Introduction to Neurotechnologies

Crédits ECTS
3 crédits

En bref

> **Langue de cours:** Anglais

Présentation

Prérequis

- **Mathematics:** Differential equations,
- **Physics fundamentals:** Electromagnetic fields, optics, and basic wave propagation

Objectifs d'apprentissage

- Understand the **multi-scale architecture** of the brain, from single-cell ion channels to whole-brain functional networks.
- Master a **comprehensive taxonomy** of neurotechnological tools (electric, magnetic, and optic) for brain measurement and perturbation

Description du programme

This course offers an interdisciplinary immersion into neurotechnology and neuroscience, examining the brain's multi-scale architecture—from single-cell ion channels to whole-brain functional networks—and the complete arsenal of technologies for measurement and perturbation. The curriculum is built around experimental and technological development, systematically covering electric modalities (microelectrode arrays and bioelectronics), optical modalities (optogenetics and advanced microscopy), and magnetic modalities (transcranial magnetic stimulation and functional MRI). Advanced materials, high-specificity probes, and signal extraction algorithms together enable us to monitor and perturb brain activity across spatial and temporal scales—essential for understanding neural function and treating neurodegenerative and traumatic disorders.

Teaching plan

1 - Introduction to neurosciences & neurotechnologies *(Neurotech Center, F. Chavane)*

This foundational module reviews the structure of the central nervous system and its electrical properties, including action potential propagation. The course introduces a comprehensive toolkit taxonomy classifying neurotechnological tools by modality (Electric, Magnetic, Optic) and measurement type (Direct vs. Indirect recording). A critical theme emphasizes why experimental work must be co-developed with computational models to decrypt the neural code.

2- Bioelectronic neurotechnologies *(EMSE Gardanne - D. Moreau & D. Reato)*

This course familiarizes students with recent trends in bioelectronic neurotechnology research. It begins with an overview of the state of the art and the fundamentals of designing hardware "in harmony with tissue." Students then learn the principles of microfabricating next-generation thin-film microelectrode arrays and analyzing electrophysiological signals through spike sorting. The course also introduces closed-loop algorithms for adaptive stimulation therapies. This theoretical foundation is complemented by a visit to the EMSE cleanroom and practical work on the electrochemical characterization of microelectrodes.

3 – Neurophotonics - *Neurotech Center*

Optical technologies provide cellular-level specificity and high spatiotemporal resolution, enabling simultaneous imaging and stimulation of neural activity. This capability requires genetic modifications but unlocks unprecedented control over individual neurons in animal models and in vitro systems.

- Fundamentals of Optogenetics and Applications – (E. Fino/M. Cazorla) **-**This module introduces optogenetics and photo-activable systems, which use light-sensitive proteins to selectively manipulate neuronal functions with light. Students learn how opsins can be used to activate or silence neurons while animals are performing a behavioral task. They will also learn about new photo-sensitive tools that can modify brain connectivity patterns and alter animal behavior.

- Imaging cellular dynamics in brain on chip devices– (M. Cazorla) - "Brain-on-chip" systems combine microfluidic engineering with microelectrode arrays to reconstruct neural circuits in vitro. These platforms isolate specific cellular compartments and enable simultaneous electrophysiological and live imaging of cellular and subcellular events for mechanistic studies of neural disorders and high-throughput drug screening.

- **Microscopy & endoscopy for neurophotonics–** (P. Berto) This module addresses optical strategies for accessing and manipulating neural circuits deep within living brain tissue. Students learn how non-linear microscopy and fiber-based endoscopy overcome light scattering for depth penetration, while holography, random access and light-field imaging enable high-speed stimulation and monitoring of multiple neurons.

4 – Magnetic Technologies

Magnetic technologies offer non-invasive access to the entire brain, trading spatial resolution for accessibility. This trade-off makes magnetic techniques uniquely suited to clinical applications and human neuroscience.

- Transcranial Magnetic Stimulation (TMS) - *(T. Brochier)* **-** Uses electromagnetic induction to trigger cortical currents, serving as a diagnostic probe or a therapeutic tool to modulate brain plasticity

- **Magnetic Resonance Imaging (MRI)** *(J. Sein & J. El Zaher)* **-** This module covers the physical foundations of nuclear magnetic resonance—polarization, resonance, and relaxation of hydrogen protons—and how functional MRI uses the blood-oxygen-level dependent signal to map whole-brain activity. Students explore the trade-offs between conventional high-field MRI and emerging ultra-low-field approaches. Practical sessions with an Ultra-Low Field MRI system demonstrate why low-field technology offers advantages in portability, cost-effectiveness, and accessibility for point-of-care neuroimaging

Equipe pédagogique

Pascal BERTO (pascal.berto@centrale-med.fr)

Julien SEIN (julien.sein@univ-amu.fr)

Maxime CAZORLA (maxime.cazorla@inserm.fr)

Frédéric CHAVANE (frederic.chavane@univ-amu.fr)

Davide REATO (davide.reato@univ-amu.fr)

Thomas BROCHIER (thomas.brochier@univ-amu.fr)

Elodie FINO (elodie.fino@inserm.fr)

David MOREAU (david.moreau@emse.fr)

Jana EL ZAHER (jana.el_zaher@centrale-med.fr)

Total des heures		**28h**
CM	Cours Magistral	16h
TP	Travaux Pratiques	12h

Infos pratiques

Nom responsable UE

Responsable pédagogique

Pascal Berto

pascal.berto@centrale-med.fr