA-UE) > 21 and partially functional corticospinal tract (CST) were randomly allocated to the NF and MI groups. The NF group (n=15) underwent a bimodal EEG-fMRI NF training focused on regulating activity in ipsilesional motor areas (M1 and SMA), while the MI group (n=15) engaged in MI training. Demographic and stroke clinical data were collected. The primary outcome measure was the post-intervention FMA-UE score. Change in bold activations in target regions, EEG and fMRI laterality index (LI) and fractional anisotropy (FA) asymmetry of the CST were assessed after the intervention in both groups (respectively ΔEEG LI, ΔMRI LI and ΔFA asymmetry) and correlated with FMA-UE improvement (ΔFMA). Participants from both groups completed the 5-week training, with the NF group successfully modulating their brain activity in target regions. FMA-UE improvement post-intervention tended to be higher in the NF group than in the MI group (p=0.048), and FMA-UE increased significantly only in the NF group (p=0.003 vs p=0.633 for MI). This improvement persisted at one-month in the NF group (p=0.029). Eight out 15 patients in the NF group positively responded (i.e., improved by at least for 4 points in FMA-UE) compared to 3 out 15 in the MI group. No significant between-group differences were found in the evolution of ipsilesional M1 (t=1.43, p=0.16) and SMA (t=0.85, p=0.40) activation maps. The NF group exhibited a more pronounced lateralisation in unimodal EEG LI (t=-3.56, p=0.0004) compared to the MI group, but no significant difference was observed for MRI LI. A non-significant difference in ΔFA asymmetry of the CST between the two groups was found (t = 25; p = 0,055). A non-significant correlation between unimodal ΔEEG LI and ΔFMA (r=0.5; p=0.058) was observed for the NF group. Chronic stroke survivors can effectively engage themselves in a NF task and can benefit from a bimodal EEG-fMRI NF training. This demonstrates potential for NF in enhancing upper-limb motor recovery more efficiently than MI training [17]. This work was done in collaboration with Simon Butet, Mathis Fleury, Giulia Lioi, Lou Scotto Di Covella, Emilie Lévêque-Le Bars and Anatole Lécuyer.

Evaluating the effects of multimodal EEG-fNIRS neurofeedback for motor imagery: An experimental platform and study protocol

Participants: Camille Muller, Elise Bannier, Isabelle Corouge, Pierre Maurel.

Neurofeedback (NF) enables the self-regulation of brain activity through real-time feedback extracted from brain measures. Recently, the combination of several neuroimaging methods to characterize brain

activity has led to growing interest in NF. The integration of various portable recording techniques, such as electroencephalography (EEG) and functional near-infrared spectroscopy (fNIRS), respectively based on electrical and hemodynamic activity, could enhance the characterization of brain responses and subsequently improve NF performance. Such multimodal NF used with motor imagery (MI) could benefit post-stroke motor rehabilitation to stimulate neuroplasticity of the lesioned motor areas. Nevertheless, their concomitant use in NF to identify brain activity features during upper-limb MI-based NF has not been studied to our knowledge. The objective of this paper is to present our fully operational experimental platform and the study protocol we propose to assess the benefits of combining EEG and fNIRS for NF in the context of MI [40, 87]. This work is in collaboration with Thomas Prampart (Seamless team).

Evaluating SynthSeg's Pediatric Brain Segmentations: Longitudinal Volume Assessments, Preprocessing Effects, and Guidelines for Improved Accuracy

Participants: Fanny Dégeilh.

Accurate pediatric brain segmentation is challenging due to rapid growth, changing tissue contrast, and motion artifacts. Longitudinal data reveals both population-wide and individual-specific developmental trajectories that single timepoints might miss. SynthSeg, a deep-learning-based automated segmentation tool, has shown potential in adults but lacks clear pediatric guidelines. This study (1) evaluates SynthSeg's performance across 33 brain regions in two longitudinal pediatric cohorts, and (2) compares segmentations generated with and without common preprocessing steps (N4 bias correction, skull stripping) to inform best practices for pediatric brain segmentation. We analyzed data from two longitudinal pediatric cohorts spanning ages 0–7 (the Baby Connectome Project [BCP], 0–5 years; and the Calgary Preschool [CP] dataset, 2–7 years). After rigorous quality control (QC) to exclude excessive noise or motion, each scan was processed using either (1) N4 bias correction (via ANTs) plus skull stripping (via SynthStrip) or (2) direct input into SynthSeg, in line with SynthSeg's recommendation that no external preprocessing is strictly required. SynthSeg produced automated segmentations for 33 brain regions. Population-level growth trends will be modeled for each region as volume versus age using generalized additive models (GAM), and these slopes will be compared against individual-specific trajectories derived from repeated measurements. By capturing both inter- and intra-individual variability, this approach will reveal whether a specific child follows population developmental patterns or exhibits unique trajectories. SynthSeg's built-in QC metrics will also be examined alongside volumetric outcomes to assess how age and preprocessing approaches jointly influence segmentation accuracy. This analysis will ultimately help identify which pipeline (with or without preprocessing) yields the most robust depiction of pediatric brain development. Both preprocessing pipelines have produced segmentations for 903 T1-weighted scans in the BCP dataset (363 participants) and 276 T1-weighted scans in the CP dataset (96 participants). Preliminary checks indicate lower segmentation performance in children under 2, which could be problematic given how very early timepoints may alter long-term volumetric trends. We are currently comparing GAM-derived population slopes against individual slopes in each dataset to evaluate how preprocessing strategies and age affect segmentation outcomes. Interactive plots display volume–age relationships for each region and pipeline, using QC metrics as colorbars for a multidimensional view. Once regional comparisons and statistical models will be finalized, we will integrate QC measures with volumetric findings to pinpoint each pipeline's strengths and weaknesses. If data from the HEALthy Brain and Child Development (HBCD) Study becomes available, the same analytic framework will be extended to that cohort. Comparing SynthSeg's performance under different preprocessing protocols in a diverse pediatric sample will help establish evidence-based guidelines for more accurate and reliable pediatric segmentations. Our longitudinal design emphasizes both population-level and individual developmental trajectories, underscoring how an early childhood timepoint may affect volumetric interpretations. [78]. In collaboration with Andjela Dimitrijevic and Benjamin De Leener from NeuroPoly, Polytechnic Montreal, Canada.

Leveraging Log Jacobian Maps to Capture Intra- and Inter-Individual Variability in Pediatric Brain Morphological Changes

Participants: Fanny Dégeilh.

Understanding how the brain changes during development is essential to identifying both typical and atypical neurodevelopment. One key challenge in this field is distinguishing between intra-individual variability (changes occurring within the same person over time) and inter-individual variability (differences between individuals). This distinction is particularly important when studying pediatric brain development, where the magnitude of inter-individual differences can overshadow the more subtle intra-individual changes. Our study investigates whether log Jacobian maps derived from brain deformation fields can encode both intra- and inter-individual variability using longitudinal pediatric MRI data. We analyzed T1-weighted MRI scans (N = 279 images) of 96 children (46 females) aged 2 to 7 years from the Calgary Preschool Dataset, generating 434 intra-individual pairs (comparing scans of the same child at two different ages) and 433 inter-individual pairs (matching children by initial age, age interval, and sex). These images were registered using the Elastic SyN ANTs algorithm to compute log Jacobian maps, which represent local volume changes in the brain, ranging from -1 (contraction) to 1 (expansion). The log Jacobian maps were used to train a 3D convolutional neural network to classify intra- versus inter-individual changes. Two experimental scenarios were explored: one allowing overlap between the training and test sets for the same subjects, and another with no overlap. We used 10-fold cross-validation to evaluate both scenarios, finding that the no-overlap scenario yielded slightly higher accuracy and F1 scores. The highest accuracy (0.989) was achieved when inter-individual pairs were matched not only by age but also by sex. The log Jacobian values showed that intra-individual pairs had a broader distribution of local volume changes compared to inter-individual pairs, indicating more pronounced brain morphology shifts within individuals. This finding aligns with the expectation that inter-individual comparisons, involving different subjects, would capture more global deformations rather than localized changes. Our results demonstrate that log Jacobian maps can effectively differentiate between intra- and inter-individual variability in pediatric brain development. This approach has the potential to contribute to modeling typical neurodevelopmental trajectories and detecting deviations that could signal pathology. [77]. In collaboration with Andjela Dimitrijevic and Benjamin De Leener from NeuroPoly, Polytechnic Montreal, Canada.

The Impact Of Pediatric Concussion On Cerebellum Neurodevelopment. World Congress on Brain Injury

Participants: Valentine Chouquet, Fanny Dégeilh.

INTRODUCTION. The cerebellum follows a protracted development, continuing across childhood and adolescence. A recent study on functional connectivity in 150 children aged 8-18 years with a concussion revealed altered interhemispheric connectivity between the right supplementary motor area and the left cerebellum, reflecting "cortico-cerebellar uncoupling"(van der Horn et al., 2024). However, little is known about structural development of the cerebellum following a pediatric concussion. This study aimed at characterizing cerebellum structural development in young adolescents with a history of childhood concussion from the large population-based Adolescent Brain Cognitive Development (ABCD). Study (Casey et al., 2018). METHODS: The following baseline, 2-years and 4 years follow-up data from the ABCD 5.1 (Garavan et al., 2018) curated data release were used: 1) The Parent Ohio State TBI Screen-Short Modified Report (Bogner et al., 2017) to retrospectively identify children with no-TBI (n = 9,430 ; baseline mean age = 9.9 years; 4,721 females) and those with a concussion (i.e., head-neck injury with loss of consciousness $\leq 30min$ or memory loss; n = 319; baseline mean age = 9.9 years; 133 females), and 2) right and left cerebellum grey matter (GM) and white matter (WM) volumes computed on T1-weighted images by the ABCD group. Scanner effects were controlled for using longitudinal-ComBat (Beer et al., 2020). Mixed effects models (Mirman, 2017) were constructed with lmerTest 3.1.3 package in R (2023.12.1) to explore group differences at baseline and on the rate of change between ages 10 to 14 years. Sex and parental education were included as covariates. RESULTS: There was no group effect on the developmental trajectories of the 4 cerebellar

volumes. Compared to non-injured peers, children with concussion showed similar intercept (all $p > 0.3$) and slope (all $p > 0.24$) with a significant increase of WM volumes (Estimates [p-value]; Right = 13.3 mm^3 [$4.74e-05$]; Left = 12 mm^3 [$5.74e-05$]) and no significant change in GM volumes (Estimates [p-value]; Right = 5 mm^3 [0.3]; Left = 3.1 mm^3 [0.4]). There was a significant effect of sex and education on both intercept and slope for the 4 metrics (all $p < 0.02$). Girls showed lower WM and GM volumes than boys at baseline and slower increase over time (all $p < 2e-16$). Higher level of education was associated with larger WM and GM volumes at baseline (all $p < 2e-16$) and faster increase over time. CONCLUSION: This study suggests that the structural development of the cerebellum between ages 10 to 14 years follows similar trajectory in young adolescents with and without concussion. However, cerebellum development was dependent on sex and parental education. Further explorations, notably on the group*sex interaction and on brain connectivity using diffusion MRI, will be conducted to fully understand these findings [76].

Inflammatory and MRI perfusion biomarkers in predicting persistence of depression: a 6-month Longitudinal Study

Participants: Jean-Marie Batail, Isabelle Corouge, Gabriel Robert.

Systemic inflammation has been linked with major depressive episode (MDE) severity and treatment-resistant depression (TRD), but not for all patients. Brain mechanisms underlying these processes are still under investigation. Objectives: based on an integrative approach, we aimed at identifying clinical, inflammatory and perfusion markers predictive of depression outcome at 6 months. We conducted a longitudinal study including 60 patients diagnosed with MDE, focusing on anxiety and anhedonia as main clinical candidates, inflammation (C-Reactive Protein - CRP) and cerebral blood flow (CBF) using pseudo-continuous arterial spin labeling (pcASL) MRI. A bootstrapped elastic net regression analysis was conducted including clinical, CBF and inflammation as predictors with depressive severity at 6 months as the dependent variable. Our findings exhibited positive association of depression outcome with baseline depression intensity, duration of current episode, CRP, right accumbens, as well as left and right orbito-frontal CBF. Negative predictors were age, disease duration, right and left caudate nuclei, left amygdala, left mid frontal gyrus, and right ventromedial prefrontal cortex CBF. Neither anxiety nor anhedonia were significant predictors. Combining clinical, inflammation and brain imaging outperformed other models in diagnosing depression severity change over time, highlighting the interest of integrative approaches. These results suggested that systemic inflammation and cerebral perfusion abnormalities in key regions involved in emotion, reward processing and decision making, may serve as biomarkers for identifying patients at risk for persistence of depression [15]. This work was done in collaboration with T. Blanchard, Jean-Charles Roy and Dominique Drapier, Adult psychiatry department, Centre Hospitalier Guillaume Régnier, Rennes, France.

8.3 Contributions to Open Science

Additionally to our main research axes, we participated to large scale transversal collaborative works devoted to the improvement and developement of best practices for open science.

CODE beyond FAIR: a roadmap for reusable research software

Participants: Camille Maumet.

FAIR principles are a set of guidelines aiming at simplifying the distribution of scientific data to enhance reuse and reproducibility. This article focuses on research software, which significantly differs from data in its living nature, and its relationship with free and open-source software. We provide a tiered roadmap to improve the state of research software, which takes into account the full range of stakeholders in the research software ecosystem: all scientific staff – regardless of prior software engineering training – but

also institutions, funders, libraries and publishers. This work [65, 22] was done as part of the national open science committee.

9 Bilateral contracts and grants with industry

9.1 Bilateral contracts with industry

9.1.1 Siemens

Participants: Elise Bannier, Emmanuel Caruyer, Isabelle Corouge, Jean-Christophe Ferré, Francesca Galassi, Jean-Yves Gauvrit.

A collaboration between Siemens, Empenn and the Neurinfo platform is in place and formalized by a research contract. Thanks to this agreement, the Neurinfo platform has received the object code of MRI sequences under development at Siemens for evaluation in clinical research. In addition, the Neurinfo platform has received the source code of selected MRI sequences. As a result, MRI sequences can be developed on site by our team. For example, an MRI diffusion sequence was modified to load arbitrarly diffusion gradient waveforms for the FastMicroDiff project (led by E. Caruyer).

Additionally, Siemens supports the **CIFRE thesis** of Youwan Mahé (2024-2027). This PhD project focuses on developing advanced AI-driven techniques for the automatic detection of post-stroke anomalies from multi-modal MRI.

10 Partnerships and cooperations

10.1 International initiatives

10.1.1 Associate Teams in the framework of an Inria International Lab or in the framework of an Inria International Program

DECRYPT

Title: Diffusion simulation for tissuE miCrostructure and bRain connectivitY with oPtimized acquisiTions

Duration: 2024 ->

Coordinator: Jean-Philippe Thiran (jean-philippe.thiran@epfl.ch)

Partners:

- Ecole Polytechnique Fédérale de Lausanne Lausanne (Suisse)

Inria contact: Emmanuel Caruyer

Summary: The reconstruction of microscopic-scale information using magnetic resonance and its application to biological tissue in vivo with magnetic resonance imaging (MRI) has boosted our understanding of the organization of organs, in health and pathology (Alexander et al., 2019). In particular, neuroimaging with diffusion MRI has unveiled unprecedented details on the brain architecture with white matter tractography and the analysis of the brain connectome. In neuro-degenerative diseases, microstructural alterations usually occur at a relatively early stage, their detection could provide unique insight for the diagnosis, prognosis and monitoring of a number of pathologies, including but not limited to multiple sclerosis, Alzheimer's disease, stroke or patients in a coma.

A number of challenges have been highlighted in this quest for a microstructure-informed connectome reconstruction (Maier-Hein et al., 2019). In particular, current methods lack specificity and sensitivity to parameters of interest. These parameters are either local descriptors of the microstructure (cellular density, shape/caliber parameters) or macroscopic descriptors of the brain connectivity (detection and quantification of the "strength" of the connectivity between two interconnected brain regions).

By developing numerical substrate, Monte-Carlo simulation methods, inverse problems solving with fingerprinting and machine learning, and the design of data acquisition methods tailored for specific tasks in microstructure characterization, we will contribute to this developing field. We will also develop methods for the integrated statistical analysis of the microstructure-informed brain connectome, building on recent development of graph-based signal processing and statistics on functional data.

10.1.2 Participation in other International Programs

Participants: Fanny Dégeilh, Claire Cury.

Program: Programme Samuel de Champlain

Title: Quantification de la variabilité intra- et inter-individuelle du développement cérébral des jeunes enfants grâce à l'apprentissage profond

Duration: 2025 -> 2026

Porteur ou porteuse de la partie québécoise : De Leener, Benjamin (Polytechnique Montréal)

Porteur ou porteuse de la partie francaise : Fanny Dégeilh

Summary: This project an innovative approach combining artificial intelligence and neuroimaging to create child-specific brain growth curves. It uses longitudinal magnetic resonance data from two cohorts of healthy children to model typical brain development and its normative variability. The project then seeks to establish the ability of such a model to identify and characterize atypical brain changes after concussion in individual children, using a cohort of children acquired in France. The main aim of the project is to develop innovative tools based on deep learning for the early detection of children whose brain development deviates from the norm, which could improve their care and prevent long-term problems. The project stands out for its longitudinal, individual approach and the use of deep learning to analyze neuroimaging data. The project aims to establish a strong collaboration between a French laboratory (Empenn, Rennes) and a Quebec laboratory (NeuroPoly, Montreal) with complementary expertise in neuroimaging, image processing and neuroscience. The project has the potential to make a significant impact in the scientific and clinical community by establishing personalized reference standards and developing technological innovations that can be applied to other areas of neuroscience research, paving the way for new advances in the understanding of brain development. By providing early detection tools and reference standards for brain development, this project could help improve healthcare for children. It could also help guide public health policies in pediatrics.

Participants: Fanny Dégeilh.

Program: Mitacs Globalink Research Internship

Title: Collaboration entre les équipes de recherche NeuroPoly et Empenn pour la modélisation de trajectoires neurodéveloppementales typiques via la création d'outils basés sur l'intelligence artificielle dédiée à l'imagerie par résonance magnétique

Duration: 2024 -> 2025

Professeur superviseur canadien : De Leener, Benjamin (Polytechnique Montréal)

Superviseur académique international : Fanny Dégeilh

Etudiant.e : Andjela Dimitrijevic

Summary: The aim of the internship project at Empenn was to model the consequences of head injuries in children based on magnetic resonance imaging (MRI) data. This internship, led by intern Andjela Dimitrijevic, focuses primarily on acquiring data related to mild traumatic brain injury (TBI) in children, as well as validating the developed model. The emphasis is on detecting atypical brain development trajectories following these injuries in children aged 0 to 5 years, using deep learning techniques to map deviations from typical neurodevelopment. Using longitudinal MRI data, the goal was to model these brain trajectories in young children, with an emphasis on detecting regional changes. The methodology involves creating brain growth curves and evaluating post-TBI MRI data. These research efforts strengthen international collaboration between the Empenn research teams at Inria and NeuroPoly at Polytechnique Montréal.

10.2 International research visitors

10.2.1 Visits of international scientists

Other international visits to the team

Andjela Dimitrijevic

Status: PhD Student

Institution of origin: Polytechnique Montreal

Country: Canada

Dates: March 2025

Context of the visit: Mitacs Globalink Research Internship

Mobility program/type of mobility: Internship

Agustina Fragueiro

Status: post-Doc

Institution of origin: Università G. d'Annunzio di Chieti-Pescara

Country: Italy

Dates: October 2025

Context of the visit: Collaboration with Claire Cury around the project PNRR - Young researchers IONA led by Agustina Fragueiro

Mobility program/type of mobility: Short visit

10.2.2 Visits to international teams

Research stays abroad

Valentine Chouquet

Status: PhD Student

Visited institution: Polytechnique Montreal

Country: Canada

Dates: March 2025

Context of the visit: Insernational collaboration

Mobility program/type of mobility: Short visit

10.3 European initiatives

10.3.1 Other european programs/initiatives

IONA : Individually Optimized Neurofeedback

Participants: Claire Cury, Pierre Maurel.

Funding: NextGenerationEU PNRR (Piano Nazionale di Ripresa e Resilienza) Young researchers. PI : Agustina Fragueiro

Summary: This funding is restricted to researchers that recieved the seal of excellence by the ERC. The main goal of the project, led by Agustina Fragueiro, is to set a bimodal EEG-fMRI neurofeedback platform in the institute ITAB at Università G. d'Annunzio di Chieti-Pescara, and then design neurofeedback protocols. The collaboration with the Empenn team will help wi the bimodal aspects of neurofeedback.

EU COST Action INDoS

Participants: Camille Maumet.

Funding: European COST Action. PI: Jochem Rieger (Uni. Oldenburg, Germany)

Summary: Improving Neuroimaging Data for Sharing (INDoS) is a European COST Action focused on transforming how human neuroimaging data — such as MRI, MEG, and EEG — is shared and reused. By addressing key challenges in data quality control, metadata standardization, preprocessing pipelines, and ethical and legal frameworks, INDoS fosters cross-disciplinary collaboration, develops FAIR-aligned guidelines and tools, and trains researchers in open science practices to accelerate innovation and reproducibility in brain research. Our mission is to make neuroimaging data truly FAIR (Findable, Accessible, Interoperable, and Reusable) by developing shared standards, tools, and ethical guidelines for data sharing. INDoS connects experts across Europe to improve data quality, transparency, and legal clarity, enabling researchers to share and reuse neuroimaging data efficiently, responsibly, and reproducibly.

10.4 National initiatives

10.4.1 ANR-20-THIA-0018: programme Contrats doctoraux en intelligence artificielle

Participants: Francesca Galassi, Ricky Walsh, Benoît Combès
.

Funding: Co-funding for a PhD thesis in AI - Duration: 2022-2025.

Summary: Co-funding (50% with Univ. Rennes) for a doctoral program in Artificial Intelligence. The PhD concerns the automatic segmentation of MS lesions in spinal cord MRI by means of AI-based solutions.

10.4.2 RHU PRIMUS: Transforming the care of patients with Multiple Sclerosis using a multidimensional data-driven clinical decision support system

Participants: Elise Bannier, Benoît Combès, Gilles Edan, Jean-Christophe Ferré, Francesca Galassi, Anne Kerbrat.

Funding: RHU - Duration: 2022-2026 - Budget: 8272k€

Partners: Observatoire Français de la Sclérose en Plaques (OFSEP), France Life Imaging (FLI), Pixyl.

Summary: The overall objective of PRIMUS is to develop and validate a CE-marked data-driven clinical decision support system (CDSS) for multiple sclerosis (MS). The CDSS will support clinical decision-making by providing easily interpretable information on treatment options. MS is a complex disease, with different phenotypes and heterogeneous progression patterns. Over the past two decades, MS practice has been flooded with data and the number of available treatments has considerably increased. Although clinical, biological and imaging information is now being generated on a massive scale, it contributes to clinical decision-making in a rather haphazard, siloed and non-standardised fashion, so that selecting the most appropriate therapeutic option remains hard. PRIMUS contributes to data-driven homogenization of shared decision practices with and for patients with MS. To achieve this goal, the project will develop advanced artificial intelligence solutions, for a patient- and physician-centred CDSS.

10.4.3 ANR-NODAL: Identification de biomarqueurs de maladies neurodégénératives par l'analyse de la connectivité multimodale.

Participants: Julie Coloigner, Carlo Ferritto.

Funding: Appel à projets générique 2022 - Duration: 2022 - 2026.

Summary: The neurodegenerative diseases like Alzheimer's (AD) and Parkinson's (PD) disease are the consequences of pathological processes that begin decades before the onset of the typical clinical symptoms. However, current diagnosis comes quite late in the course of the disease, while evidences underline the multiple benefits that would be associated with earlier diagnosis. An outstanding challenge for clinical neurosciences is therefore to provide reliable, non-invasive, affordable and easy-to-track biomarkers able to improve both the early detection and the monitoring of neurodegenerative diseases. Recent advances in non-invasive connectome mapping techniques offer great hope for significant progress in taking up this challenge by investigating cerebral organization. Indeed, it is well acknowledged that AD and PD display a progressive multifactorial disruption of functional and structural cerebral networks, all along the course of the diseases. A recent framework called Graph Signal Processing (GSP) is particular promising to shed new light on the complex interplay between brain function and structure. For the first time, GSP will be extended to the development of more sensitive metric of AD and PD progression, taking into account the cerebral functional-structural coupling, contrary to the classical biomarkers using a single-modality data or clinical assessment. In the PRESCO project, we will develop a new multimodal and multi-stage approach using innovative machine learning methods, adapted for GSP-based features, to provide non-invasive, reliable and easy-to-track candidate biomarkers for each stage of AD and PD diseases. We will apply this approach on two large patients' cohorts. Then, we will assess the effectiveness of candidate disease-specific biomarkers on a new innovative local multimodal cohorts including patients with and without cognitive impairment, at various stages of AD and PD. At the end of 2023, we began the acquisition of the cohort including the MRI data and neurocognitve assessment. Carlo Ferritto, a PhD student, works on this project from October 2023. This is a collaborative project with Pierre-Yves Jonin, CHU Rennes and Giulia Lioi, researcher, IMT, Brest.

10.4.4 ANR-PASTRAMI: Patient-specific statistics for microstructure-augmented connectomics

Participants: Élise Bannier, Emmanuel Caruyer, Julie Coloigner, Claire Cury, Marie Poirier.

Funding: Appel à projets générique 2023 - Duration: 2023 - 2028.

Summary: The PASTRAMI project proposes to promote the use of diffusion magnetic resonance imaging (MRI) to derive biomarkers of axonal injury along white matter (WM) fascicles as prognostic factors of functional recovery after severe traumatic brain injury (TBI). We propose to develop statistical methods for patient-specific localization of abnormalities in microstructure and/or structural connectivity, along specific WM fascicles and/or on the full connectome. In a clinical study, the objective will be to assess the predictive accuracy of the proposed model evaluated in the 10 days period following TBI to predict unfavourable outcome at 1-year after the first injury in patients admitted in intensive care for severe TBI. This project is a collaboration with the Laboratoire de mathématiques Jean Leray (Nantes), CHU Rennes and the HIA Sainte-Anne (Toulon).

10.4.5 ANR-JCJC-VICUNA: Exploring the variabiIity induced by different configurations in the neuroimaging analytical space

Participants: Camille Maumet, Boris Clenet, Youenn Merel.

Funding: Appel à projets générique 2022 - Duration: 2022 - 2026.

Summary: Using the same data to answer the same scientific question, researchers may reach contradictory conclusions depending on the analytical pipeline they choose. For many years this problem has been rampant in experimental sciences and recent studies stemming from many fields have brought scientific evidence of this issue. Overall this phenomenon has reduced confidence in research findings and is effectively an important remaining driver of the reproducibility crisis. Software is central to modern scientific research and with the development of data science and its subfields (such as bioinformatics or neuroinformatics) the different tools and approaches available to study a dataset have multiplied. Those software have been very valuable to practitioners and brought the capacity to process more data in a shorter amount of time. But overall, they also provide a large number of possible analysis paths that can be used in order to address a scientific question. With VICUNA, we will provide a proof-of-concept explorat analytical variability in brain imaging. We will navigate in the pipeline space at large and understand which parts of the space are effectively in-use. We will explore and look into how results vary in 3 large open datasets (NARPS, UK Biobank and HCP). This is a collaborative project with Mathieu Acher, INSA Rennes. Boris Clenet is a research engineer (since May 2024) and Youenn Merel is a PhD student (since October 2024).

10.4.6 ANR-JCJC-CoYoKi: Commotion cérébrale chez le jeune enfant : altération cérébrale aiguë et neurodéveloppement

Participants: Fanny Dégeilh, Claire Cury, Pierre Maurel, Mathieu Labrunie, Dorian Le Quilleuc.

Funding: Appel à projets générique 2024 - Duration: 2024 - 2028. Budget : 397k€

Summary: Paediatric concussion (also now as mild traumatic brain injury) is a public health concern affecting more than 2.7 million children every year in the world. Young children (< 6 years old) are the most vulnerable population: 1) concussion is highly prevalent at this age (early concussion), the double than in children aged 6 years and up, and 2) at such an early age, the injury hits the brain during a critical developmental period, which can weaken the foundations of later neurocognitive development and lead to long-term impairment. Yet, young children have been largely ignored by neuroimaging studies of paediatric concussion, and the impact of early concussion on the brain development is still understudied. The underlying reasons for this gap of knowledge resident in 1) the inherent challenge of accurately compute the uniqueness of young child's brain, and 2) the complexity to disentangle typical inter-individual variability in brain development from pathological changes induced by the injury. CoYoKi proposes to combine cutting-edge advanced neuroimaging, computational and longitudinal statistical models to characterise the impact of early concussion on brain and its development at the individual-level. CoYoKi's innovative transdisciplinary approach will allow to develop novel tools and methods for the individualised longitudinal study of typical or pathological brain development, and lead to a new understanding of the individual variability of typical brain development and the complexity of the consequences of early concussion. CoYoKi's findings have the potential to accelerate progress towards the identification of cerebral prognostic biomarkers of early concussion, an essential first step of personalised medicine to improve the healthcare of child with a concussion.

10.4.7 ANR-JCJC-NIRVANA: Unravelling bimodal neurofeedback efficiency for dynamic non-invasive brain rehabilitation

Participants: Claire Cury, Elise Bannier, Julie Fournier, Gracia Khoury.

Funding: Appel à projets générique 2024 - Duration: 2024 - 2028. Budget: 320k€

Summary: Neurofeedback approaches (NF) provide real-time feedback to a patient or participant about his or her own brain activity to self-regulate brain areas or networks, targeted by a neural rehabilitation. The estimation of neurofeedback information is done through online brain functional feature extraction. This is a very promising brain rehabilitation technique for major depression, stroke and other neurological pathologies. NF is based on real-time measures of brain activity usually using a single brain imaging modality, with the majority relying on electroencephalography (EEG) and some recent ones employing functional magnetic resonance imaging (fMRI). Both EEG and fMRI are non-invasive methods, indirectly coupled, that measure complementary aspects of brain activity. Simultaneous EEG-fMRI recording has been used to understand the links between EEG and fMRI, and is recognised as a promising multi-modal measurement of brain activity. Moreover, recent studies have shown the high potential of combining EEG and fMRI in a bimodal NF training (i.e., NF scores estimated from EEG and fMRI) to achieve advanced self-regulation, by providing a more specific estimation of the underlying neural activity. This recent technology combined withthe use of Carbon Wire Loops (CWL) - implemented in few labs in the world - that synchronises both signals for real-time NF, has the potential to bring synergy between both signals during NF task. Yet, NF approaches suffer from an inefficiency problem. Indeed, between 30-50% of the participants undergoing a NF training fail to regulate their brain activity. The origin of this problem can come from (i) signal quality, (ii) task difficulty, (iii) participant's inability to learn, or (iv) lack of participant's task engagement. With NIRVANA, at the interface between signal processing and neuroscience, I propose to address the origins of NF inefficiency problem and to provide dynamic NF protocols adapted to each participant. Results from NIRVANA will contribute to boost the potential of NF as a rehabilitation technique, and thus, to reduce the burden of brain disorders.

10.4.8 INCLUDE: Integrating fuNctional MRI and EEG with Carbon-wire Loops : towards the characterization of mUltimoDal functional biomarkErs

Participants: Elise Bannier, Julie Coloigner, Claire Cury, Mathis Piquet.

Funding: Exploratory action Inria - Duration: 2024 - 2028. Budget: 250k€

Summary: Simultaneous EEG-fMRI combines two complementary neuroimaging techniques, that could allow to establish an enhanced high-resolution spatiotemporal connectivity imaging technique. However, the EEG signals acquired under MRI are usually contaminated by many artifacts hampering the estimation of the connectivity. To overcome this issue, we propose to develop an innovative multimodal connectivity estimation using an accurate denoising method with carbon-wire loops. This will be done in collaboration with Frédéric Grouiller, University of Geneva, Geneva. The research engineer, Mathis Piquet was recruited at the beginning of the project. He or she is working on Aim 1 to implement offline and online pre- processing of EEG data using the CWL. The post-doctoral researcher will be recruited in 2025. He or she will work on the Aim 2.

10.4.9 ACTIDIFF: Apathy in Late Life Depression: New Biomarkers Using Actimetry and Diffusion Imaging

Participants: Gabriel Robert, Julie Coloigner.

Funding: Institut des Neurosciences Cliniques de Rennes (INCR) - 50k€

Summary: A better understanding of the apathy in late-life depression would help predict the pejorative course of this disorder, such as dementia or persistent depression. Actimetry allows an objective and ecological assessment of motor activity, but still needs to be evaluated in the depression of the elderly. To better understand the pathophysiology of apathy, a study linking measurements of apathy, motor activity and functional connectivity was conducted. Previous results showed that apathy is associated with changes in brain connectivity at rest in regions of the brain involved in goal-directed behaviors. The objective of this ACTIDIFF project is to study the neuronal fibers between these regions in order to better understand the pathophysiology of apathy in depression in elderly people. To do this, we propose to develop an innovative method for studying microstructure changes, based on MRI-estimated metrics of diffusion along fibers in relation to apathy. The joint exploration of actimetry, apathy and brain imaging opens new hopes in preventing cognitive impairment and identifying novel biomarkers for the early stages of dementia.

10.4.10 INCA: Individual attention monitoring during Neurofeedback for Clinical Applications

Participants: Claire Cury, Julie Fournier.

Funding: Institut des Neurosciences Cliniques de Rennes (INCR) - 50k€

Summary: il existe une grande variabilité dans la réussite du neurofeedback (NF), puisqu'un tiers des participants suivant un entrainement neurofeedback n'apprennent pas à réguler leur propre activité cérébrale. Les facteurs motivationnels et attentionnels sont les principaux responsables de la réussite du NF. La motivation est susceptible d'influencer l'attention, car de mauvaises performances peuvent

accroître la peur de l'incompétence et réduire la confiance en soi, ce qui peut conduire à un désengagement envers la tâche et à une potentielle étiquette de « non-répondant » pour les individus au fil du temps. Nous savons que maintenir son attention sur une tâche durant une période prolongée est crucial pour une bonne performance, mais cela est exigeant et conduit à des pertes d'attention. L'état d'alerte physiologique est appelé arousal. Lorsque l'arousal est trop faible ou trop élevé, le participant a des pertes d'attention conduisant à de moins bons résultats. En effet, lorsque nous sommes trop détendus, notre esprit peut vagabonder, et lorsque le niveau d'arousal est élevé il peut être lié au stress ou à une distraction provoquée par des pensées intrusives. Seul un niveau d'arousal intermédiaire est lié à la concentration sur la tâche et à une bonne performance. En neurosciences comportementales, le suivi oculaire et la conductance cutanée, ont été largement utilisés pour mesurer les caractéristiques psychophysiologiques liées à l'arousal et à la concentration. En utilisant ces capteurs psychophysiologiques, l'objectif d'INCA est de développer une méthode permettant de suivre le niveau d'engagement des patients lors d'un entrainement neurofeedback. Nous validerons cette méthode sur des données cliniques de patients post-AVC aillant suivi un entraînement neurofeedback. Les résultats d'INCA permettront par la suite d'optimiser individuellement les séances de NF en estimant avec précision et en temps réel l'engagement des patients dans la tâche afin d'adapter la séance en conséquence. L'adaptation individuelle des procédures NF et la réduction conséquente de la proportion de « non-répondeurs » augmenteront l'efficacité du NF et renforceront sa capacité de rééducation cérébrale. INCA a le potentiel d'impacter positivement la qualité de vie d'une grande variété de patients.

10.4.11 Knowledge addition through Neuroimaging of Alcohol consumption in healthy young Volunteers, causes or consequences

Participants: Elise Bannier, Quentin Duché, Gabriel Robert.

Funding: Funding: INCR - Duration: 2020-2023 - Budget: 45k€

Summary: Alcohol consumption is responsible for 3 million annual deaths worldwide (5.1 percent of the global burden of disease). It causes disease (liver cirrhosis, cancers, etc.) and other social costs (injuries, road accidents, alcohol dependence, etc.). Excessive alcohol consumption grows through adolescence. This type of behavior has also been shown to have subtle but significant deleterious effects on cognitive function in adolescents. Advances in the field of neuroimaging make it possible to characterize anatomical changes and the evolution of neuropsychological deficits. Besides, focusing on the societal causes of alcohol abuse, a large body of studies show that exposure to alcohol advertising through media bootstraps early consumption initiation, greater desire to drink, increased alcohol use and binge drinking patterns among young people, especially minors. We aim to combine the analysis of the locally acquired IMAJ dataset (PI Karine Gallopel-Morvan, INCA Funding) and data from the european consortium IMAGEN datasets to determine whether there are functional characteristics and external factors that can explain behavior towards alcohol and to extract biomarkers capable of predicting excessive behavior. Relying on the IMAJ dataset, we will analyze whether, depending on warning formats displayed on ads (small and text-only vs. larger, shock-inducing and pictorial), health messages can influence brain activity by decreasing the effect of attractive alcohol content ads on the reward system area and on behavioral responses. Relying on the already effective collaboration of Dr Robert with Prof Schumann, we will explore the longitudinal anatomical and functional data from the IMAGEN cohort to extract biomarkers of alcohol consumption evolution and complement the analysis with the results obtained from the IMAJ dataset.

10.4.12 PHRC EMISEP: Evaluation of early spinal cord injury and late physical disability in Relapsing Remitting Multiple Sclerosis

Participants: Elise Bannier, Emmanuel Caruyer, Benoit Combès, Gilles Edan, Jean-Christophe Ferré, Anne Kerbrat.

Funding: PHRC - Duration: 2016-2023 - Budget: 200k€

Summary: Multiple Sclerosis (MS) is the most frequent acquired neurological disease affecting young adults (1 over 1000 inhabitants in France) and leading to impairment. Early and well adapted treatment is essential for patients presenting aggressive forms of MS. This PHRC (Programme hospitalier de recherche clinique) project focuses on physical impairment and especially on the ability to walk. Several studies, whether epidemiologic or based on brain MRI, have shown that several factors are likely to announce aggressive development of the disease, such as age, number of focal lesions on baseline MRI, clinical activity. However, these factors only partially explain physical impairment progression, preventing their use at the individual level. Spinal cord is often affected in MS, as demonstrated in postmortem or imaging studies. Yet, early radiological depiction of spinal cord lesions is not always correlated with clinical symptoms. Preliminary data, on reduced number of patients, and only investigating the cervical spinal cord, have shown that diffuse spinal cord injury, observed via diffusion or magnetisation transfer imaging, would be correlated with physical impairment as evaluated by the (EDSS) Expanded Disability Status Scale score. Besides, the role of early spinal cord affection (first two years) in the evolution of physical impairment remains unknown. In this project, we propose to address these different issues and perform a longitudinal study on Relapsing Remitting Multiple Sclerosis (RRMS) patients, recruited in the first year of the disease. Our goal is to show that diffuse and focal lesions detected spinal cord MRI in the first two years can be used to predict disease evolution and physical impairment at 5 years. Twelve centers are involved in the study to include 80 patients. To date, all subjects have been included and the last visit of the last patient is scheduled early 2023. The EMISEP data consists of brain and spinal cord structural and quantitative MR images of early MS patients followed over 5 years. Four papers have been published so far on data acquired at baseline on healthy controls and patients. Three papers were co-authored in the context of international collaborations. Additional papers are in preparation.

10.4.13 Estimating the impact of multiple sclerosis lesions in motor and proprioceptive tracts, from the brain to the thoracic spinal cord, on their functions, assessed from clinical tests (MS-TRACTS and MAP-MS)

Participants: Elise Bannier, Benoit Combès, Malo Gaubert, Anne Kerbrat.

Funding: ARSEP, COREC and INCR - Duration: 2020-2023 - Budget: 200k

Summary: Previous studies, whether epidemiologic or based on brain MRI, have shown that several factors were likely to announce aggressive development of the disease, such as age, clinical relapses, number of focal lesions on baseline MRI. However, these factors only partially explain physical disability progression, preventing their use at the individual level. We hypothesize that a fine assessment of damage on specific networks, from the brain to the thoracic cord, offers a relevant biomarker of disability progression in MS. Such damage assessments must take into account both lesion location, assessed on structural brain and cord MR images and lesion severity, assessed using advanced brain and cord imaging through quantitative MRI.We propose to test this hypothesis by combining assessments of lesion location and severity on corticospinal and proprioceptive tracts from the brain to the thoracic cord with clinical and () electrophysiological measurements. The MS-TRACTS study involves two French centers (Rennes,Marseille) and includes a total of 60 relapsing remitting MS patients. The

expected outcome is to obtain early biomarkers of physical impairment evolution in RRMS patients, first treated with immunomodulatory treatment. The long-term goal is to provide the clinician with biomarkers able to anticipate therapeutic decisions and support the switch to alternative more aggressive treatment. Inclusions are ongoing. The MAP-MS study involves the same two French centers and will nclude 40 progressive MS patients. The investigation will focus on motor asymetry in these more advanced patients. This study includes two French centers (Rennes, Marseille) and includes a total of 60 patients. The expected outcome is to obtain early biomarkers of physical impairment evolution in RRMS patients, first treated with immunomodulatory treatment. The long-term goal is to provide the clinician with biomarkers able to anticipate therapeutic decisions and support the switch to alternative more aggressive treatment. Inclusions are ongoing.

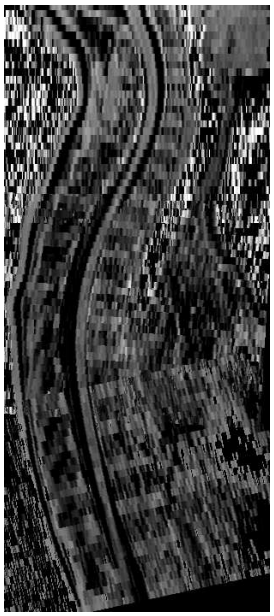


Figure 3: Estimating the impact of multiple sclerosis lesions in motor and proprioceptive tracts, from the brain to the thoracic spinal cord, on their functions, assessed from clinical tests (MS-TRACTS and MAP-MS): An example of Magnetization Transfer Ratio (MTR) mapping of the whole spinal cord acquired from the MS-TRACTS imaging protocol.

10.4.14 France Life Imaging (FLI)

Participants: Michael Kain, Camille Maumet, Jean-Christophe Ferré.

Funding: Funding: FLI - Duration: 2012-2024 - Total budget: 2000k€ (phase 1) + 1200k€ (phase 2) + 800k€ (phase 3)

Summary: France Life Imaging (FLI) is a large-scale research infrastructure project to establish a coordinated and harmonized network of biomedical imaging in France. This project was selected by the call "Investissements d'Avenir - Infrastructure en Biologie et Santé". One node of this project is the node Information Analysis and Management (IAM), a transversal node built by a consortium of teams that contribute to the construction of a network for data storage and information processing. Instead of building yet other dedicated facilities, the IAM node use already existing data storage and information processing facilities (LaTIM Brest; CREATIS Lyon; CIC-IT Nancy; Empenn U1228 Inria Rennes; CATI CEA Saclay; ICube Strasbourg) that increase their capacities for the FLI infrastructure.

Inter-connections and access to services are achieved through a dedicated software platform that is developed based on the expertise gained through successful existing developments. The IAM node has several goals. It is building a versatile facility for data management that inter-connects the data production sites and data processing for which state-of-the-art solutions, hardware and software, are available to infrastructure users. Modular solutions are preferred to accommodate the large variety of modalities acquisitions, scientific problems, data size, and to be adapted for future challenges. Second, it offers the latest development that are made available to image processing research teams. The team Empenn fulfills multiple roles in this nation-wide project. Michael Kain is the technical manager, Camille Maumet is part of the steering committee. Apart from the team members, software solutions like MedInria and Shanoir are part of the software platform.

10.4.15 OFSEP: French Multiple Sclerosis Observatory

Participants: Elise Bannier, Gilles Edan, Jean-Christophe Ferré, Francesca Galassi, Benoît Combès, Anne Kerbrat.

Funding: ANR-PIA - Duration: since 2017 - Budget: 175k€

Summary: The French Observatory of Multiple Sclerosis (OFSEP) is one of ten projects selected in January 2011 in response to the call for proposal in the "Investissements d'Avenir - Cohorts 2010" program aunched by the French Government. It allows support from the National Agency for Research (ANR) of approximately 10 million € for 10 years. It is coordinated by the Department of Neurology at the Neurological Hospital Pierre Wertheimer in Lyon (Professor Christian Confavreux), and it is supported by the EDMUS Foundation against multiple sclerosis, the University Claude Bernard Lyon 1 and the Hospices Civils de Lyon. OFSEP is based on a network of neurologists and radiologists distributed throughout the French territory and linked to 61 centers. OFSEP national cohort includes more than 50,000 people with Multiple Sclerosis, approximately half of the patients residing in France. The generalization of longitudinal monitoring and systematic association of clinical data and neuroimaging data is one of the objectives of OFSEP in order to improve the quality, efficiency and safety of care and promote clinical, basic and translational research in MS. For the concern of data management, the Shanoir platform of Inria has been retained to manage the imaging data of the National OFSEP cohort in multiple sclerosis. One long term objective of the OFSEP project is to identify prognostic factors of the evolution of Multiple Sclerosis. The HD Cohort is an enhanced cohort specifically designed for this purpose in which some patients are followed-up on a yearly basis. Additional clinical, quality of life and other patient-reported data is also collected. This study aims at developing personalized predictive tools to improve patient care management, and help in making decision to start, maintain or adapt medical care. Collected data will be processed to extract valuable information enabling to determine specific biomarkers of the evolution of the disease. Multiple Sclerosis brain lesions are of particular interest, hence the need for a careful comparison of lesion segmentation methods. A litterature review enabled to gather most promising cross-sectionnal methods, designed to identify and localize lesions with precise measurement of the lesion load at one particular point in time ; and longitudinal methods which gives more insight on the evolution of those lesions over the different time points. Those later methods are particularly interesting for clinicians for whom the type of lesion evolution is of foremost importance. A cross-sectionnal method and a longitudinal method were trained and evaluated to select the ones which will be used to analyze the entire HD Cohort dataset. Moreover, an experimental and a statistical design to compare the accuracy, sensitivity and specificity of the active/inactive classification of MS patients based on brain MRI as assessed using the analysis of brain was proposed. These designs will allow to assess the interest of re-analyzing the MRI data to improve the quality of the standardized reports used in most epidemiologic studies from the OFSEP cohorts. The collaboration has recently been extended until end of 2025 with a particular focus on spinal cord imaging and slowly evolving lesions.

10.4.16 QSM-SPICO: Quantitative Susceptibility Mapping for Spinal Cord

Participants: Elise Bannier, Benjamin Streichenberger, Anne Kerbrat, Benoit Combès.

Fundings: FLI-RE4 - 20k€, ARSEP - 60 k€, Fondation de l'Avenir 40 k€

Summary: Quantitative Susceptibility Mapping (QSM) is a promissing quantative imaging technique for the characterization of lesions in Multiple Sclerosis (MS). QSM provides a novel type of contrast linked to the tissue magnetic susceptibility. The latter is sensitive to iron accumulation and myelin content, which are both important metrics when studying MS lesions. As part of a research expertise transfer sponsored by France Life Imaging, in collaboratin with Mathieu Santin, at ICM/CENIR, Ludovic de Rochefort and Stéphane Roche from the Ventio Startup in Marseille, we started exploring the possibility to perform QSM in the spinal cord. This is challenging because of size of the cord and the presence of fat in the spine. To tackle this challenge, we implemented the IDEAL algorithm - iterative decomposition of water and fat with echo asymmetry and least-squares estimation. The aim is be able to characterize spinal MS lesions using QSM. The first results are encouraging.Additional fundings from France SEP (PostDoc) and Fondation de l'Avenir (HR and Licence) were obtained at the end of 2024 to continue the projet in 2025.

10.4.17 PEPR ShareFAIR

Participants: Camille Maumet, Elise Bannier, Melvin Atay.

Funding: PEPR Santé numérique.

Summary: Access to a wide variety of complementary, multi-scale and massive data collections offers unprecedented opportunities for healthcare research. A large number of analyses can be performed on these datasets, for scientific advances and discoveries to emerge. The national 'Digital Health'Acceleration Strategy ambitions to boost digital health innovation which includes designing innovative health data analysis approaches.Importantly, such data analyses are complex, they rely on various computational tools that have to be parametrized and chained together. There is now compelling evidence that many scientific discoveries will not stand the test of time: increasing the reproducibility of computed results is of paramount importance, especially in the healthcare domain.

Sharing of health data is often hampered by personal data protection requirements and comes up against technical constraints (security, volume). These constraints can however be limited when the protocols and the workflows implementing analyses are sufficiently reusable to reproduce analyses in situ. Additionally, when designed to be reusable, protocols and their implementations - workflows - provide the provenance traces of the analyzed data, describing how data results have been obtained and thus increasing scientists' confidence in the results produced. This calls for innovative solutions for the annotation of biomedical and clinical datasets and extraction of provenance. Protocols and their implementation as workflows using and generating datasets should be elevated to first-class objects and the inherent dual relationship between datasets and protocols/workflows should be better exploited. Challenges thus include standardization and annotation for datasets and protocols, extracting protocols and workflows from text and other datasets, and synthesizing them into interoperable, yet shareable protocols.

The originality of ShareFAIR lies in tackling both the reliability of datasets and analysis protocols and in harnessing the dual relationship between datasets and protocols. Specifically, ShareFAIR will provide:

1. standards to uniformly represent datasets, ontologies/common vocabularies to annotate datasets and protocols/workflows, and provenance to trace the origin of datasets,

2. an interoperable framework for the design, annotation and reuse of reliable and shareable protocols,
3. approaches to extract protocols from textual data to enrich the set of protocols and workflows and better document the provenance of datasets, and approaches to learn protocols from biomedical and clinical datasets.

This project is led by Sarah Boulakia-Cohen from Univ Paris Saclay.

10.5 Regional initiatives

10.5.1 ICON: Improving clinical diagnosis of COgNitive dysfunction in Parkinson's disease

Participants: Julie Coloigner, Claire Cury.

Funding: Labex CominLabs : from Sept. 2025 to end of 2026 - Budget: 290k€

Summary: Parkinson's disease (PD) is the second most frequent neurodegenerative disease. While PD is known for its motor symptoms, it can also involve incapacitating cognitive symptoms1, some of them potentially being associated with the later development of dementia2. However, no effective drug treatment for those cognitive symptoms is available, and identifying different profiles of cognitive deficits remains an unmet clinical challenge3. The objective of the ICON project is to tackle this challenge, by identifying electrophysiological signatures corresponding to distinct profiles of cognitive impairment in PD, as an indispensable first step towards improving prognosis and the conception of innovative treatments targeting specific brain regions / processes. Such identification of cognitive profiles would be crucial for proposing a personalized therapeutic approach by anticipating the occurrence of cognitive and behavioral adverse effects associated with currently available treatments (such as impulse control disorders or excessive daytime sleepiness) and for the use of novel drugs, potentially targeting specific mechanisms or brain circuits. To achieve this ambitious objective, we will use an innovative approach combining machine learning techniques on highresolution electroencephalography (HR-EEG) and neuropsychological assessments of different cognitive domains, with a unique clinical database acquired here in Rennes (STIMPARK+EEGCOG clinical studies). This project is in collaboration with Julien Modolo and Jean-François Houvenaghel (LTSI U1099, Inserm/UR1).

10.5.2 PEPERONI : Portable and Personalized Neurofeedback for Stroke Rehabilitation

Participants: Elise Bannier, Isabelle Bonan, Julie Coloigner, Isabelle Corouge, Claire Cury, Pierre Maurel, Camille Muller.

Funding: Labex CominLabs : from Sept. 2022 to end of 2025 - Budget: 290k€

Summary: Neurofeedback (NF) consists in presenting a person with a stimulus directly related to his or her ongoing brain activity. NF can be used to teach subjects how to regulate their own brain functions by providing real-time sensory feedback of the brain "in action". Recent studies showed that NF is promising for the treatment of various neuronal pathologies. Electroencephalography (EEG), which has historically been the preferred modality for NF, suffers from a lack of specificity, preventing the transfer of this treatment to clinical use. On the other hand functional Magnetic Resonance Imaging (fMRI) has a good specificity, but it is a cumbersome and expensive modality, making it difficult to develop personalized protocols. In this project, we aim to develop a methodological and experimental framework opening the door to a more portable and personalized NF, for easier and effective clinical use, with a focus on post-stroke motor rehabilitation. We propose to organize the project in four work packages, grouped in two axes.

11 Dissemination

Participants: Emmanuel Caruyer, Julie Coloigner, Benoît Combès, Claire Cury, Fanny Dégeilh, Francesca Galassi, Camille Maumet, Pierre Maurel, Elise Bannier, Quentin Duché.

11.1 Promoting scientific activities

11.1.1 Scientific events: organisation

General chair, scientific chair

- Isabelle Corouge: session chair in international conference on Information Processing in Medical Imaging (IPMI) 2025.
- Claire Cury, Pierre Maurel: Co-chair, with marie-Constance Corsi, of the "Handicap et Numérique" days - 11th and 12th June, Paris

Member of the organizing committees

- Elise Bannier, Julie Coloigner, Quentin Duché and Malo Gaubert were part of the organization committe of the national MR Physics congress for Biology and Medecine SFRMBM 2025, that was held in March 2025 in Saint Malo and institutionally supported by IRISA.
- Benoit Combès, Anne Kerbrat: organization of the 2025 Miccai challenge ms-multi-spine dedicated to Multiple Sclerosis Spinal Cord Lesion Detection from MultiSequence MRIs.
- Emmanuel Caruyer : Co-organizer of the 2nd Microstructure imaging workshop, ESMRMB, 8 Oct 2025, Marseille

11.1.2 Scientific events: selection

Member of the conference program committees

- Elise Bannier, Julie Coloigner, Quentin Duché, Malo Gaubert : SFRMBM 2025
- Francesca Galassi : IABM 2025

Reviewing activities

- ISBI (Julie Coloigner, Francesca Galassi)
- Gretsi 2025 - Code reproducibility review (Youenn Merel Jourdan)
- IABM (Francesca Galassi, Claire Cury, Pierre Maurel)
- MICCAI (Francesca Galassi)
- MICCAI Challenge Proposals (Benoit Combès)
- Journal of NeuroEngineering and Rehabilitation (4 papers, Camille Muller)
- Scientific Repport (4 papers, Camille Muller)

11.1.3 Journal

Member of the editorial boards

- Camille Maumet. Editorial board member, Scientific Data (Nature Publishing Group).

Reviewer - reviewing activities

- Human Brain Mapping (1 paper, Julie Coloigner)
- Advances in Methods and Practices in Psychological Science (1 paper, Camille Maumet)
- Imaging Neuroscience (1 paper, Francesca Galassi; 1 paper, Emmanuel Caruyer)
- Communications Biology (1 paper, Fanny Dégeilh)
- Medical Image Analysis (1 paper, Emmanuel Caruyer)
- Computer Methods and Programs in Biomedicine (1 paper, Emmanuel Caruyer)

11.1.4 Invited talks

- Camille Maumet, "Variability in brain imaging studies across different analysis pipelines" [86], Keynote at VAMOS 2025 - 19th International Working Conference on Variability Modelling of Software-Intensive Systems, Feb 2025, Rennes, France.
- Camille Maumet, "Towards reproducible neuroimaging across different analysis pipelines" [84], OHBM 2025 - Annual Meeting of the Organization of Human Brain Mapping, Jun 2025, Brisbane, Australia (Online).
- Camille Maumet, "Joining the open data movement and unlock the potential of neuroscience", Journées Inria Handicap et Numérique, Juin 2025, Paris, France.
- Camille Maumet "Pratiquer la science ouverte vers une recherche reproductible" [83], PEPR-SanteNum 2025 - Journées annuelles du PEPR Santé Numérique, Oct 2025, Lille, France. 2025
- Camille Maumet " Improving computational reproducibility or how-to share your research code" [82], Basel ReproducibiliTea 2025, Oct 2025, Basel, Switzerland (Online).
- Fanny Dégeilh "Neurodevelopmental outcomes following early childhood concussion, NeuroSpin Seminar, Dec 2025, NeuroSpin, France.
- Valentine Chouquet, Thesis Presentation - Neuropoly, Polytechnique Montréal (Québec), Canada (March 2025)
- Malo Gicquel, "Vers un biomarqueur clinique de l'activité chronique de la sclérose en plaques : les Slowly Expanding Lesions (SELs). Résumé de la littérature." Assises de l'OFSEP, mars 2025
- Malo Gicquel, "Vers un biomarqueur clinique de l'activité chronique de la sclérose en plaques : les Slowly Expanding Lesions (SELs). Proposition de projet de recherche." AG RHU PRIMUS, juin 2025
- Malo Gaubert, "Projet MS-TRACTS: Étude du tractus moteur dans le cerveau et la moelle épinière chez des patients atteints de sclérose en plaques et association avec les fonctions motrices" Journée scientifique du Hub Grand Ouest de France Life Imaging, 19 November
- Nolwenn Jégou "Apports de nouveaux biomarqueurs de démyélinisation issus de l'IRM quantitative pour le suivi des patients vivant avec une sclérose en plaques", AG RHU PRIMUS Juin 2025
- B. Streichenberger gave a talk on Quantitative Susceptibility Mapping of the cervical spinal cord for MS monitoring at the France SEP MRI workshop on February 7th. [61]
- B. Streichenberger gave a talk on Quantitative Susceptibility Mapping of the cervical spinal cord for MS monitoring at SFRMBM 2025 on March 25th. [60]
- B. Streichenberger gave a talk on Quantitative Susceptibility Mapping of the cervical spinal cord and application to multiple sclerosis on November 24th at the REMI meeting, Paris.
- E. Bannier gave a talk on Multicentric initiatives, Feedbacks and lessons learned on October 7th at the Spinal Cord MRI workshop in Marseille, just before the ESMRMBM meeting.

- E. Caruyer gave an educational talk at the SFRMBM 2025 (Saint-Malo) on Diffusion MRI.
- P. Maurel, "Neurofeedback simultané EEG IRMf pour la rééducation motrice post AVC", Journée scientifique du Hub Grand Ouest de France Life Imaging, 19 November

11.1.5 Leadership within the scientific community

- Boris Clenet, maintainer of the Brain Imaging Data Structure (BIDS), since July 2025.
- Camille Maumet, member (elected) of the steering committee of the Brain Imaging Data Structure (BIDS).
- Camille Maumet, member (by selection) of the national committee on Open Science, Working group "open software" led by Roberto Di Cosmo and François Pellegrini (until March 2025).
- Elise Bannier, board member (by election) of the national french MRI society (SFRMBM)
- Elise Bannier, president of the SFRMBM 2025 conference in Saint-Malo and of the organizing committee.
- Emmanuel Caruyer, coordinator of the Western France hub of France Life Imaging
- Emmanuel Caruyer, member of the International Society for Tractopgrahy (working group on Methods validation)

11.1.6 Scientific expertise

- Julie Coloigner, expert in the evaluation process of the HORIZON MSCA PF 2025, European Research Executive Agency (REA)
- Emmanuel Caruyer, expert in the evaluation process of ANR AAPG2025

11.1.7 Research administration

Camille Maumet, member of the Inria Evaluation Committee ("commission d'évaluation") since October 2023.

11.2 Teaching - Supervision - Juries - Educational and pedagogical outreach

11.2.1 Teaching

École Normale Supérieure de Rennes (ENS Rennes) / Université de Rennes:

- Constance Bocquillon, "Mathématiques 2", L3 SIF, (TD/TP/Projet 18h)
- Francesca Galassi, "Traitement d'images", M2 Info (CM: 10h, TP: 10h)
- Emmanuel Caruyer, "Introduction au traitement d'image", L3 Info (CM: 10h, TP: 10h)

Institut National des sciences appliquées (INSA), Rennes:

- Nolwenn Jégou, "TP Programmation orienté objet" (TP 18h)

École supérieure d'ingénieurs de Rennes (ESIR):

- ESIR - CUPGE2
  - Julie Coloigner, "Mathématiques appliqués" (25h).
  - Carla Joud, CUPGE2,"Mathématiques appliqués" (TP: 24h).
- ESIR2/ESIR3 - IN

  - Pierre Maurel is co-head of the Master program "imagerie numérique" (two last year of the Engineering School)
  - Pierre Maurel, "General image processing" (CM : 30h).
  - Pierre Maurel, "Algorithmique et complexité" (CM : 30h).
  - Pierre Maurel, "Imagerie médicale" (CM : 30h).
  - Gracia Khoury, Traitement Avancé des Images (CM: 10h)
  - Mathys Georgeais, Imagerie Médicale (TP : 20h)
  - Mathys Georgeais, Mathématiques pour l'image (TP : 24h)
- ESIR 2 - Info
  - Francesca Galassi, "Apprentissage Artificiel" (CM: 12h)
  - Youwan Mahé, "Apprentissage Artificiel" (TP: 24h)
  - Cedric Maueree, "Apprentissage Artificiel" (TP: 24h)
  - Grégoire Ville, "Algorithmique et Complexité" (TD: 13.5 h)
- ESIR 2 - Technologies de l'Information pour la santé (TIS)
  - Julie Coloigner, "Analyse avancé de Signaux et images" (35h)
  - Adèle Savalle, "Analyse avancé de Signaux et images" (9h)
- ESIR 1 - Info
  - Francesca Galassi, "Algorithmique des graphes" (CM: 6h, TD: 6h).
  - Boris Clénet, "Algorithmique des graphes" (TP: 12h).

Master SIBM, M2, University of Angers-Brest-Rennes:

- Julie Coloigner, "Méthode d'analyse de la connectivité cérébrale" (Plenary: 3h).
- Isabelle Corouge, "IRM de perfusion par Arterial Spin Labeling (ASL)" (Plenary: 3h).
- Quentin Duché, "Traitement des données d'IRM fonctionnelle" (Plenary: 1h).
- Youenn Merel Jourdan, "Workflows de traitement d'images" (Plenary: 3h).
- Elise Bannier, "IRM fonctionnelle" (Plenary: 1h).
- Elise Bannier, "Utilisation et ré-utilisation de données d'imagerie : confidentialité et aspects réglementaires" (Plenary: 1h).
- Benoit Combès, "Méthodes de segmentation pour l'imagerie médicale" (Plenary: 3h).
- Benoit Combès, "Méthodes de recalage linéaire et non-linéaires des images médicales" (Plenary: 6h).
- Benoit Combès, "Applications des méthodes de traitement des images médicales" (Plenary: 3h).
- Benoit Combès, "Eléments de statistiques pour l'induction scientifique" (Plenary: 4.5h).
- Benoit Combès, "Soutenance de présentations critiques d'articles scientifiques" (TD: 3h).
- Emmanuel Caruyer, "IRM de diffusion" (Plenary: 3h)

Institut de formation de manipulateurs d'électroradiologie médicale (IFMEM) Rennes:

- Valentine Chouquet, "Ma vie de doctorante" (Plenary: 2h)
- Elise Bannier, "Physique appliquée en IRM" (Plenary: 13h)

Master Physique Médicale, M2, University of Rennes:

- Elise Bannier, "TD IRM" (Plenary: 4h).

Orthophonie, L1, University of Rennes:

- Elise Bannier, "IRM fonctionnelle" (Plenary: 2h).

Licence Biology, L2, University of Rennes:

- Mathilde Liffran, "Etude de la respiration humaine par EXAO – Adaptation à l'effort" (TP: 12h).

Licence Psychology, L2, University of Rennes 2:

- Mathilde Liffran, "NEUROSCIENCES ET COMPORTEMENT HUMAIN" (TD: 12h).

Licence STAPS, L2, University of Rennes 2:

- Mathilde Liffran, "Communication et contrôle des grandes fonctions" (TD: 9h).

DEUST Métiers de la Forme, D1 STAPS, Univeristy of Rennes 2:

- Camille Muller, "Biomécanique" (TD: 20h).
- Camille Muller, "Neurosciences" (TD: 12h).

11.2.2 Supervision

Master

- Julie Coloigner, Gabriel Robert: Sonia Tifrea, from January to July 2025 "Evaluating WMH automatic segmentation performance across lesion topographies: a comparative study".
- Elise Bannier, Quentin Duché, Gabriel Robert : Célia Bouvier, from January "Latent growth models and brain development : magnetic resonance imaging analysis and correlation with alcohol consumption in healthy young adults".
- Boris Clenet, Camille Maumet : Anne-Gaelle Geffroy (M2 Bio-informatique, UR) from January "Reproducing brain imaging pipelines to study analytical variability".
- Youwan Mahé, Florent Leray, Francesca Galassi : Yann Kerverdo (ESIR 1 (SI), UR) Jun-Aout 2025 "Développement et optimisation d'un outil de segmentation des lésions cérébrales sur IRM après AVC"
- Valentine Chouquet, Pierre Maurel, Fanny Dégeilh : Maurane Omnes (M1 SIBM) Janv-Mai 2025 "Impact d'une commotion cérébrale pédiatrique sur le neurodéveloppement"
- Anne Kerbrat and Mathilde Liffran : Maxime Jardin, " Etude de la répartition cérébrale et médullaire des lésions chez les patients vivant avec une sclérose en plaques : aspects anatomopathologique".
- Benoit Combès, Malo Gaubert: Rodolphe Fenech, Master Biologie et Imagerie Médicale "Intérêt de la séquence IRM MTSat pour la caractérisation des lésions dans la sclérose en plaques" (Université Tours)
- Anne Kerbrat, Malo Gaubert: Jérémy Hong, thèse de Médecine "Limited added value of systematic spinal cord MRI vs brain MRI alone to classify patients with MS as active or inactive during follow-up" (CHU Rennes)
- Claire Cury, Pierre Maurel, Mathys Georgais : Kieran Le Mouel (ESIR 1) from June to August 2025 "Deep learning appliqué à la detection des éléctrodes dans des volumes IRM"

PhD

- Mathilde Liffran - PhD, ED SVS - Supervisors Anne Kerbrat, Benoit Combès, Malo Gaubert.

- Malo Gicquel - PhD, ED Matisse - Supervisors: Anne Kerbrat, Benoit Combès - Subject: "MRI quantification of spinal cord slowly evolving lesions in patients with multiple sclerosis."
- Nolwenn Jégou - PhD, ED Matisse - Supervisors: Benoit Combès, Anne Kerbrat, Elise Bannier - Subject: "Apports de nouveaux biomarqueurs de démyélinisation issus de l'IRM quantitative pour le suivi des patients vivant avec une sclérose en plaques".
- Youwan Mahé - PhD, ED Matisse - Supervisors: Francesca Galassi, Stephanie Leplaideur, Elise Bannier, Elisa Fromont - Subject: "Unsupervised Detection of Post-Stroke Brain Abnormalities". Started in November 2023 and funded by a CIFRE agreement (University of Rennes and Siemens Healthineers).
- Ricky Walsh - PhD, ED Matisse - Supervisors: Francesca Galassi, Benoit Combès, Anne Kerbrat - Subject: "Accurate and Robust Automated Detection and Segmentation of Multiple Sclerosis Lesions in Spinal Cord MRI", started in Nov 2022 and defended in October 2025, funded by the University of Rennes.
- Mathys Georgais - PhD, ED Matisse - Supervisors: Claire Cury, Pierre Maurel- Subject: "Machine learning for efficient bimodal EEG-fMRI neurofeedback", started in 2024 and funded by the University of Rennes.
- Melvin Atay - PhD, ED Matisse - Supervisors: Camille Maumet, Elise Bannier - Subject: "Sharing FAIR protocols and workflows to better understand analytical variability in neuroimaging". Started in September 2024 and funded by PEPR ShareFAIR.
- Constance Bocquillon - PhD, ED Matisse - Supervisors: Emmanuel Caruyer, Isabelle Corouge - Subject: Optimizing acquisition parameters in diffusion MRI for the estimation of brain structural connectivity, started in October 2022, funded by the University of Rennes.
- Lisa Borgmann - PhD, ED SVS - Supervisors: Jean-Marie Batail, Julie Coloigner - Subject: "Neural and Physiological Surrogates of Sustained Antidepressant Response to Repetitive Transcranial Magnetic Stimulation", started in December 2025, funded by Centre Hospitalier Guillaume Regnier (CHGR)
- Sébastien Dam - PhD, ED Matisse -supervisors: Julie Coloigner, Pierre Maurel- Subject: "Structural Brain Connectivity and Treatment Response in Mood Depressive Disorder", started in Oct 2022 and defended in October 2025, funded by ARED.
- Alix Lamouroux - PhD, -supervisors: Julie Coloigner, Pierre Maurel- Subject: "Connectivity and Neurofeedback", at IMT Atlantique Brest, started in Oct. 2022, and defended in October 2025, co-supervised with Giulia Lioi and Nicolas Farrugia (Brain team, IMT Atlantique).
- Yann Serrand - PhD, ED SVS -supervisor: Pierre Maurel- Subject: "Development of new neuroimaging markers and analysis methods in the context of eating disorders and obesity", at INRAE, Rennes started in Feb. 2025, co-supervised with Nicolas Coquery and David Val-Laillet (Numecan, Inrae).
- Carlo Ferritto - PhD, ED Matisse - supervisor: Julie Coloigner - Subject "Modeling brain structural andfunctional connectivity in neurodegenerative diseases", Started in Oct 2023, funded by ANR NODAL.
- Carla Joud - PhD, ED Matisse - supervisor: Julie Coloigner - subject "Analyse conjointe de données multimodales en épilepsie", stared in Oct 2023 and defended in December 2025, funded by ED Matisse and ED SVS.
- Youenn Merel Jourdan - PhD, ED Matisse - Supervisors: Camille Maumet, Mathieu Acher - Subject: "Exploring the variability induced by different configurations in the neuroimaging analytical space". Started in October 2024 and funded by ANR JCJC VICUNA.
- Benjamin Prigent - PhD, ED Matisse - supervisor: Elise Bannier, Julie Coloigner - subject "Measuring brain microstructure through myelin content modelling in neurodegenerative diseases", stared in Dec 2024, funded by Inria.

- Grégoire Ville - PhD, ED Matisse - Supervisors: Emmanuel Caruyer, Julie Coloigner - Subject: "Tractography informed by anatomical and microstructure priors", started in October 2024 and funded by Moyen incitatif Inria.
- Adèle Savalle - PhD, ED Matisse - Supervisors: Emmanuel Caruyer, Julie Coloigner, Claire Cury - Subject: "Shape analysis of microstructure augmented whiter matter fascicles", started in October 2024 and funded by ANR PASTRAMI.
- Valentine Chouquet - PhD in Neuroscience, ED SVS - Supervisors: Fanny Dégeilh, Pierre Maurel - Subject: "Study of changes in brain structure and function following concussion in young children", started in September 2024.
- Andjela Dimitrijevic - PhD in Biomedical Engineering, Polythech Montreal, Canada - Supervisors: Fanny Dégeilh, Benjamin De Leener (Polythech Montreal) - Subject: "Development of a normative templates based on pediatric magnetic resonance imaging for monitoring neurodevelopmental trajectories", started in 2022.
- Gracia Khoury - PhD, ED Matisse - Supervisors: Claire Cury, Giulia Lioi, Frédéric Grouiller - Subject: "Analysis and model of MR-related artifacts on EEG signal when recorded during a fMRI sequence", started in September 2025, funded by the ANR JCJC NIRVANA
- Maud Guillen - PhD, ED SVS - supervisor: Isabelle Bonan, Pierre Maurel, Elise Bannier - Subject: "Longitudinal study after stroke of the clinical motor pattern and the cerebral reorganization according to the different damaged motor pathways (main and accessory).", started in Jan 2024, Part time (Medical Doctor)
- Marie Poirier - PhD, ED Matisse - Supervisors: Emmanuel Caruyer, Aymeric Stamm - Subject: "Robust and Patient-specific statistics in diffusion MRI"

11.2.3 Juries

- Julie Coloigner, reviewer of the PhD of Sarah Reynaud, IMT Brest, entitled "Machine learning for inverse problem resolution to study brain electrophysiological activity",defended September 29th, Brest, France.
- Julie Coloigner, reviewer of the PhD of Natacha Lambert, Univ Caen, entitled "Apprentissage à partir de données multimodales pour la classification et la prédiction de la maladie d'Alzheimer",defended December 11th, Caen, France.
- Francesca Galassi, reviewer for the PhD of P. Mathur, "From Image to Insight: Modelling Disease Progression in Medical Imaging as a Change Detection Problem", School of Computer Science, University College Dublin, defended on September 30, Dublin, Ireland.
- Fanny Dégeilh, reviewer for the PhD of E. Kerdreux, "Neuroanatomie fonctionnelle et marqueurs cérébraux dans les troubles causés par l'alcoolisation foetale, de la clinique à l'imagerie cérébrale à ultra-haut champ", Université Paris Cité, defended on December 15, Paris-Saclay, France.
- Elise Bannier, reviewer for the PhD of Z. Belkacemi "Identification de marqueurs cérébraux de la fonction motrice par Imagerie par Résonance Magnétique fonctionnelle couplée à la cinématique : comparaison entre sujets sains et pathologies neuromotrices", Université de Montpellier, defended on June 26th, Montpellier, France.
- Francesca Galassi, examiner for the PhD thesis of N. Lambert, "Apprentissage à partir de données multimodales pour la classification et la prédiction de la maladie d'Alzheimer", University of Caen, defended on December 11, Caen, France.
- Francesca Galassi, examiner for the PhD thesis of V. Tesan, "Classification automatique des traumatismes crâniens dans l'imagerie CT d'urgence", Université Grenoble Alpes, defended on December 17, Grenoble, France.

- Julie Coloigner, member for the Jury of the selection PhD grant from University of Rennes.
- Camille Maumet, member for the Jury of selection for CRCN Inria 2025 in Lyon and in Lille.
- Emmanuel Caruyer, reviewer for the PhD thesis of Élise Cosenza, "Développement de l'IRM de diffusion et de la tractographie des fibres de la substance blanche chez le petit animal à 7 Teslas", Université de Bordeaux, defended on December 5th, Bordeaux, France.
- Emmanuel Caruyer, reviewer for the PhD thesis of Nicolas Tempier, "Étude de la région subthalamique en histologie et tractographie ex et in vivo chez l'homme : Vers la réalisation d'un atlas déformable dédié à la neurochirurgie fonctionnelle", Sorbonne Université, defended on December 19th, Paris, France.
- Emmanuel Caruyer, examiner for the PhD thesis of Yanis Aeschlimann, "Alignement multimodal des réseaux cérébraux pour corriger la variabilité inter-sujets avec une application au lien structure-fonction", Université Côte d'Azur, defended on December 15th, Sophia Antipolis, France.
- Pierre Maurel, president of the doctoral defence Jury of Chloé Mercier, IMT Atlantique, Brest.
- Pierre Maurel, president of the doctoral defence Jury of Pierre Rougé, INSA, Lyon.

11.3 Popularization

11.3.1 Specific official responsibilities in science outreach structures

- Claire Cury is Scientific mediation officer in the scientific mediation team of Inria centre at Rennes Universiy.
- Claire Cury is representing the Fondation Blaise Pascal in Brittany.
- Elise Bannier, Emmanuel Caruyer, Isabelle Corouge and Camille Muller organized a visit for scholars of the Neurinfo facility on March 11th in the content of the brain awareness week (Semaine du cerveau). Five classes of about 20 scholars each took part in the visit with 4 topics : MRI, functional MRI, EEG neurofeedback, MR image processing.
- Commité scientifique local de Rennes pour la semaine du cerveau 2025 (Camille Muller)

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

- Claire Cury is the co-designer and co-supervisor of the project *Ma thèse une sacré histoire*
- Claire Cury, interview for the article "Neurofeedback : un entraînement cérébral prometteur" published in the magazine Mutualistes.

11.3.3 Participation in Live events

- Élise Bannier, Emmanuel Caruyer, Isabelle Corouge, Julie Fournier, Malo Gaubert, Pierre Maurel, Camille Muller, Alexandre Pron, Sonia Tifrea, Julie Fournier: "Semaine du cerveau 2025": Visit of the Neurinfo plateform for pupils (March 10, 2025).
- Claire Cury participated to the Séminaire national Inria Médiation Scientifique at the Ministère de l'enseignement supérieur et de la recherche (November 2025), and presented with Thomas Maugey and Camille Sicot, the project Ma thèse une sacrée histoire.

11.3.4 Others science outreach relevant activities

- Julie Fournier, Annimation of a debate game (Jeu à débattre) "IA & Santé" at a highschool in Rennes.
- Mathilde Liffran, "Les métiers de la recherche". Une co-animation dans le cadre de la formation "Médiation Scientifique", Rennes, March 2025
- Malo Gaubert, Mathilde Liffran, "Imagerie des déficits moteurs dans la sclérose en plaques". Journée Portes Ouvertes France SEP, CHU de Rennes, 28 March 2025
- Nolwenn Jégou, Valentine Chouquet, Youwan Mahé, Carla Joud, Mathilde Liffran: Semaine du cerveau (Brain Awareness Week): organization and preparation of a quiz on neuroimaging research (jobs, image processing, methods, and key findings), presented at the Café des Champs Libres, Rennes. [52]
- Youwan Mahé: "1 scientifique, 1 classe : chiche !": outreach session on the basics of AI at Lycée La Mennais, Ploërmel.
- Adèle Savalle, Prigent Benjamin, Youwan Mahé: Fête de la science (Science Festival): presentation of our research and the use of AI at the Village des Sciences, Cité des Métiers in Ploufragan Octobre 2025.

12 Scientific production

12.1 Major publications

[1] A. Ackaouy, N. Courty, E. Vallée, O. Commowick, C. Barillot and F. Galassi. 'Unsupervised Domain Adaptation With Optimal Transport in Multi-Site Segmentation of Multiple Sclerosis Lesions From MRI Data'. In: *Frontiers in Computational Neuroscience* 14 (9th Mar. 2020), pp. 1–13. DOI: 10.3389/fncom.2020.00019. URL: https://hal.archives-ouvertes.fr/hal-02317028.

[2] A. Bowring, T. Nichols and C. Maumet. 'Isolating the Sources of Pipeline-Variability in Group-Level Task-fMRI results'. In: *Human Brain Mapping* 43.3 (15th Feb. 2022), pp. 1112–1128. DOI: 10.1002/hbm.25713. URL: https://inserm.hal.science/inserm-03323001.

[3] B. Combès, A. Kerbrat, J.-C. Ferré, V. Callot, J. Maranzano, A. Badji, E. Le Page, P. Labauge, X. Ayrignac, C. Carra Dallière, N. M. de Champfleur, J. Pelletier, A. Maarouf, J. De Sèze, N. Collongues, D. Brassat, F. Durand-Dubief, C. Barillot, E. Bannier and G. Edan. 'Focal and diffuse cervical spinal cord damage in patients with early relapsing–remitting MS: A multicentre magnetisation transfer ratio study'. In: *Multiple Sclerosis Journal* 25.8 (Feb. 2019), pp. 1113–1123. DOI: 10.1177/1352458518781999. URL: https://www.hal.inserm.fr/inserm-02457569.

[4] O. Commowick, A. Istace, M. Kain, B. Laurent, F. Leray, M. Simon, S. C. Pop, P. Girard, R. Ameli, J.-C. Ferré, A. Kerbrat, T. Tourdias, F. Cervenansky, T. Glatard, J. Beaumont, S. Doyle, F. Forbes, J. Knight, A. Khademi, A. Mahbod, C. Wang, R. Mckinley, F. Wagner, J. Muschelli, E. Sweeney, E. Roura, X. Llado, M. Santos, W. P. Santos, A. G. Silva-Filho, X. Tomas-Fernandez, H. Urien, I. Bloch, S. Valverde, M. Cabezas, F. J. Vera-Olmos, N. Malpica, C. R. G. Guttmann, S. Vukusic, G. Edan, M. Dojat, M. Styner, S. K. Warfield, F. Cotton and C. Barillot. 'Objective Evaluation of Multiple Sclerosis Lesion Segmentation using a Data Management and Processing Infrastructure'. In: *Scientific Reports* 8.1 (Dec. 2018), p. 13650. DOI: 10.1038/s41598-018-31911-7. URL: https://www.hal.inserm.fr/inserm-01847873.

[5] C. Cury, P. Maurel, R. Gribonval and C. Barillot. 'A sparse EEG-informed fMRI model for hybrid EEG-fMRI neurofeedback prediction'. In: *Frontiers in Neuroscience* 13 (Jan. 2020). DOI: 10.3389/fnins.2019.01451. URL: https://www.hal.inserm.fr/inserm-02090676.

[6] T. Durantel, G. Girard, E. Caruyer, O. Commowick and J. Coloigner. 'A Riemannian framework for incorporating white matter bundle priors in ODF-based tractography algorithms.' In: *PLoS ONE* (2024), pp. 1–10. URL: https://hal.science/hal-04246380. In press.

[7] E. Germani, E. Fromont and C. Maumet. 'On the benefits of self-taught learning for brain decoding'. In: *GigaScience* 12 (3rd May 2023), pp. 1–17. DOI: 10.1093/gigascience/giad029. URL: https://inria.hal.science/hal-03769993.

[8] A. Kerbrat, C. Gros, A. Badji, E. Bannier, F. Galassi, B. Combès, R. Chouteau, P. Labauge, X. Ayrignac, C. Carra Dallière, J. Maranzano, T. Granberg, R. Ouellette, L. Stawiarz, J. Hillert, J. Talbott, Y. Tachibana, M. Hori, K. Kamiya, L. Chougar, J. Lefeuvre, D. Reich, G. Nair, P. Valsasina, M. Rocca, M. Filippi, R. Chu, R. Bakshi, V. Callot, J. Pelletier, B. Audoin, A. Maarouf, N. Collongues, J. de Sèze, G. Edan and J. Cohen-Adad. 'Multiple sclerosis lesions in motor tracts from brain to cervical cord: spatial distribution and correlation with disability'. In: *Brain - A Journal of Neurology* 143.7 (1st July 2020), pp. 2089–2105. DOI: 10.1093/brain/awaa162. URL: https://www.hal.inserm.fr/inserm-02910842.

[9] A. Legouhy, F. Rousseau, C. Barillot and O. Commowick. 'An iterative centroid approach for diffeomorphic online atlasing'. In: *IEEE Transactions on Medical Imaging* 41.9 (2022), pp. 2521–2531. DOI: 10.1109/tmi.2022.3166593. URL: https://hal.inria.fr/hal-03672588.

[10] G. Lioi, S. Butet, M. Fleury, E. Bannier, A. Lécuyer, I. Bonan and C. Barillot. 'A Multi-Target Motor Imagery Training Using Bimodal EEG-fMRI Neurofeedback: A Pilot Study in Chronic Stroke Patients'. In: *Frontiers in Human Neuroscience* 14 (Feb. 2020), pp. 1–13. DOI: 10.3389/fnhum.2020.00037. URL: https://hal.inria.fr/hal-02491848.

[11] G. Lioi, A. Veliz, J. Coloigner, Q. Duché, S. Butet, M. Fleury, E. Leveque-Le Bars, E. Bannier, A. Lécuyer, C. Barillot and I. Bonan. 'The impact of Neurofeedback on effective connectivity networks in chronic stroke patients: an exploratory study'. In: *Journal of Neural Engineering* 18.5 (22nd Sept. 2021), p. 056052. DOI: 10.1088/1741-2552/ac291e. URL: https://hal-imt-atlantique.archives-ouvertes.fr/hal-03354296.

[12] C. Meurée, P. Maurel, J.-C. Ferré and C. Barillot. 'Patch-Based Super-Resolution of Arterial Spin Labeling Magnetic Resonance Images'. In: *NeuroImage* 189 (Jan. 2019), pp. 85–94. DOI: 10.1016/j.neuroimage.2019.01.004. URL: https://www.hal.inserm.fr/inserm-01880726.

[13] G. H. Robert, Q. Luo, T. Yu, C. Chu, A. Ing, T. Jia, D. Papadopoulos-Orfanos, E. Burke-Quinlan, S. Desrivières, B. Ruggeri, P. Spechler, B. Chaarani, N. Tay, T. Banaschewski, A. L. Bokde, U. Bromberg, H. Flor, V. Frouin, P. Gowland, A. Heinz, B. Ittermann, J.-L. Martinot, M.-L. P. Martinot, F. Nees, L. Poustka, M. N. Smolka, N. C. Vetter, R. Whelan, P. Conrod, T. Barker, H. Garavan and G. Schumann. 'Association of Gray Matter and Personality Development With Increased Drunkenness Frequency During Adolescence'. In: *JAMA Psychiatry* 77.4 (1st Apr. 2020), pp. 409–419. DOI: 10.1001/jamapsychiatry.2019.4063. URL: https://hal-univ-rennes1.archives-ouvertes.fr/hal-02443923.

[14] J.-C. Roy, T. Desmidt, S. Dam, I. Mirea-Grivel, L. Weyl, E. Bannier, L. Barantin, D. Drapier, J.-M. Batail, R. David, J. Coloigner and G. H. Robert. 'Connectivity patterns of the core resting-state networks associated with apathy in late-life depression'. In: *Journal of Psychiatry and Neuroscience* 48.6 (1st Nov. 2023), E404–E413. DOI: 10.1503/jpn.230008. URL: https://hal.science/hal-04295208.

12.2 Publications of the year

International journals

[15] J.-M. Batail, I. Corouge, T. Blanchard, J.-C. Roy, G. Robert and D. Drapier. 'Inflammatory and MRI perfusion biomarkers in predicting persistence of depression: a 6-month Longitudinal Study'. In: *Translational Psychiatry* 15.1 (2025), p. 370. DOI: 10.1038/s41398-025-03587-x. URL: https://hal.science/hal-05341038 (cit. on p. 38).

[16] A.-C. Binter, M. López-Vicente, S. Petricola, E. Hessel, E. Bannier, M. Cirach, M. Nieuwenhuijsen, C. Chevrier, M. van den Heuvel, M. Vrijheid, D. Saint-Amour, H. Tiemeier and M. Guxens. 'Urban environment in early-life and brain morphology in preadolescents'. In: *Environmental Pollution* 388 (1st Nov. 2025), p. 127333. DOI: 10.1016/j.envpol.2025.127333. URL: https://hal.science/hal-05400321 (cit. on p. 24).

[17] S. Butet, M. Fleury, Q. Duché, E. Bannier, G. Lioi, L. Scotto Di Covella, E. Lévêque-Le Bars, A. Lécuyer, P. Maurel and I. Bonan. 'EEG-fMRI neurofeedback versus motor imagery after stroke, a randomized controlled trial'. In: *Journal of NeuroEngineering and Rehabilitation* 22.1 (25th Mar. 2025), p. 67. DOI: 10.1186/s12984-025-01598-9. URL: https://inria.hal.science/hal-05007645 (cit. on p. 35).

[18] N. Coquery, M. Som, Y. Serrand, M.-O. Guittière, E. Bannier, F. Lainé, A. Constant, R. Moirand, E. Stice, D. Val-Laillet and R. Thibault. 'Food addiction severity is associated with decreased functional connectivity and responses to palatable food pictures in brain areas involved in emotion and cognitive control'. In: *Clinical Nutrition* 51 (Aug. 2025), pp. 115–125. DOI: 10.1016/j.clnu.2025.06.001. URL: https://ehesp.hal.science/hal-05110837 (cit. on p. 31).

[19] S. Dam, J.-M. Batail, P. Maurel and J. Coloigner. 'Multimodal Graph Convolutional Network on Brain Structure and Function in Adolescent Anxiety and Depression'. In: *IEEE Transactions on Signal and Information Processing over Networks* 11 (June 2025), pp. 617–629. DOI: 10.1109/TSIPN.2025.3577354. URL: https://hal.science/hal-04764608 (cit. on p. 32).

[20] S. Dam, J. Coloigner and D. v. D. Ville. 'Graph Slepian Framework for Guided Filtering With Application to Neuroimaging'. In: *IEEE Transactions on Biomedical Engineering* (2025), pp. 1–10. DOI: 10.1109/TBME.2025.3628058. URL: https://inria.hal.science/hal-05353573 (cit. on p. 32).

[21] T. Desmidt, M.-J. Santiago-Ribeiro, G. Robert, F. Blanc, S. L. de la Chapelle, R. David, P. Vandel, S. Benbrika, V. Leroy, F. Lejeune, F. Andersson, L. Barantin, V. Gissot, J. Vercouillie, N. Arlicot, W. El-Hage, A. Caille and V. Camus. 'Affective Symptoms and Amyloid Plaques: Antidepressant Response and Clinical Outcome Associated With Brain Amyloid Load in a 2-Year Cohort of Nondemented Older Adults With Depression—The ASAP Study'. In: *American Journal of Geriatric Psychiatry* 33.9 (Sept. 2025), pp. 962–973. DOI: 10.1016/j.jagp.2025.04.214. URL: https://hal.science/hal-05392996.

[22] R. Di Cosmo, S. Granger, K. Hinsen, N. Jullien, D. Le Berre, V. Louvet, C. Maumet, C. Maurice, R. Monat and N. Rougier. 'Stop treating code like an afterthought: record, share and value it: Scientists, research institutions, funders, libraries and publishers must all improve software practices'. In: *Nature* 646.8084 (7th Oct. 2025), pp. 284–286. DOI: 10.1038/d41586-025-03196-0. URL: https://inria.hal.science/hal-05306427 (cit. on p. 39).

[23] A. Di Matteo, Y. Mahé, S. s. Leplaideur, I. Bonan, E. Bannier and F. Galassi. 'Deep Learning and Multi-Modal MRI for the Segmentation of Sub-Acute and Chronic Stroke Lesions'. In: *Pattern Recognition Letters* 199 (14th Nov. 2025), pp. 225–231. DOI: 10.1016/j.patrec.2025.11.017. URL: https://inria.hal.science/hal-04647365 (cit. on p. 27).

[24] T. Durantel, G. Girard, E. Caruyer, O. Commowick and J. Coloigner. 'A Riemannian framework for incorporating white matter bundle priors in ODF-based tractography algorithms.' In: *PLoS ONE* (25th Mar. 2025), pp. 1–10. URL: https://hal.science/hal-04246380. In press (cit. on p. 30).

[25] N. Fortin-Bédard, A. Pellichero, S. Leplaideur, M.-C. Delebecque, C. Charette, W. Allègre, A. Champagne, C. Rahn, A. K. Blanchette, L. Bouyer, J. Kerdraon, M.-E. Lamontagne and F. Routhier. 'Acceptability of Overground Wearable Powered Exoskeletons for People with Spinal Cord Injury: A Multicenter Qualitative Study'. In: *Biomimetics* 10.1 (8th Jan. 2025), p. 36. DOI: 10.3390/biomimetics10010036. URL: https://hal.science/hal-04937531.

[26] E. Foussat, A. Geffrier, C. Guignans, M. Ropars, S. Butet and I. Bonan. 'Pericapsular hip chemical denervation with phenol: A case report suggesting the interest of this new tool in rehabilitation medicine'. In: *Annals of Physical and Rehabilitation Medicine* 68.6 (2025), p. 101982. DOI: 10.1016/j.rehab.2025.101982. URL: https://hal.science/hal-05068067.

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