



# Forum **TERATEC** 24

**Unlock the future**

The science of brain-computer interfaces

2

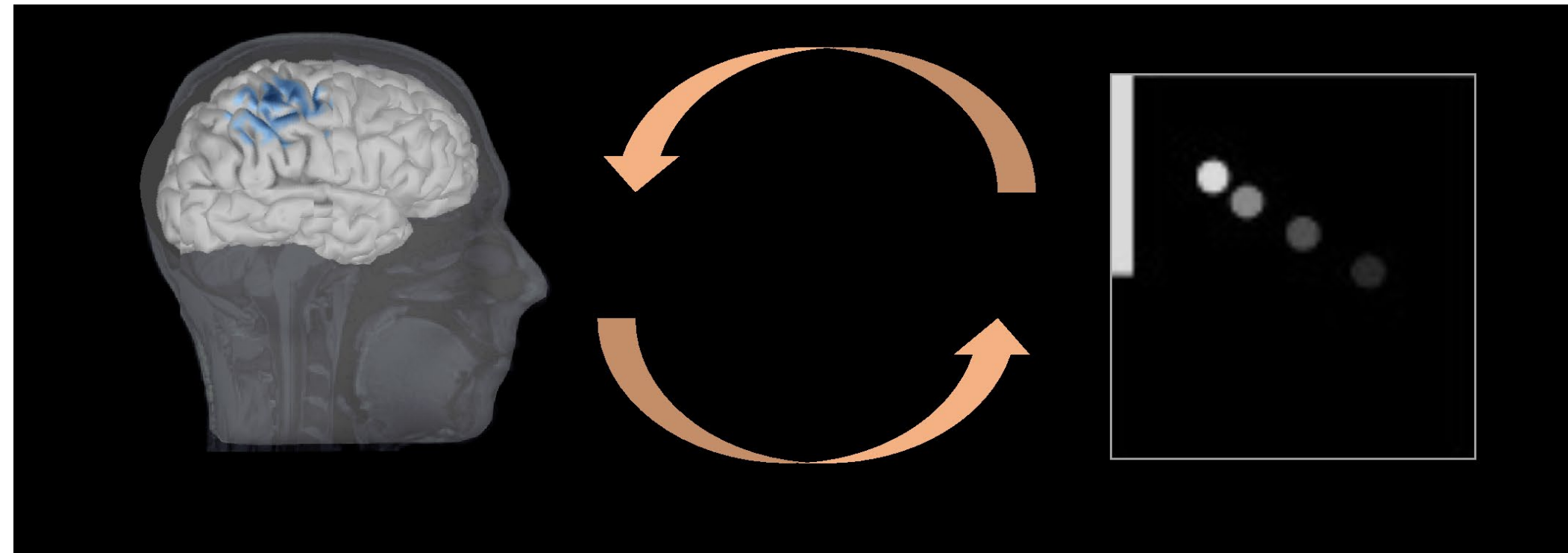
Marie-Constance Corsi

Inria research scientist,

NERV team, Paris Brain Institute



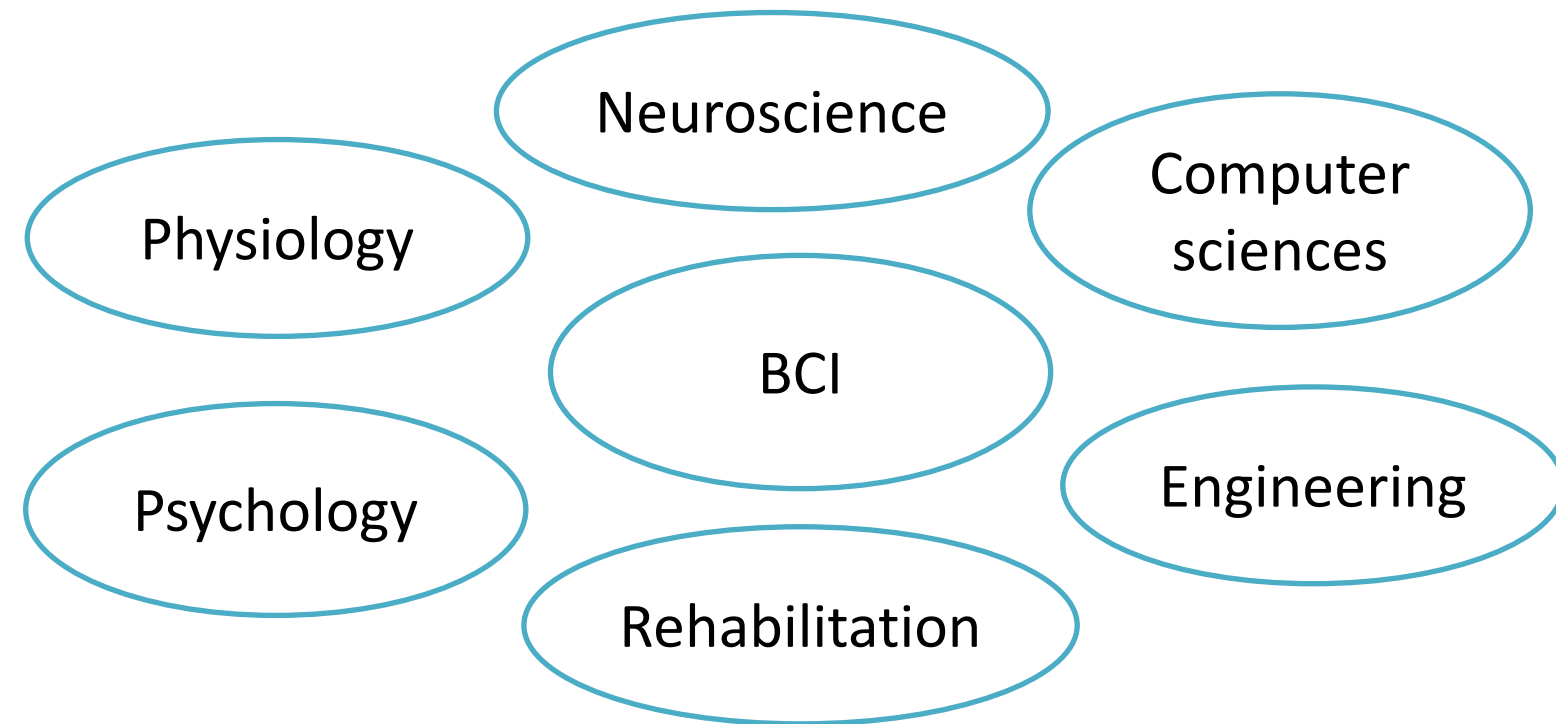
# What is a BCI?



3

**Unlock the future**

# Context



1970

1st  
implanted  
BCI

~10k publications  
3 research groups

2000

> 30k publications  
6-8 research groups

2005

> 50k publications  
> 100 research groups

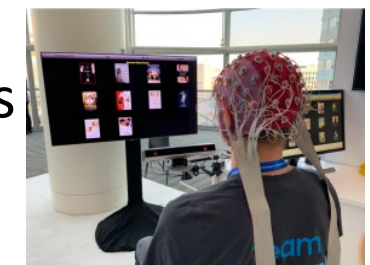
Commercialization of devices  
oriented to general public

2010



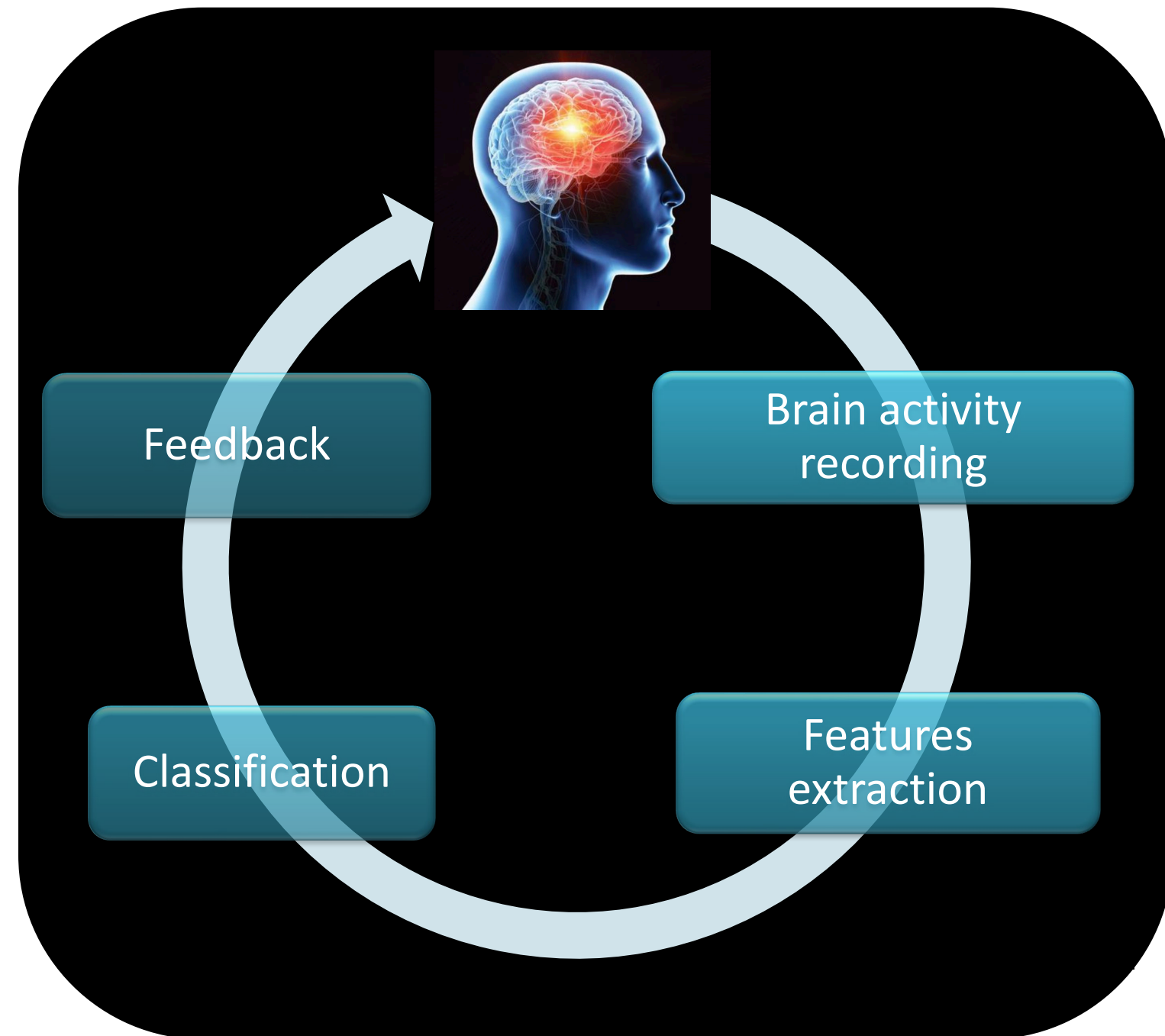
Emotiv, US

Today



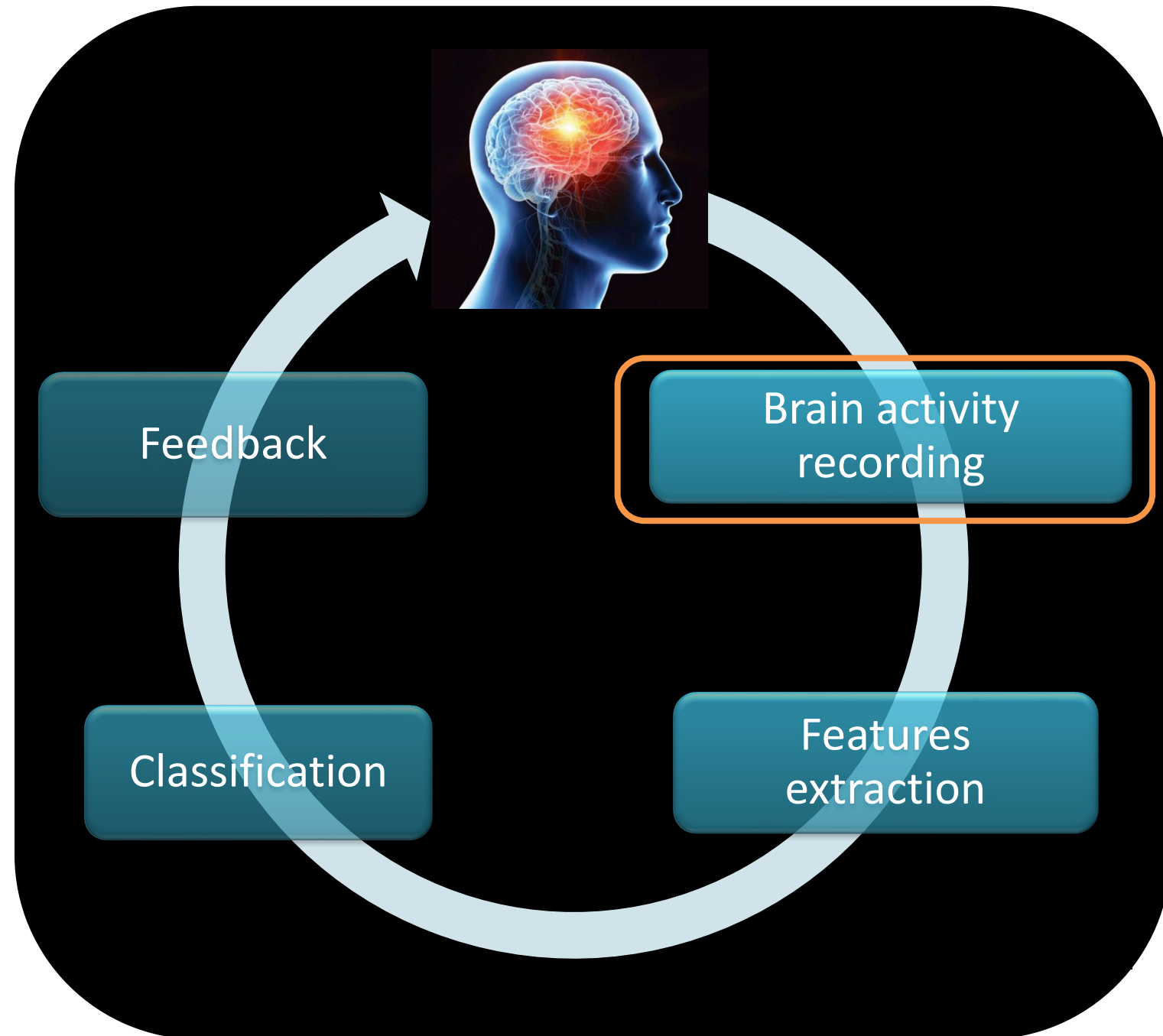
# Unlock the future

## Behind the magic...



**Unlock the future**

# Behind the magic...

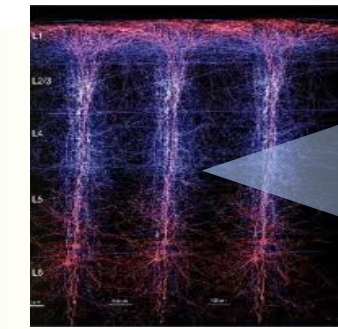


## Neurons



Micro-scale  
(nm,  $\mu\text{m}$ )

## Columns



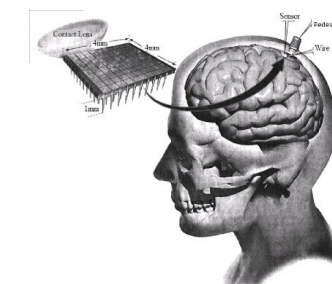
Meso-scale  
( $\mu\text{m}$ , mm)

## Regions

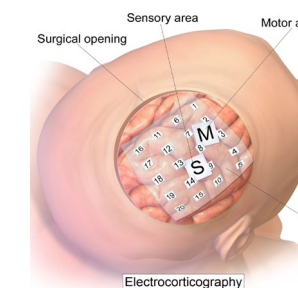


Macro-scale  
(mm, cm)

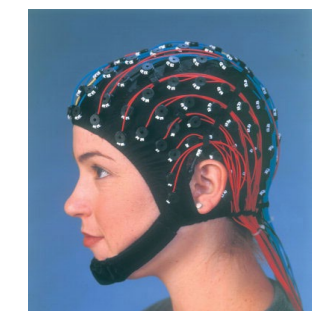
## Microarray Chip



## Electrode Grid



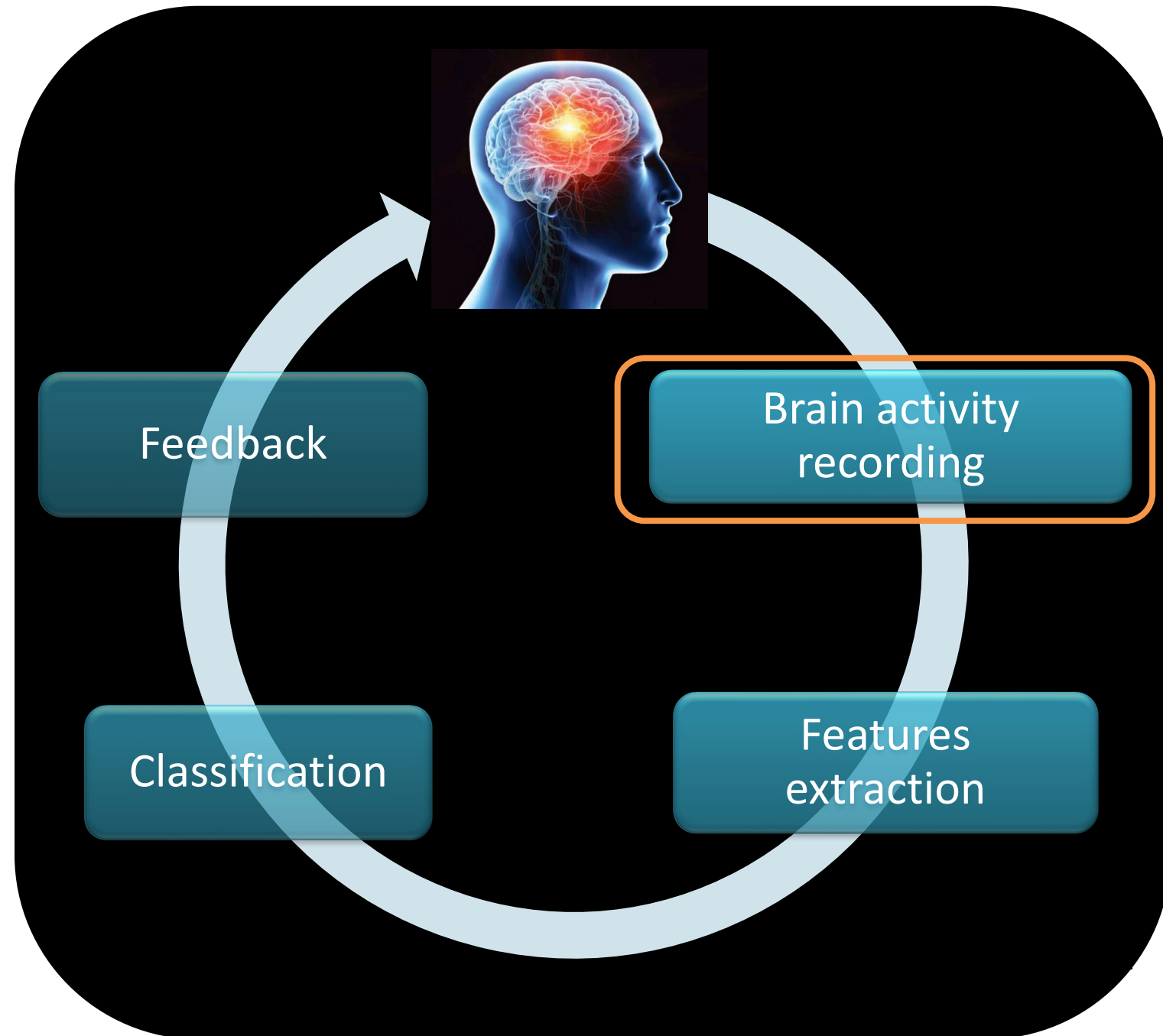
## EEG



# Unlock the future

# Behind the magic...

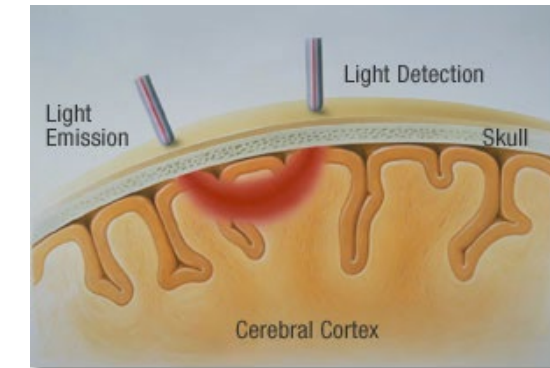
## Non-invasive tools



EEG



NIRS

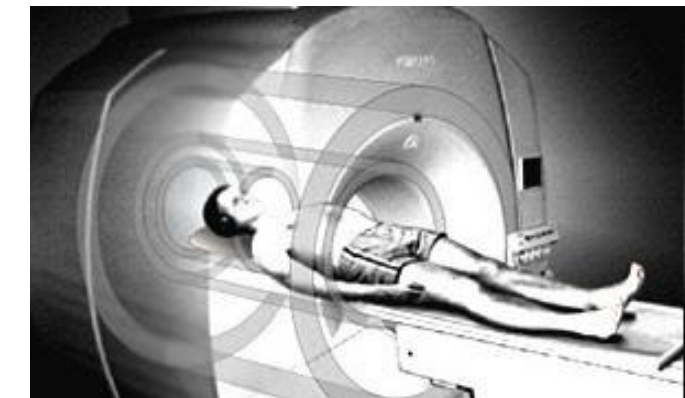


Near Infrared Spectroscopy  
(Fazli et al, 2012)

MEG



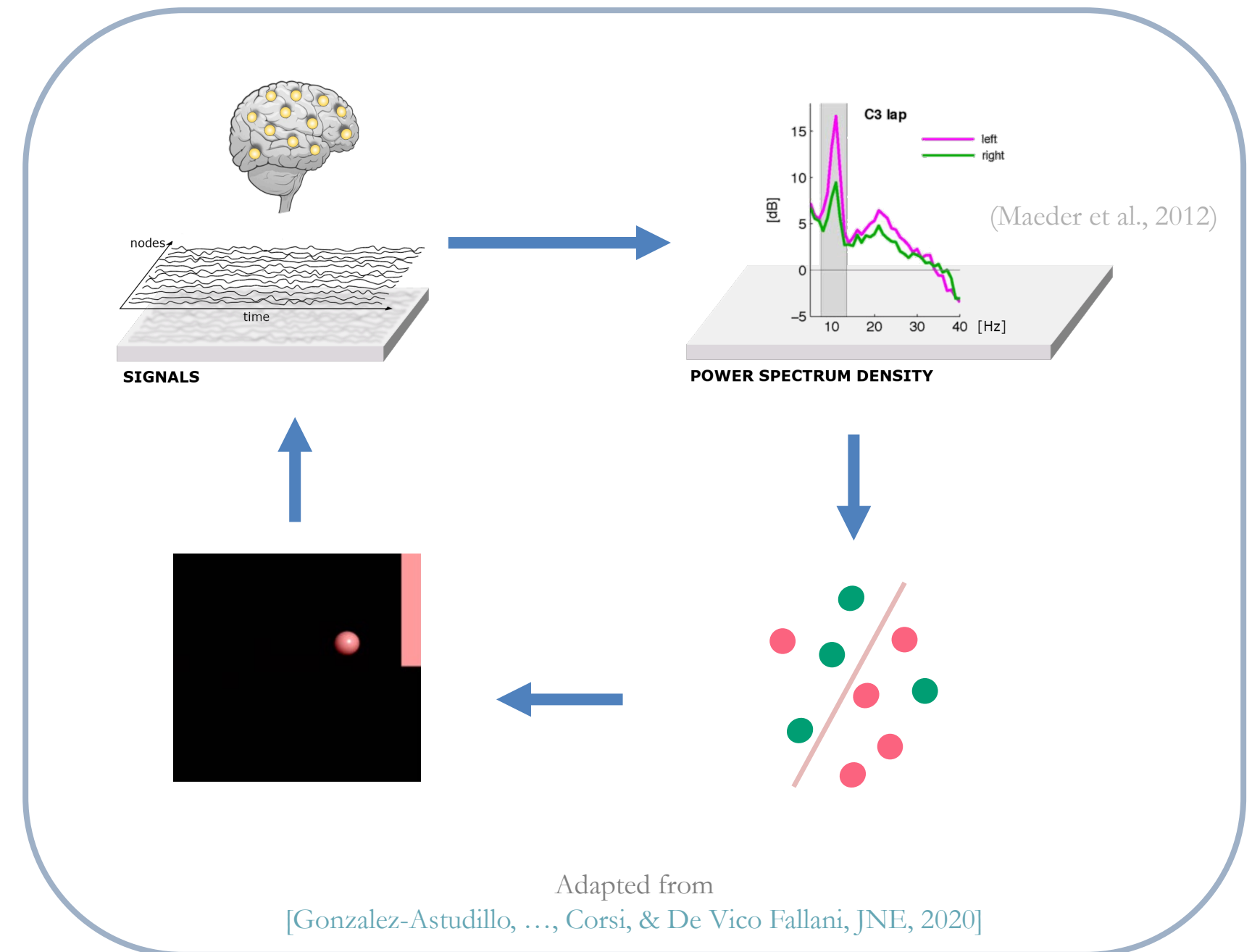
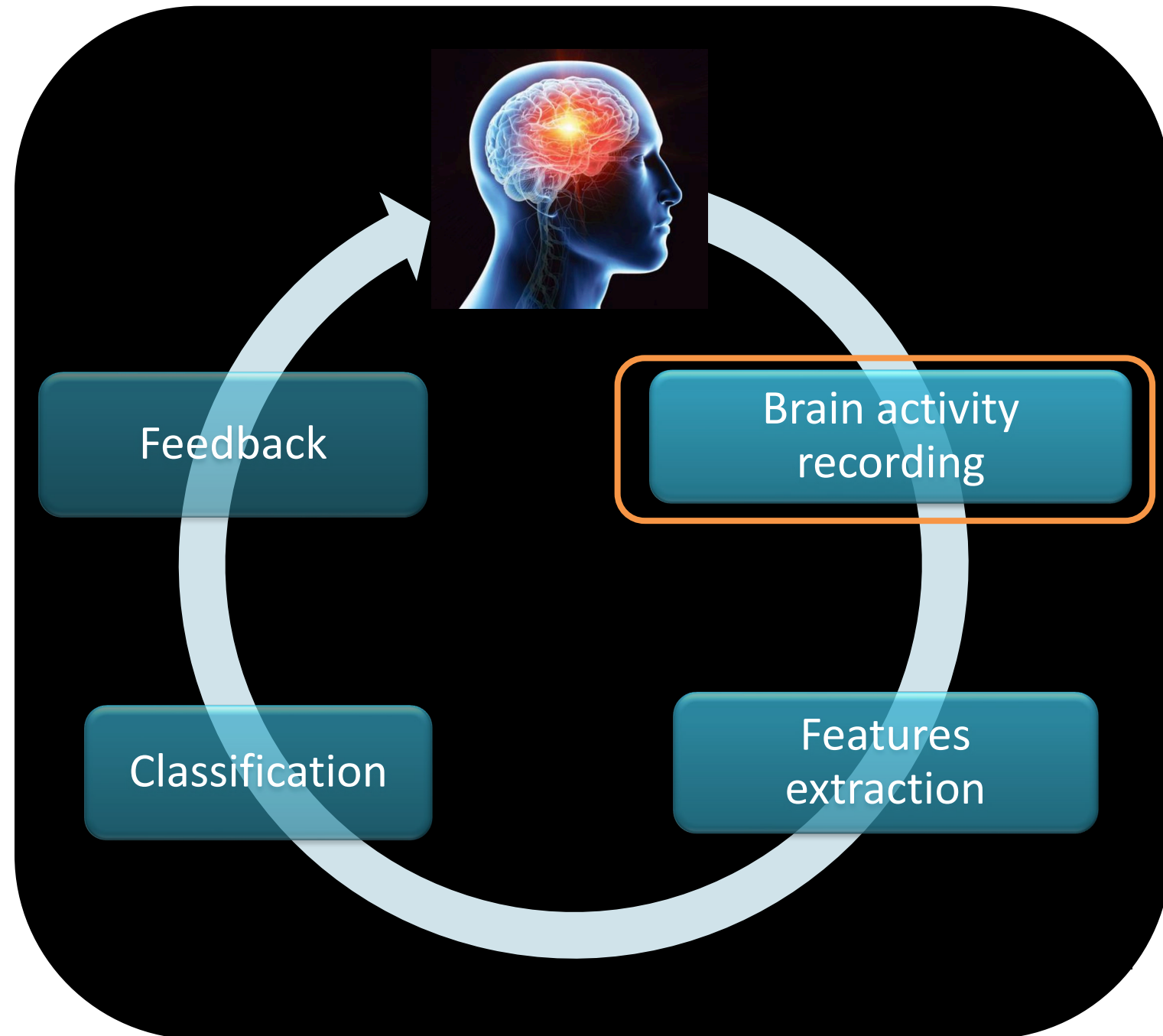
fMRI



Functional MRI  
(Sitaram et al, 2009)

# Unlock the future

# Behind the magic...



# Unlock the future

# Clinical applications

## ■ Control

- Prosthesis (Fifer et al, 2014)
- Wheelchair (Carlson & Millan, 2013)
- Quadcopter (LaFleur et al, 2013)



## ■ Communication

- Verbal & nonverbal communication (Jin et al, 2012; Hwang et al, 2012; Kashihara, 2014)
- Silent talk (Naci et al, 2013)



[BCI & communication](#)

## ■ Neurological disorders treatment

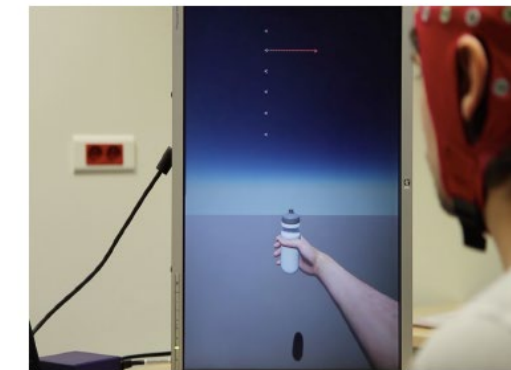
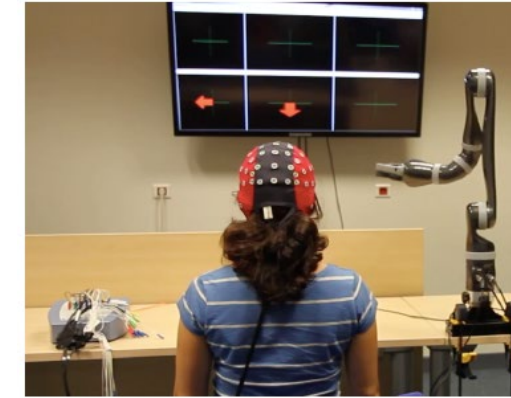
- Stroke (Prasad et al, 2010)
- Spinal cord injury (King et al, 2013)
- Consciousness (Chatelle et al, 2012)
- Psychiatric disorders (Arns et al, 2017)

**Unlock the future**

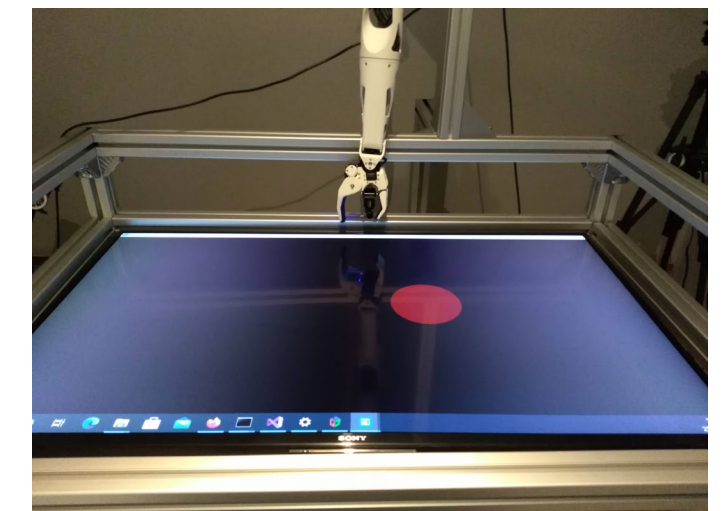


# Example of BCI research and clinical applications

- Inria software development w/ OpenViBE for:
  - Robotic device control
  - Stroke rehabilitation
  - Better monitoring general anesthesia



LORIA projects  
Courtesy of S. Rimbart

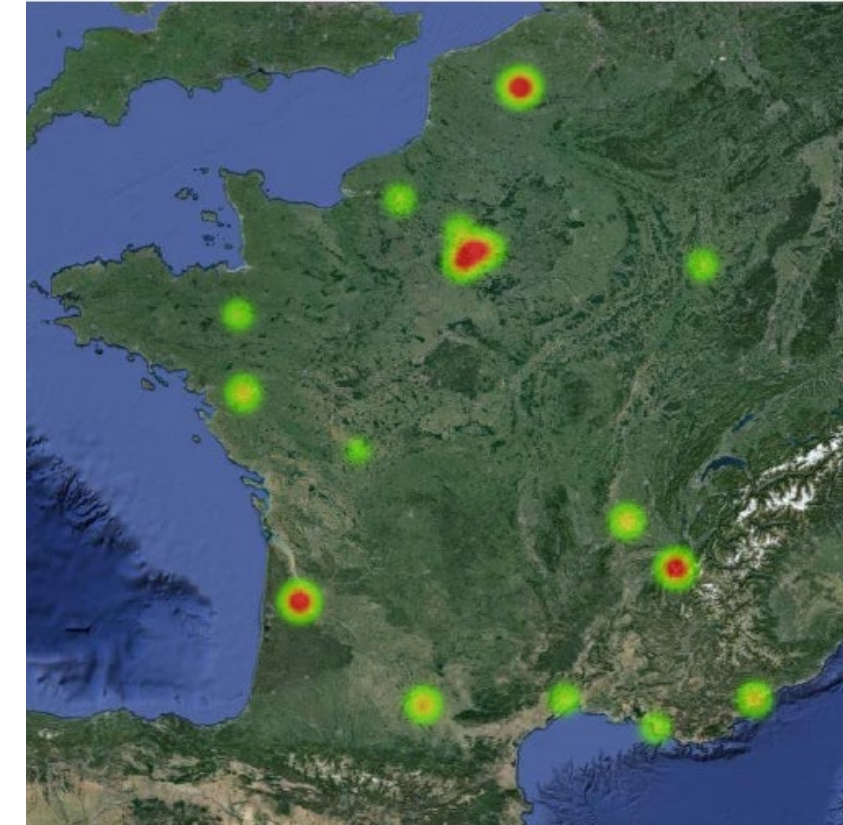


NERV projects  
Courtesy of T. Venot

**Unlock the future**

# Example of BCI research and clinical applications

- Examples of French BCI laboratories
  - LORIA team (Nancy, France)
  - Hybrid team (Rennes, France)
  - Potioc team (Bordeaux, France)
  - NERV team (Paris, France)
- Most salient disciplines:
  - EEG Signal Processing & Machine Learning
  - Clinical Neuroscience
  - Human-Computer Interaction & BCI
  - Computational Neuroscience
  - Invasive BCI research
  - Ethics



BCI labs localization in France

⇒ Access to an interactive map of laboratories: [here](#) (work in progress, not exhaustive!)

## Unlock the future

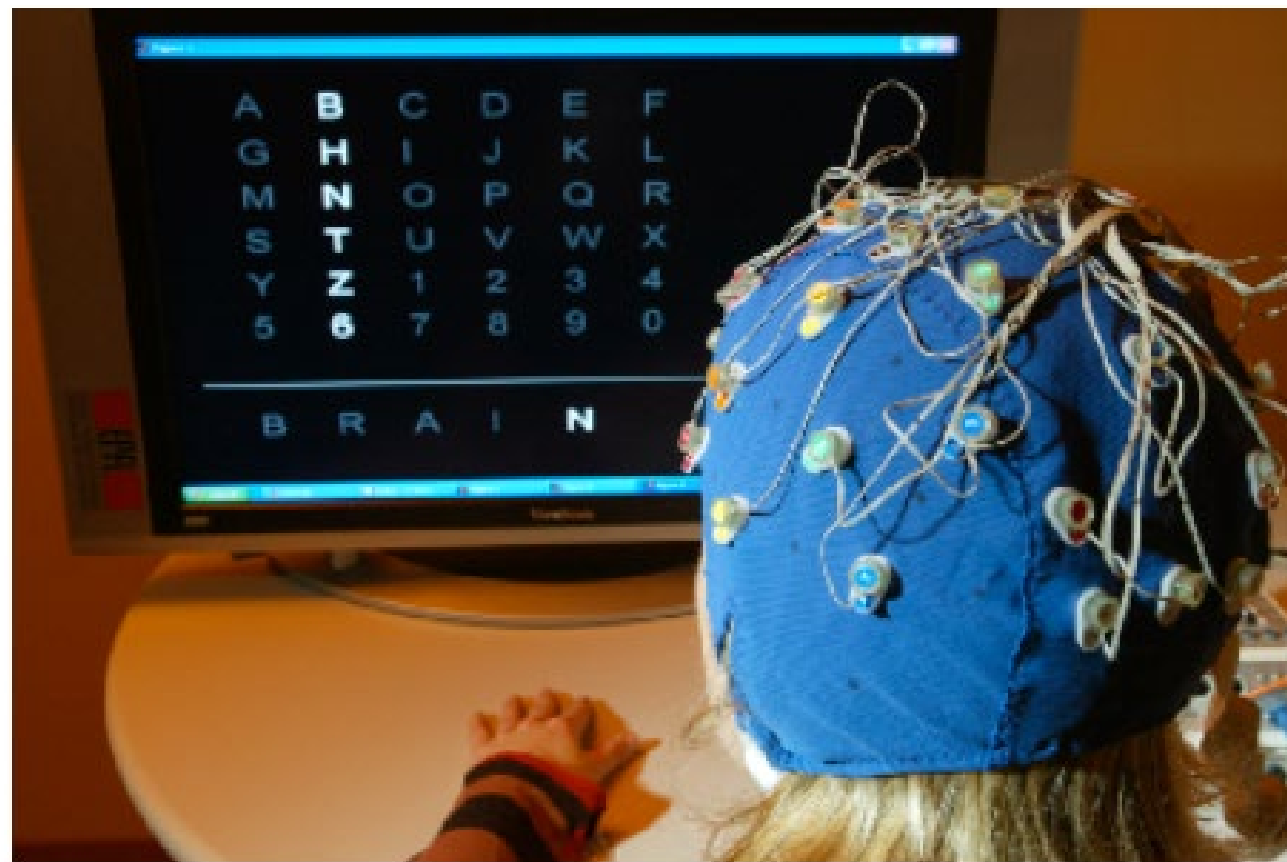
## Different types of BCI

### Underlying idea

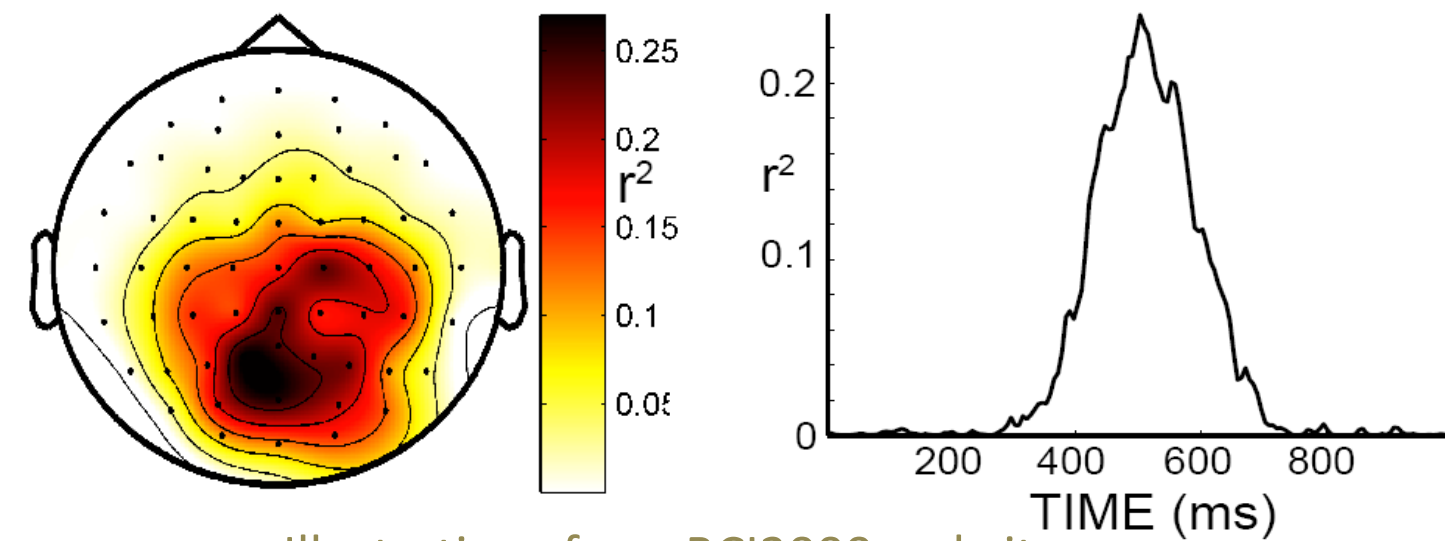
Taking advantage of a neurophysiological phenomenon to establish a communication between the brain and the computer

**Unlock the future**

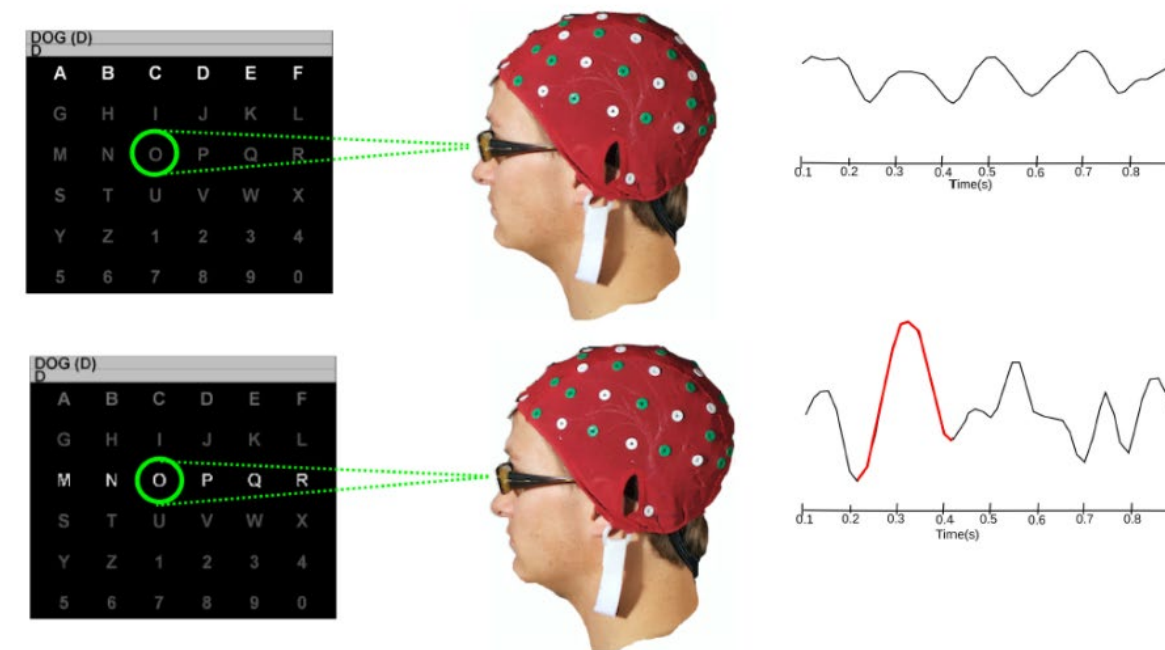
# Different types of BCI – P300 Speller



P300 Speller



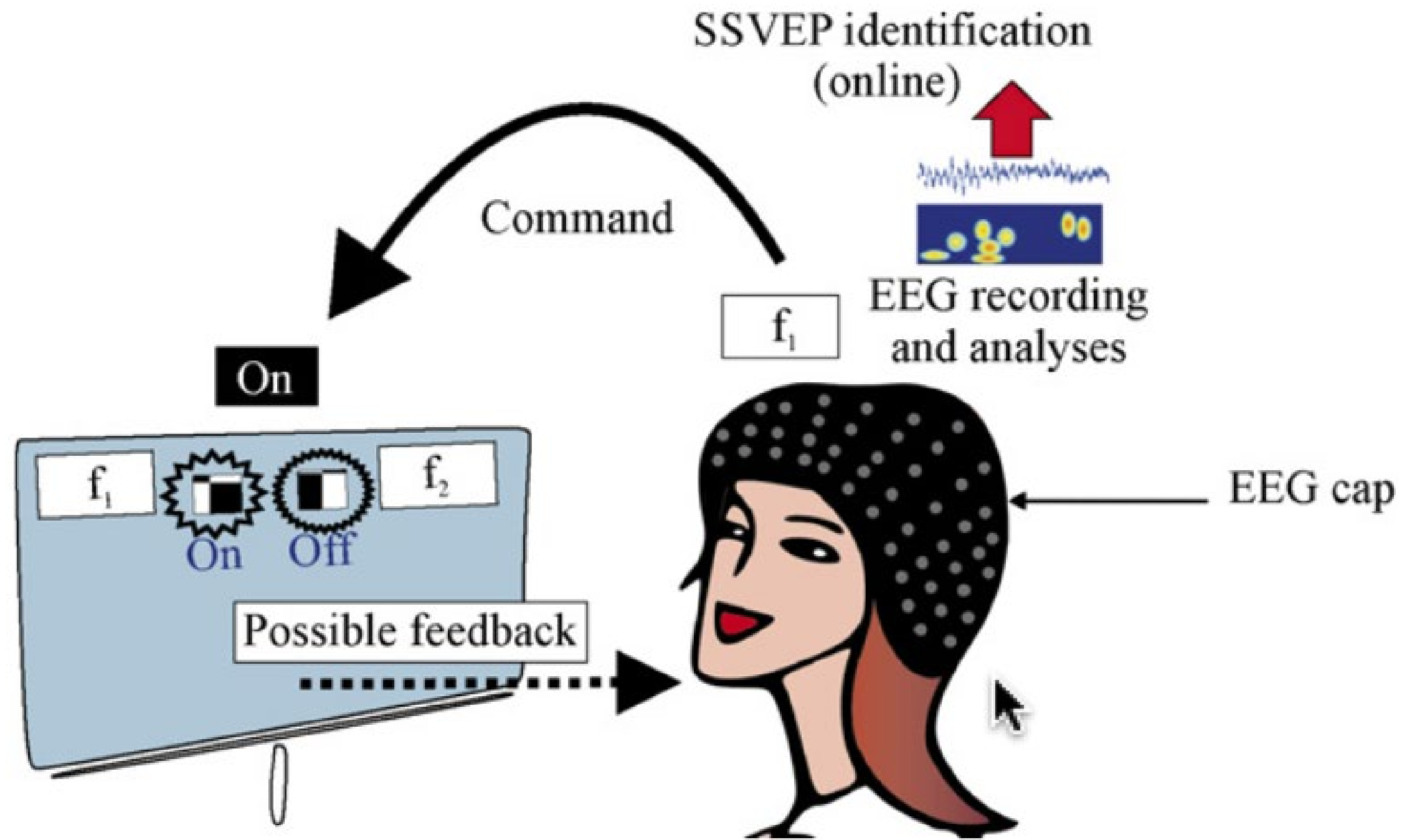
Illustrations from BCI2000 website



Adapted from [Lotte et al, 2015]

**Unlock the future**

# Different types of BCI – Visual evoked potential

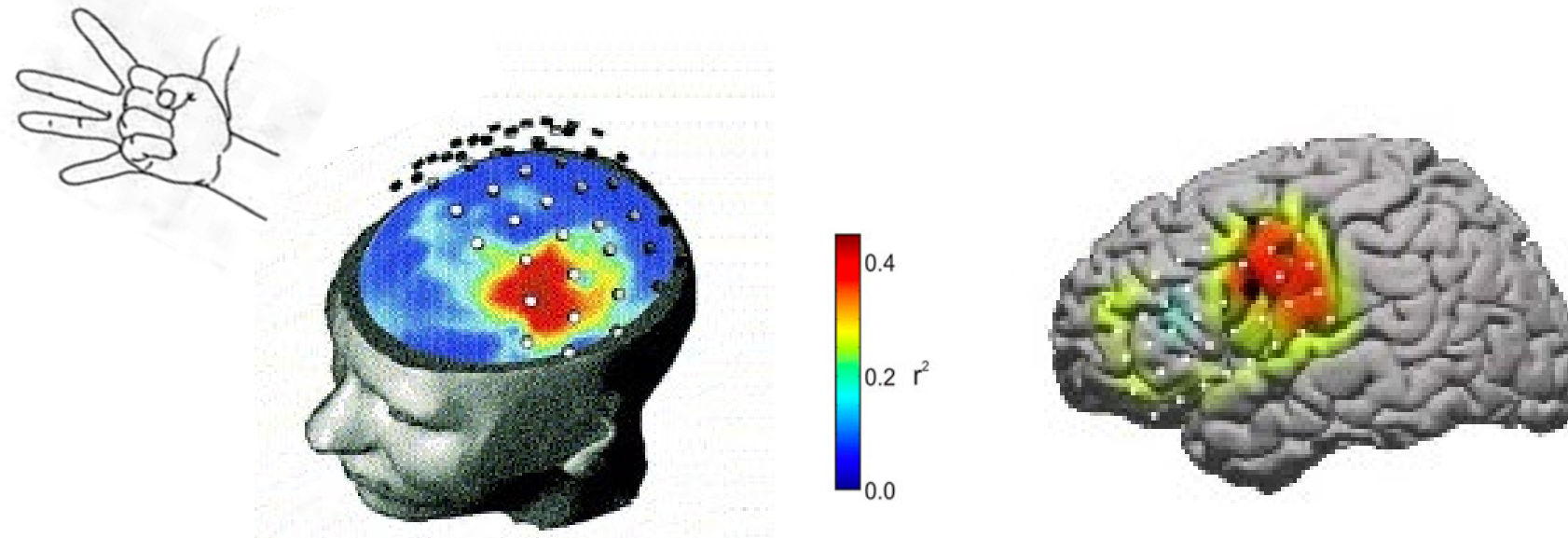


(Vialatte et al, 2010)

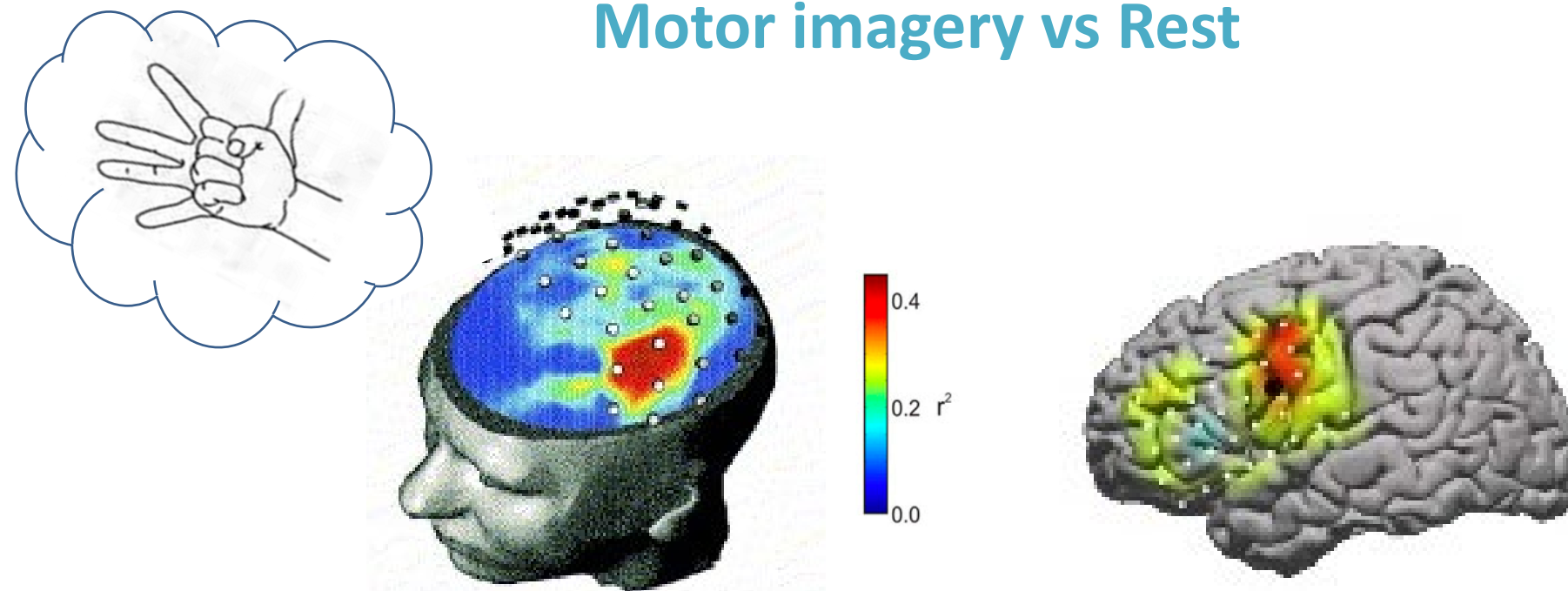
**Unlock the future**

# Different types of BCI – Motor imagery

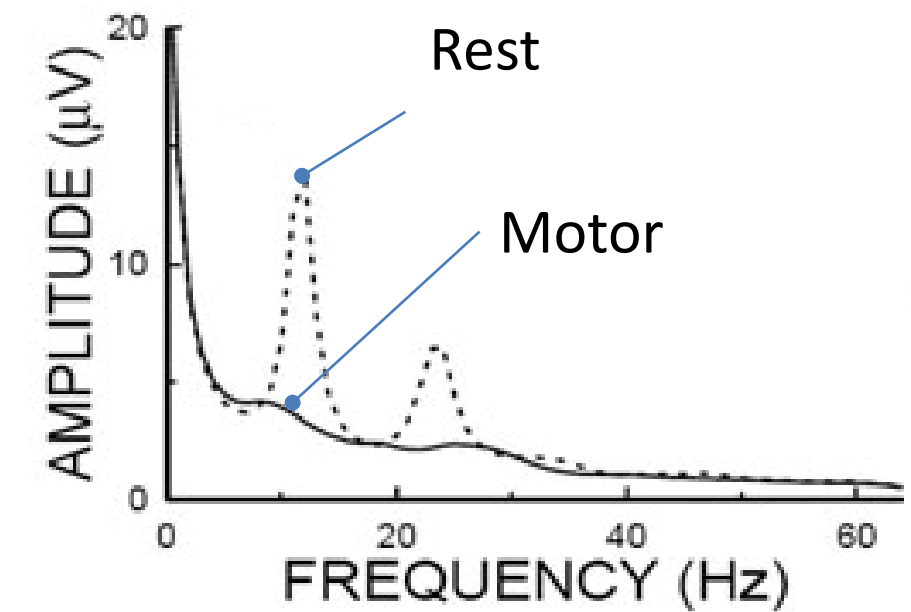
## Motor execution vs Rest



## Motor imagery vs Rest



Power decrease



Desynchronization effect  
(Pfurtscheller et al, 1999)

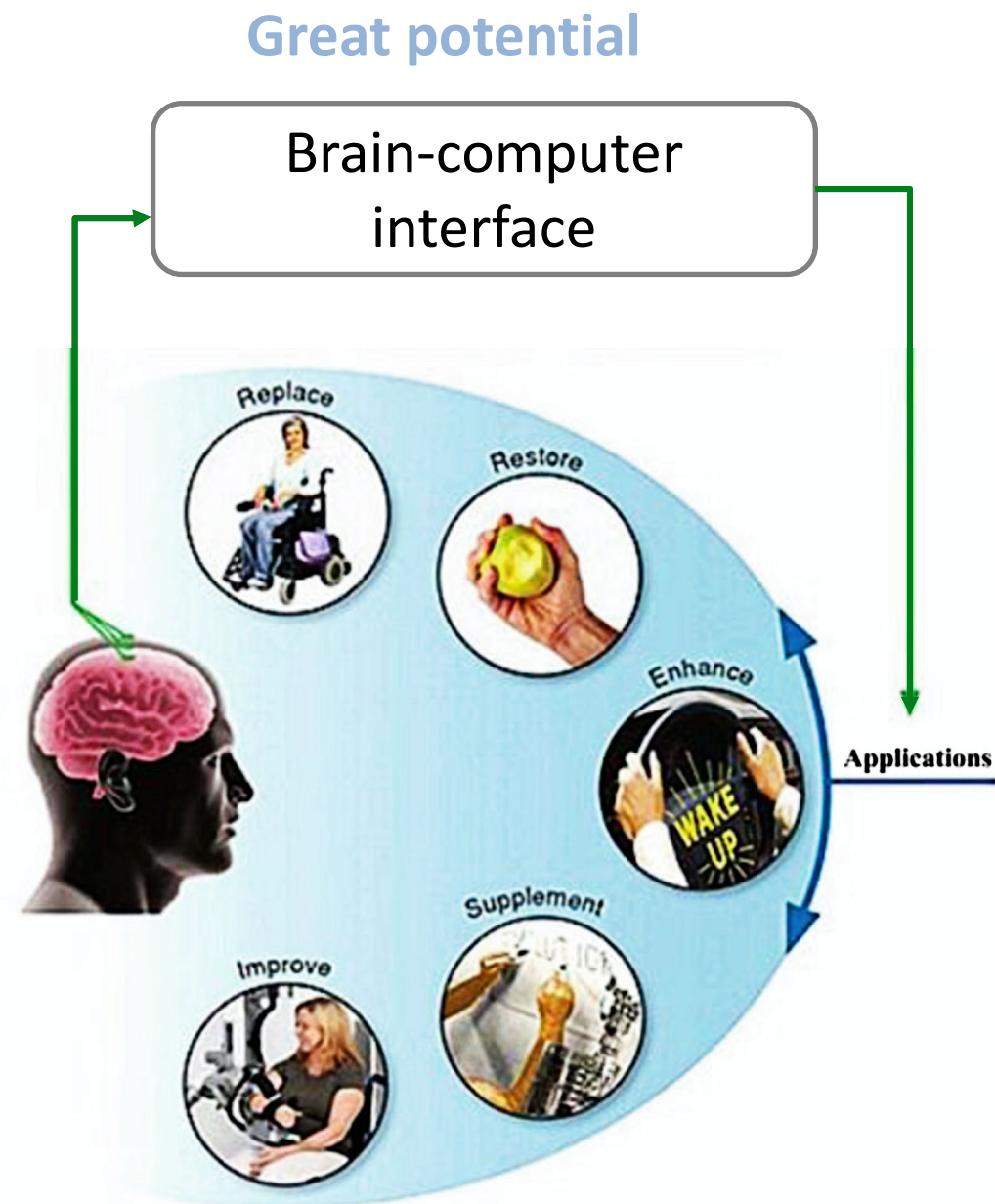
**Unlock the future**

## Different types of BCI – Motor imagery: in practice

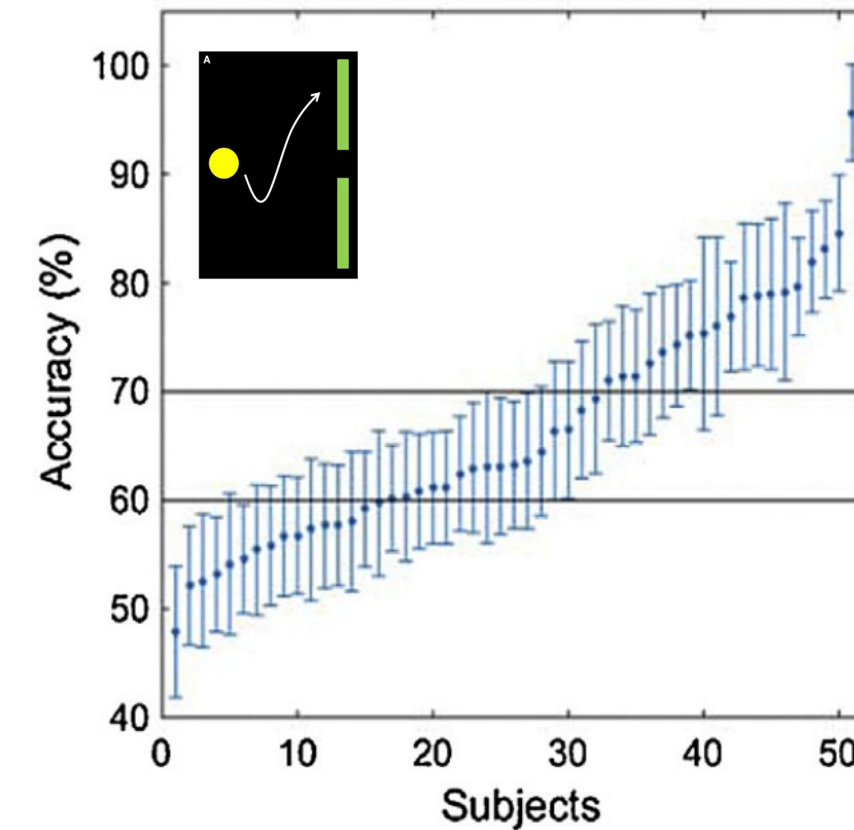


**Unlock the future**

# BCI inefficiency challenge



## Poor usability



(Ahn & Jun, 2015)

**Problem:** Current BCIs fail to detect the mental intentions in ~30% of users – **BCI inefficiency** (Thompson, 2018)

# Unlock the future



# BCI inefficiency challenge

Controlling a BCI – A tale of two learners

## Machine-centered approaches

- Signal processing (Vidaurre et al, 2011)
- Classification algorithms (Lotte et al, 2018)

⇒ Rely on EEG signals

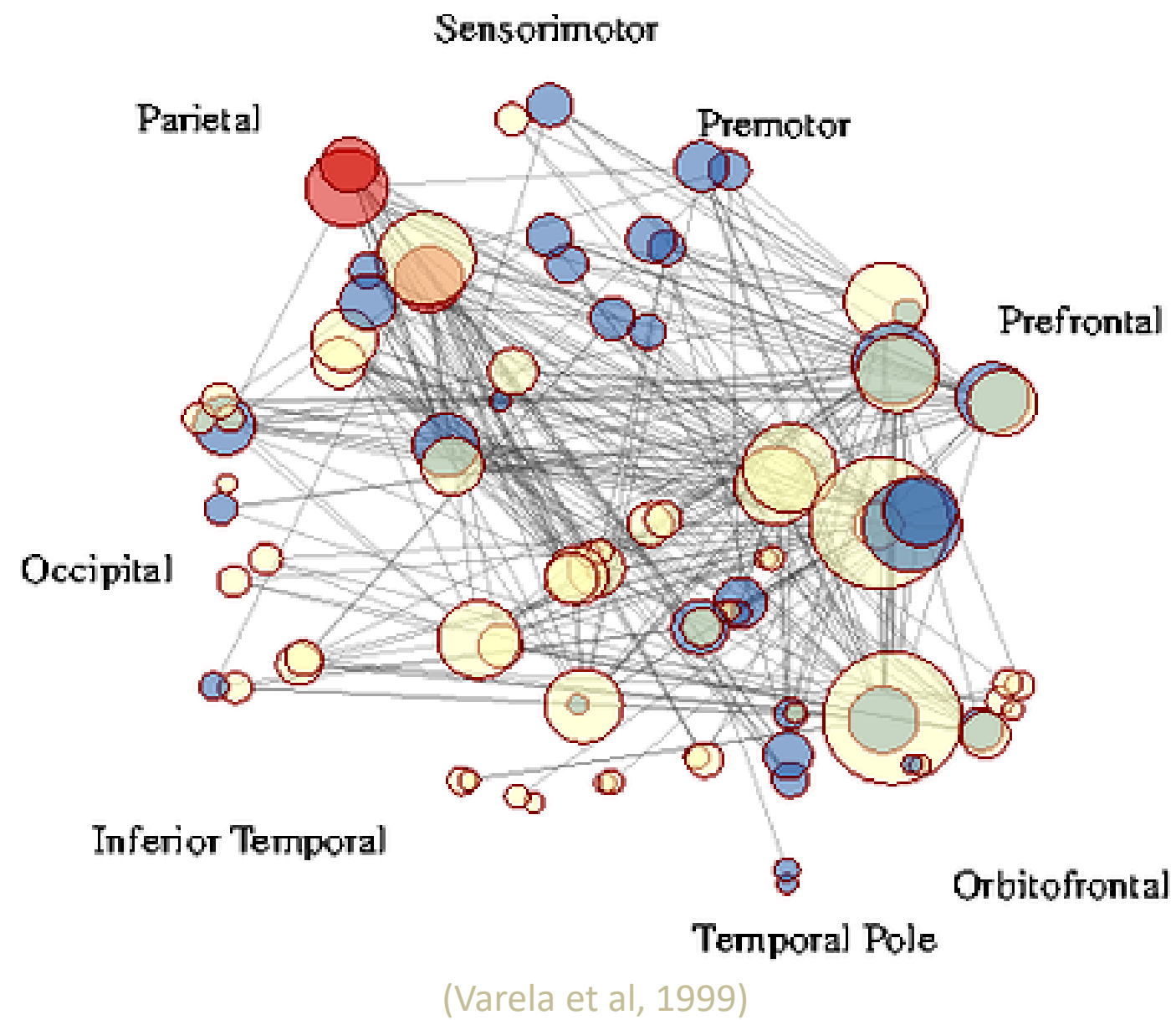
## User-centered approaches

- Neurophysiological patterns (Blankertz et al, 2010; Ahn et al, 2015)
- Human factors & Cognitive profile (Hammer et al, 2012; Jeunet et al, 2015)

⇒ Lack of reliable markers

**Unlock the future**

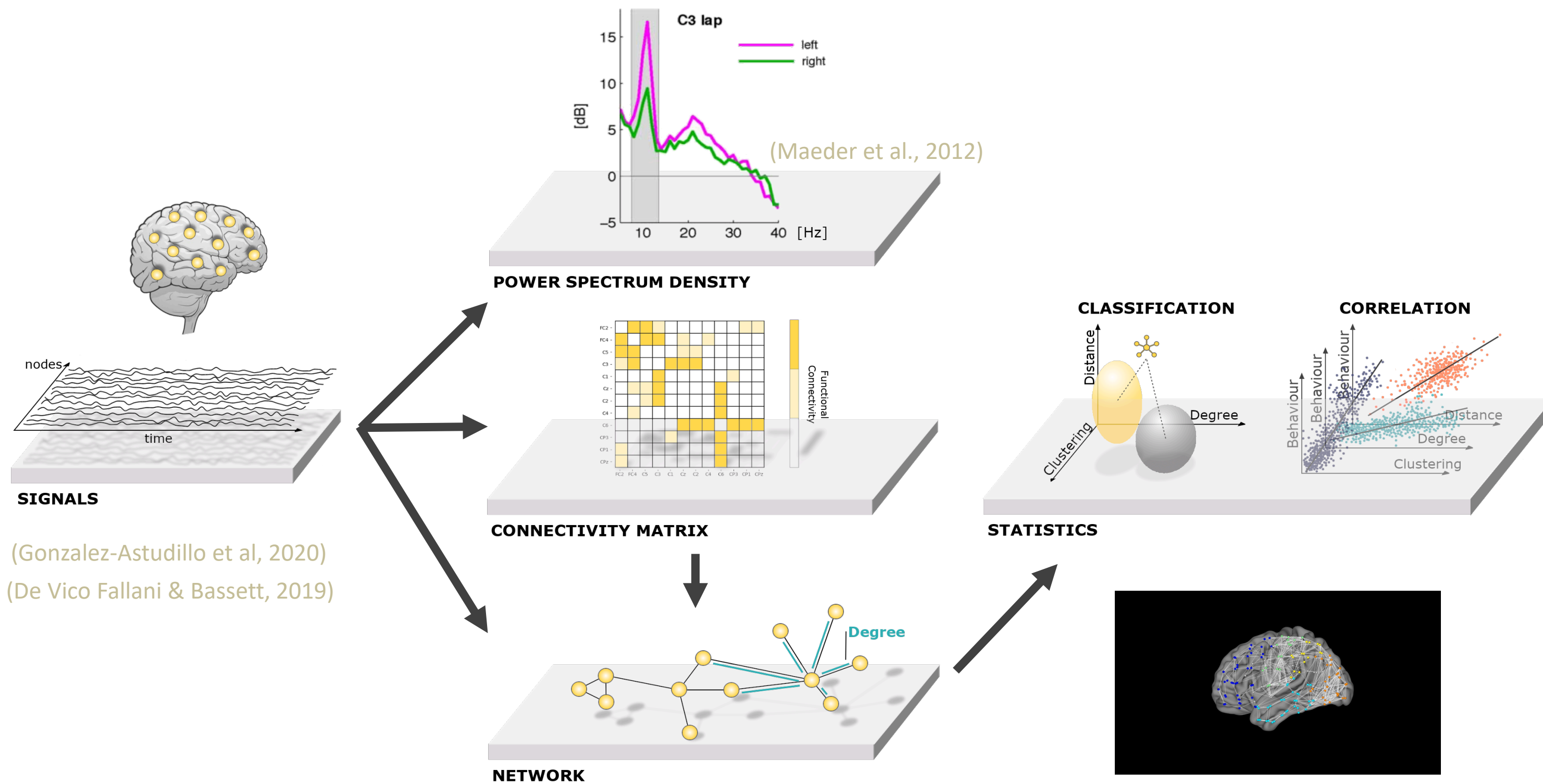
# BCI inefficiency challenge – a network approach



Use of multimodal brain networks to identify alternative features & BCI learning patterns

**Unlock the future**

# Network metrics to characterize mental states

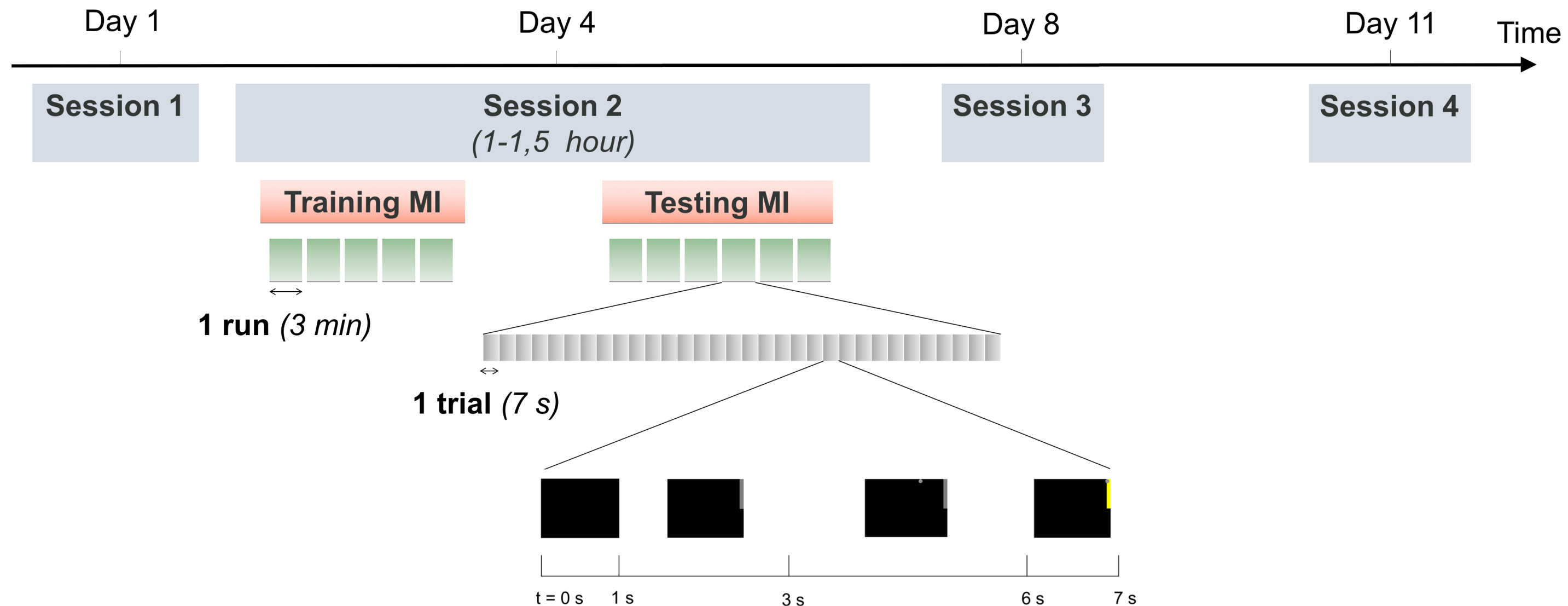


**Unlock the future**

# How do we learn to use BCI?

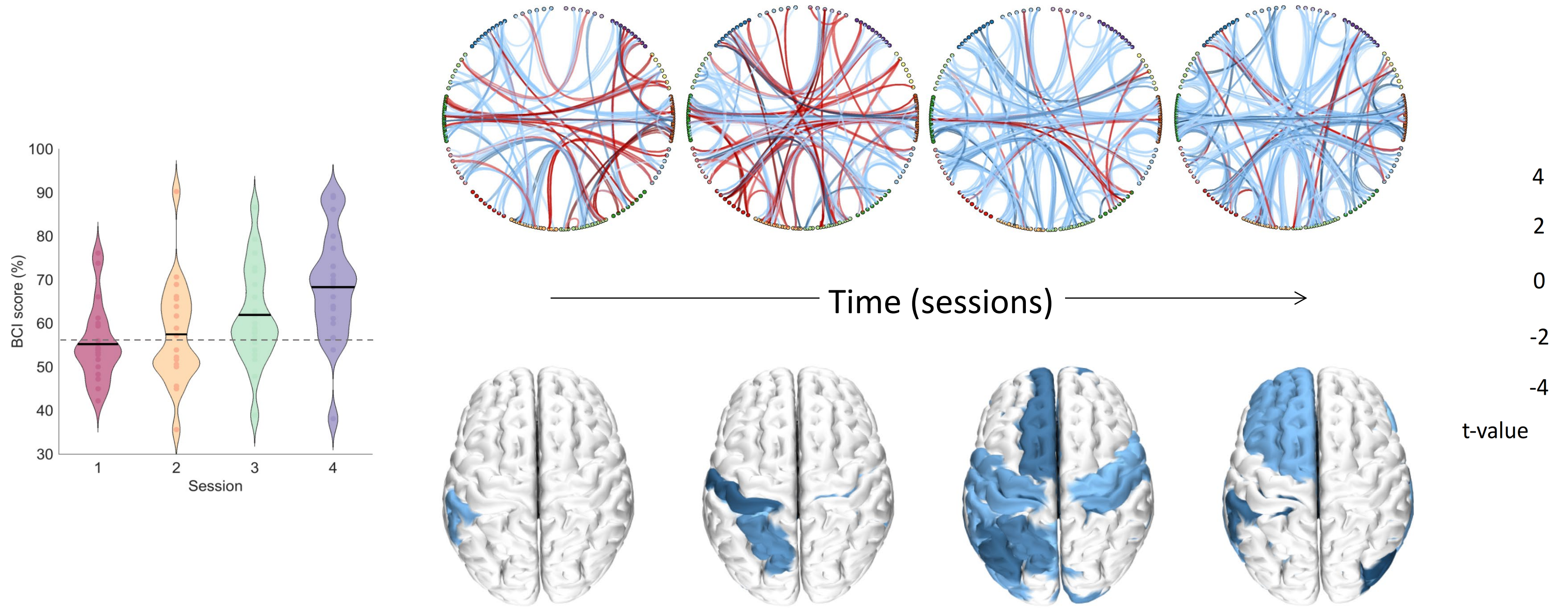


NETBCI project



**Unlock the future**

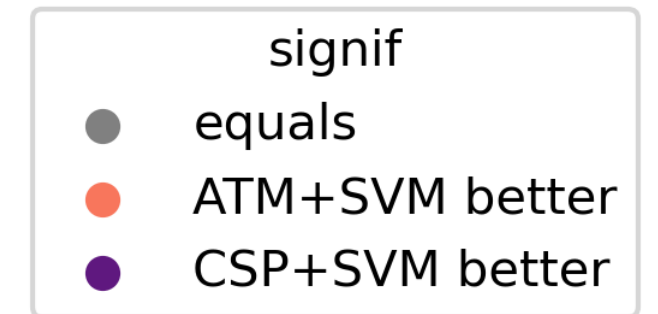
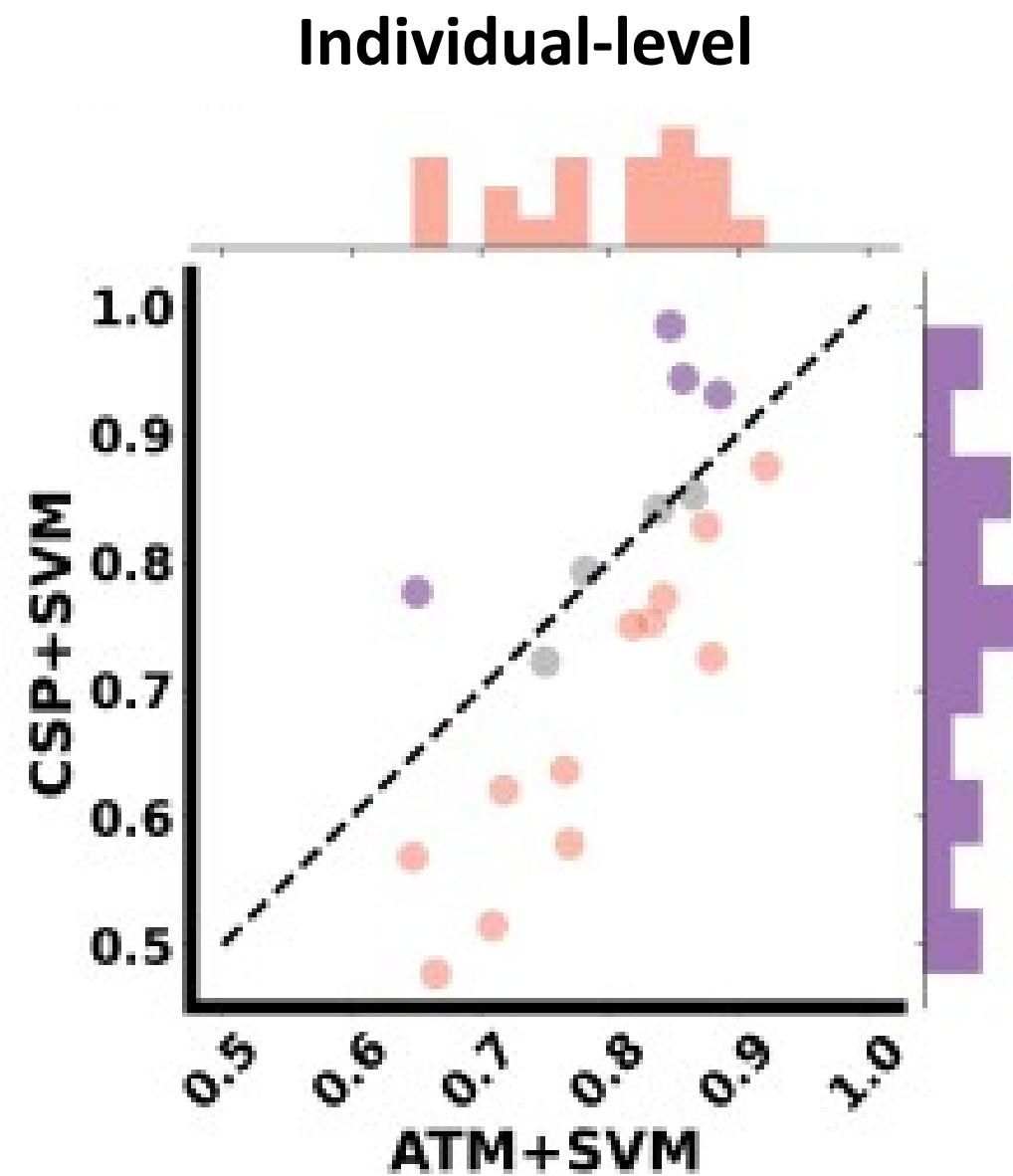
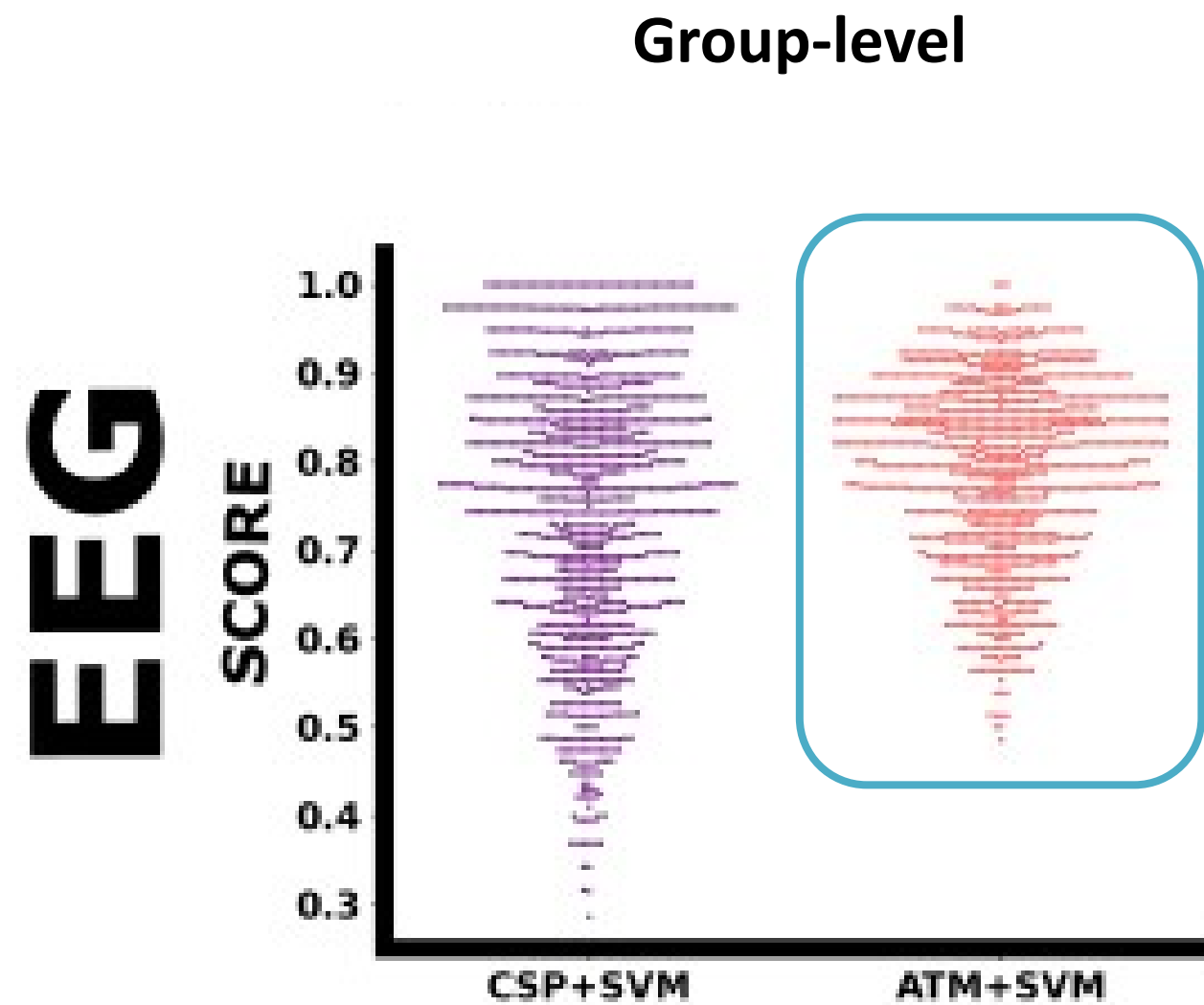
# Brain interactions over time



(Corsi et al, Neuroimage, 2020)

**Unlock the future**

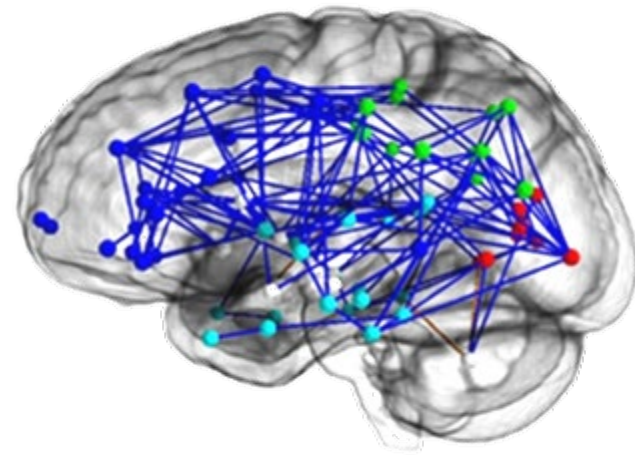
# Brain interactions to inform BCI



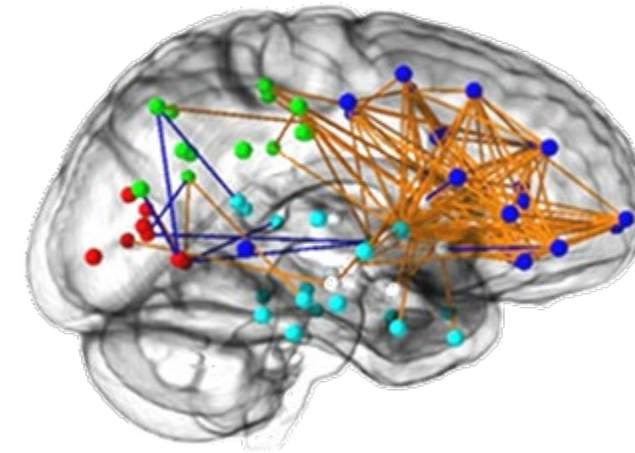
Adapted from [Corsi\*, Sorrentino\* et al, iScience, 2024]

**Unlock the future**

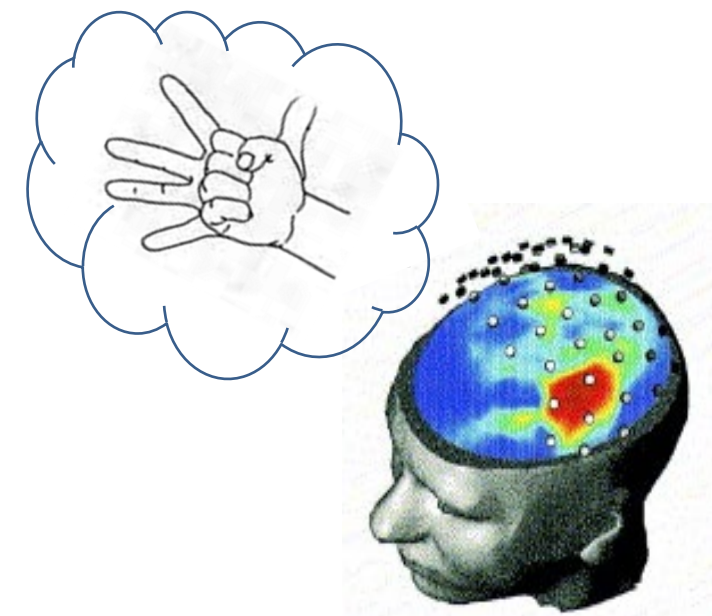
# Stroke – cortical reorganization



Disability



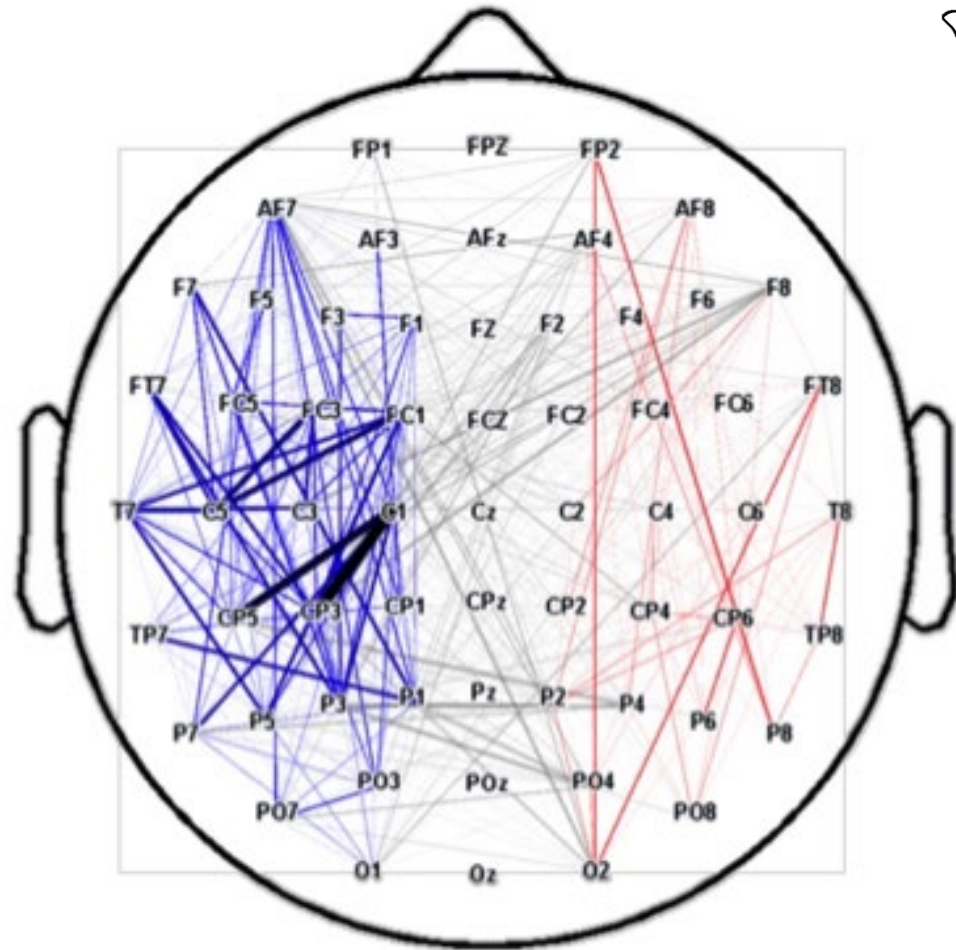
Motor Imagery



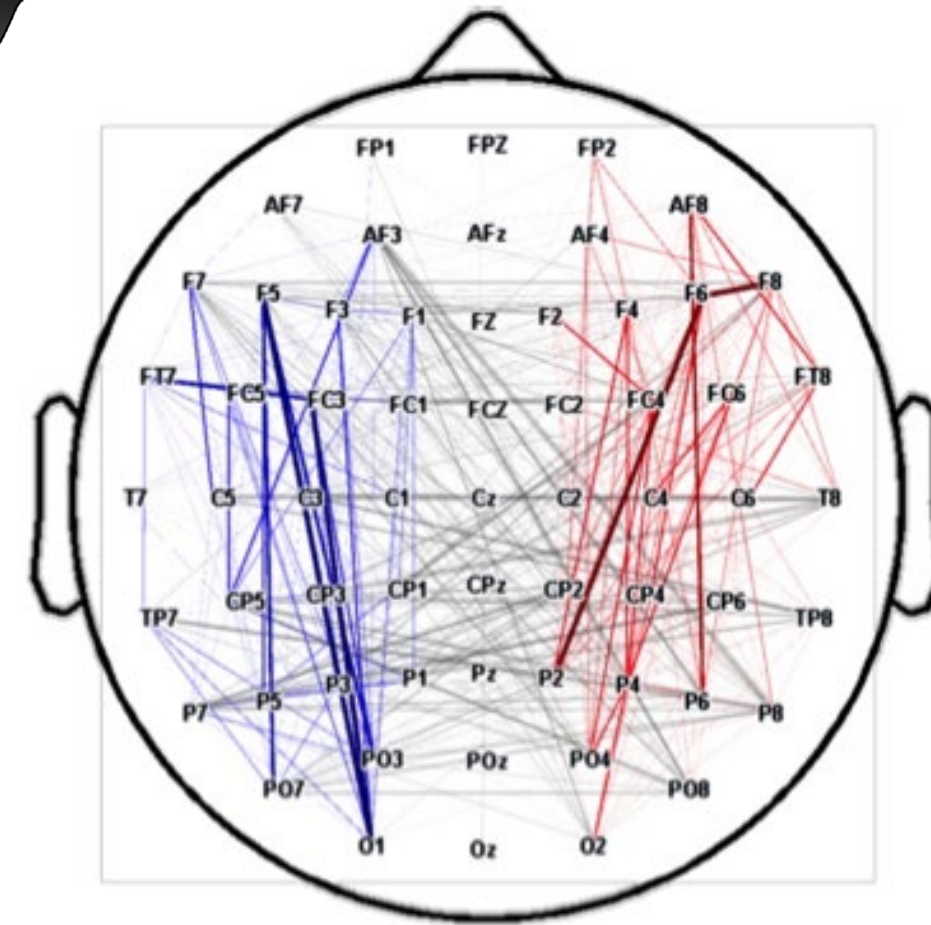
**Unlock the future**

# Stroke – interhemispheric connectivity

Control



Affected

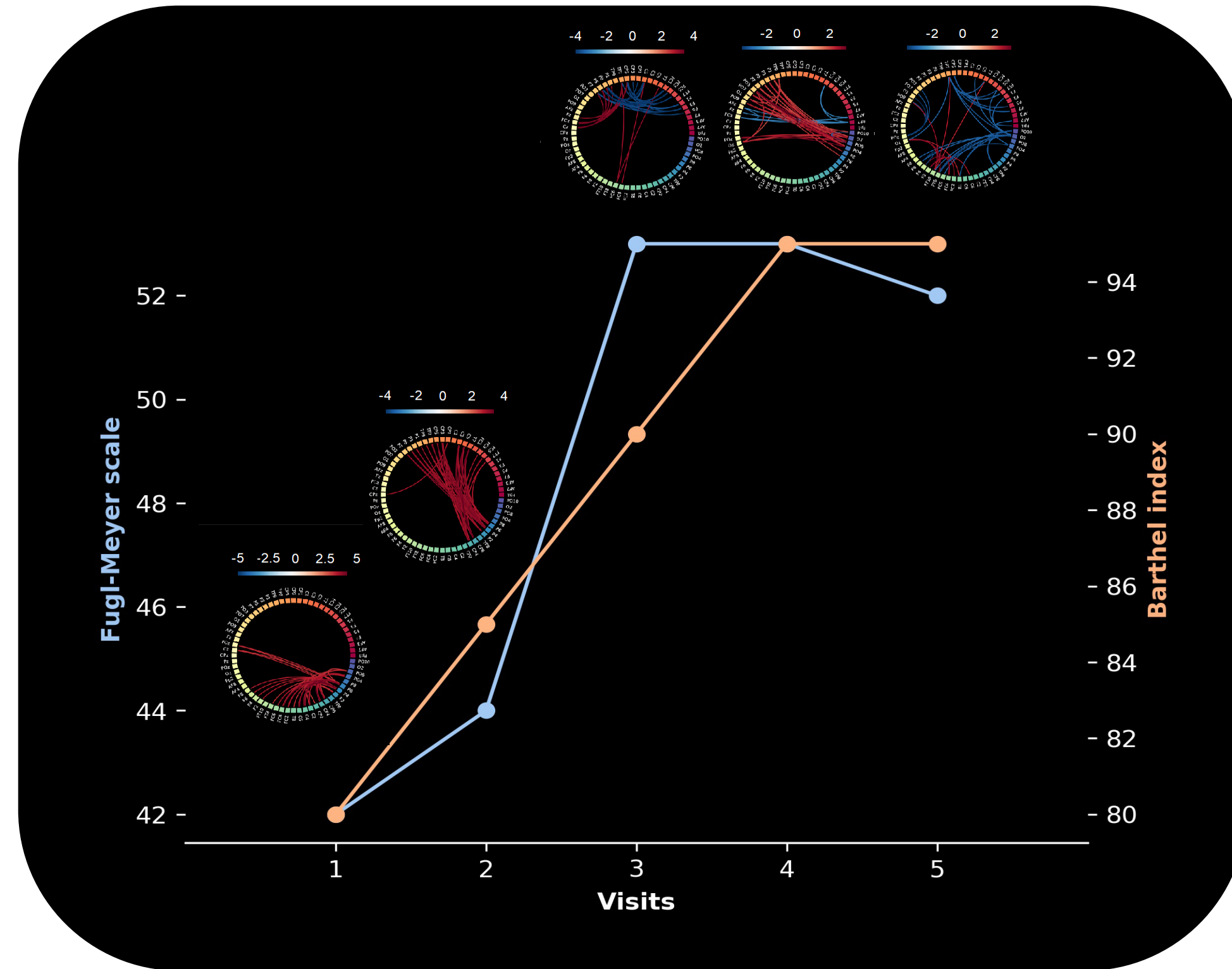


(De Vico Fallani et al, 2013)

**Unlock the future**



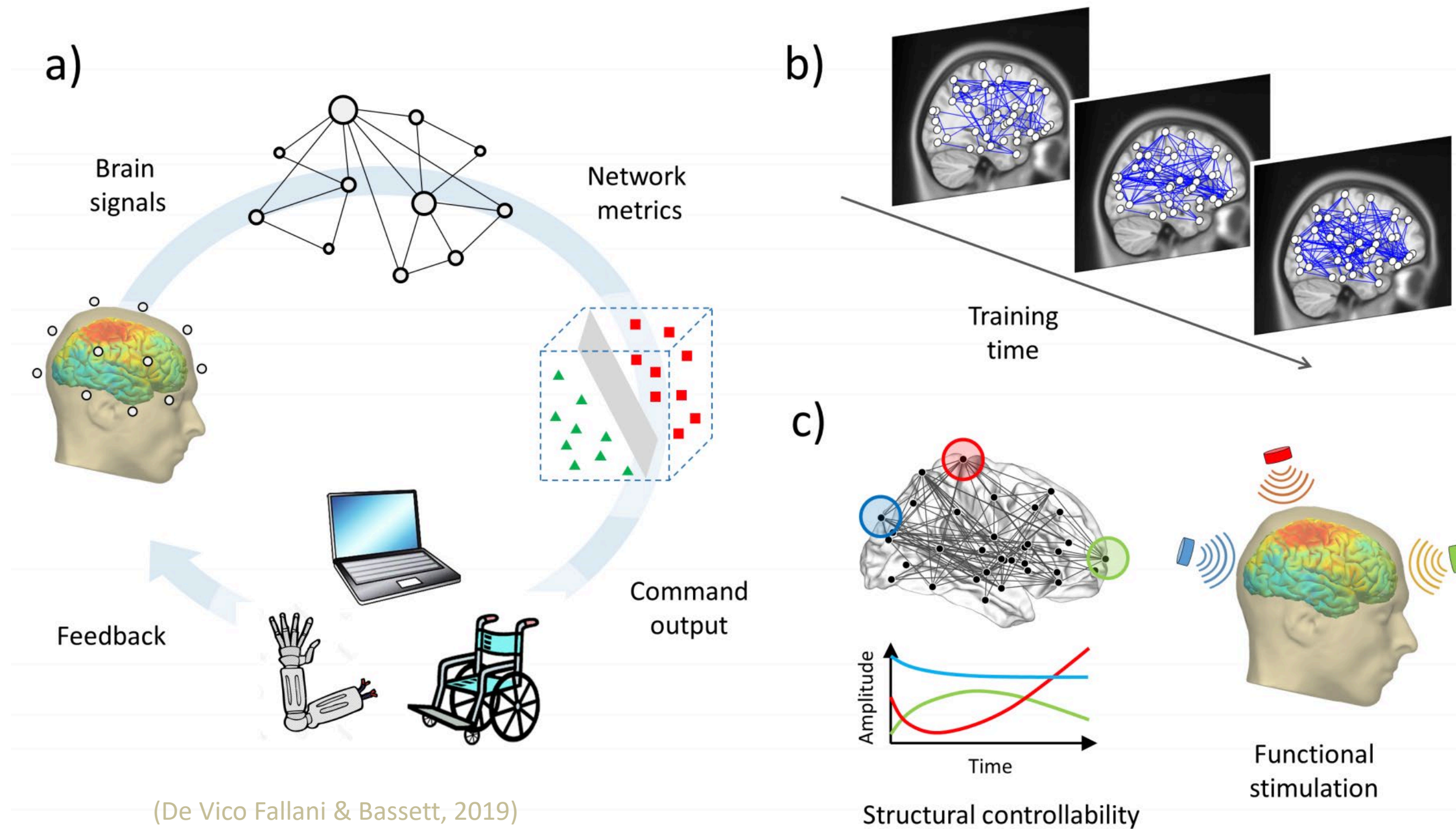
# Stroke – search for alternative features



Neurophysiological patterns of stroke recovery over 1 year (in collaboration w/ AP-HP)

**Unlock the future**

# New perspectives to optimize BCIs



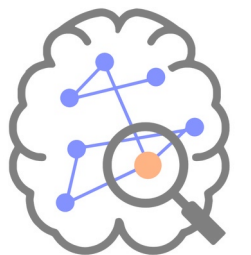
Need to develop dedicated tools to facilitate the experiments...

## Unlock the future

# Guiding the clinician in the features selection - HappyFeat

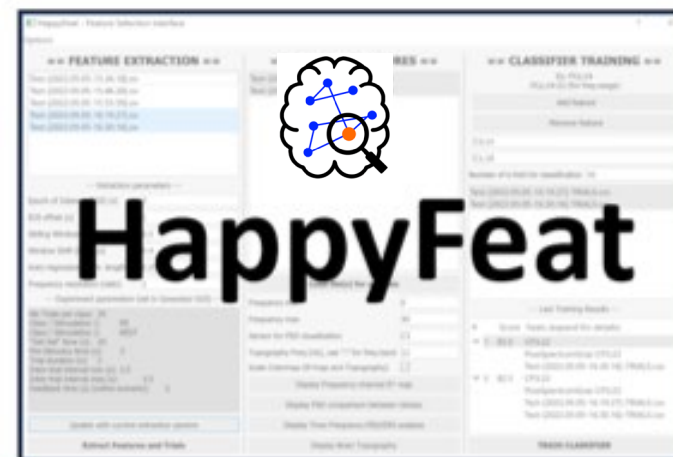
- Sources of variabilities
    - Data acquisition (sensors performance)
    - Tiredness
    - Brain signature
- ⇒ Need to reduce the calibration time
- ⇒ Need to identify the features that best capture the patients' intent

**HappyFeat** is a software aiming to simplify the use of BCI pipelines in **clinical settings by non-expert users** by **assisting the extraction and the selection of the classification features.**



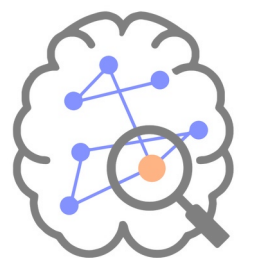
**Unlock the future**

# Guiding the clinician in the features selection - HappyFeat



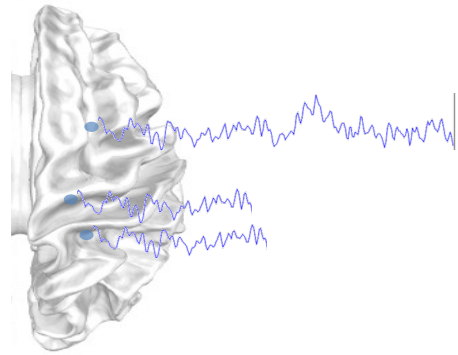
Unified, dashboard-like GUI

**Unlock the future**

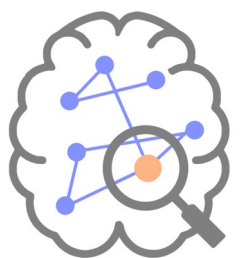
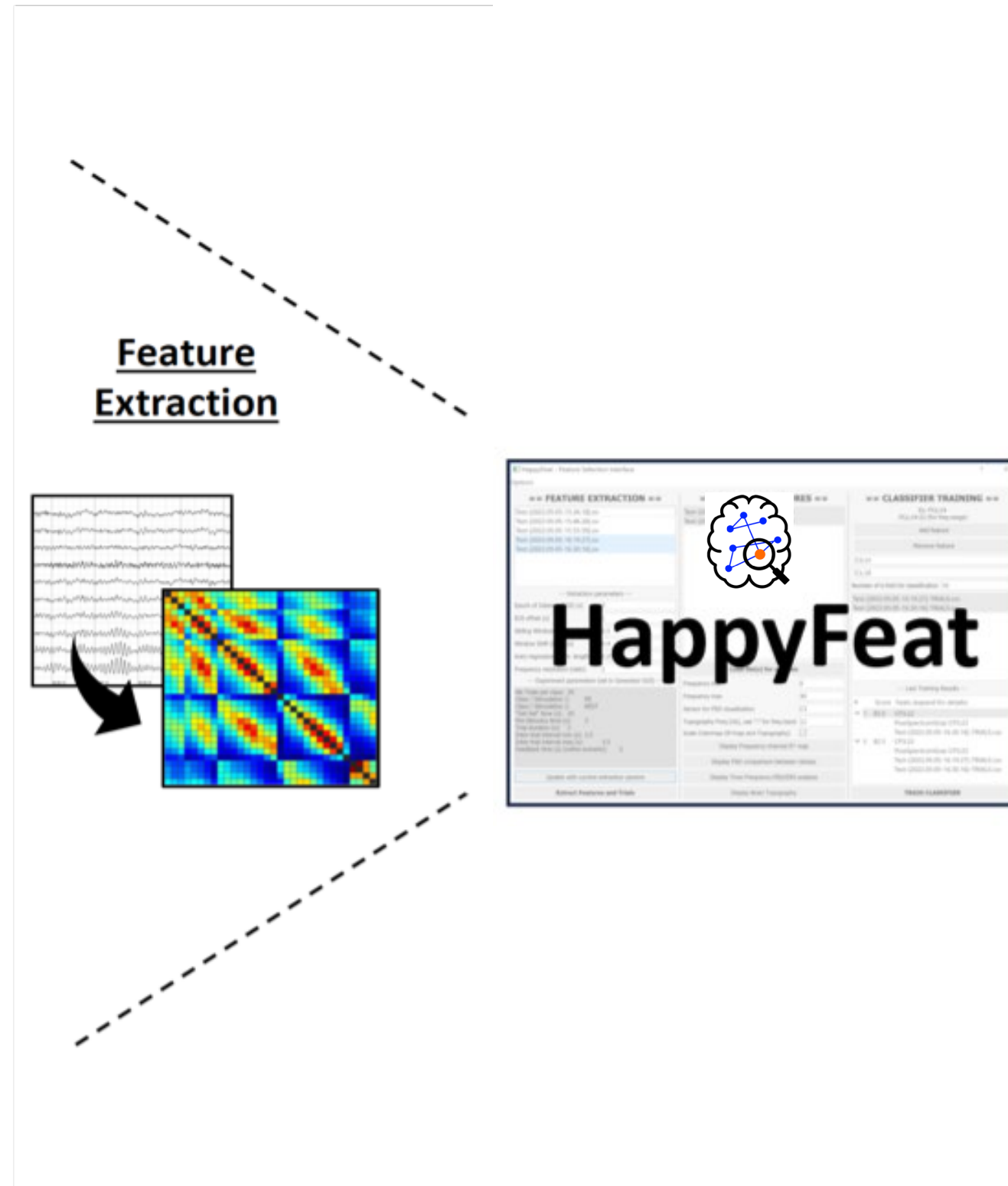
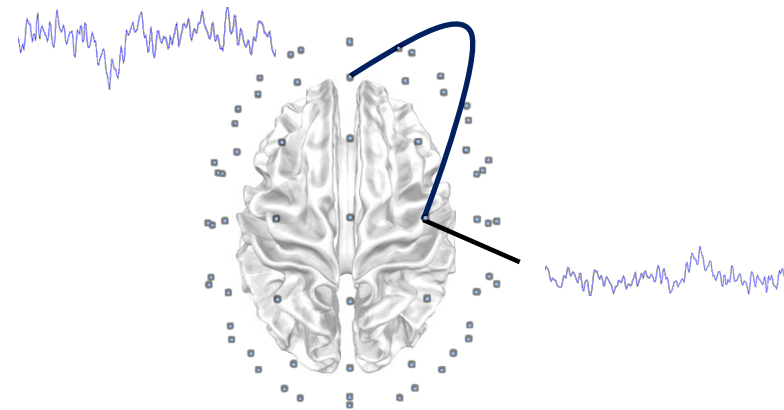


# Guiding the clinician in the features selection - HappyFeat

Classical **local** measures



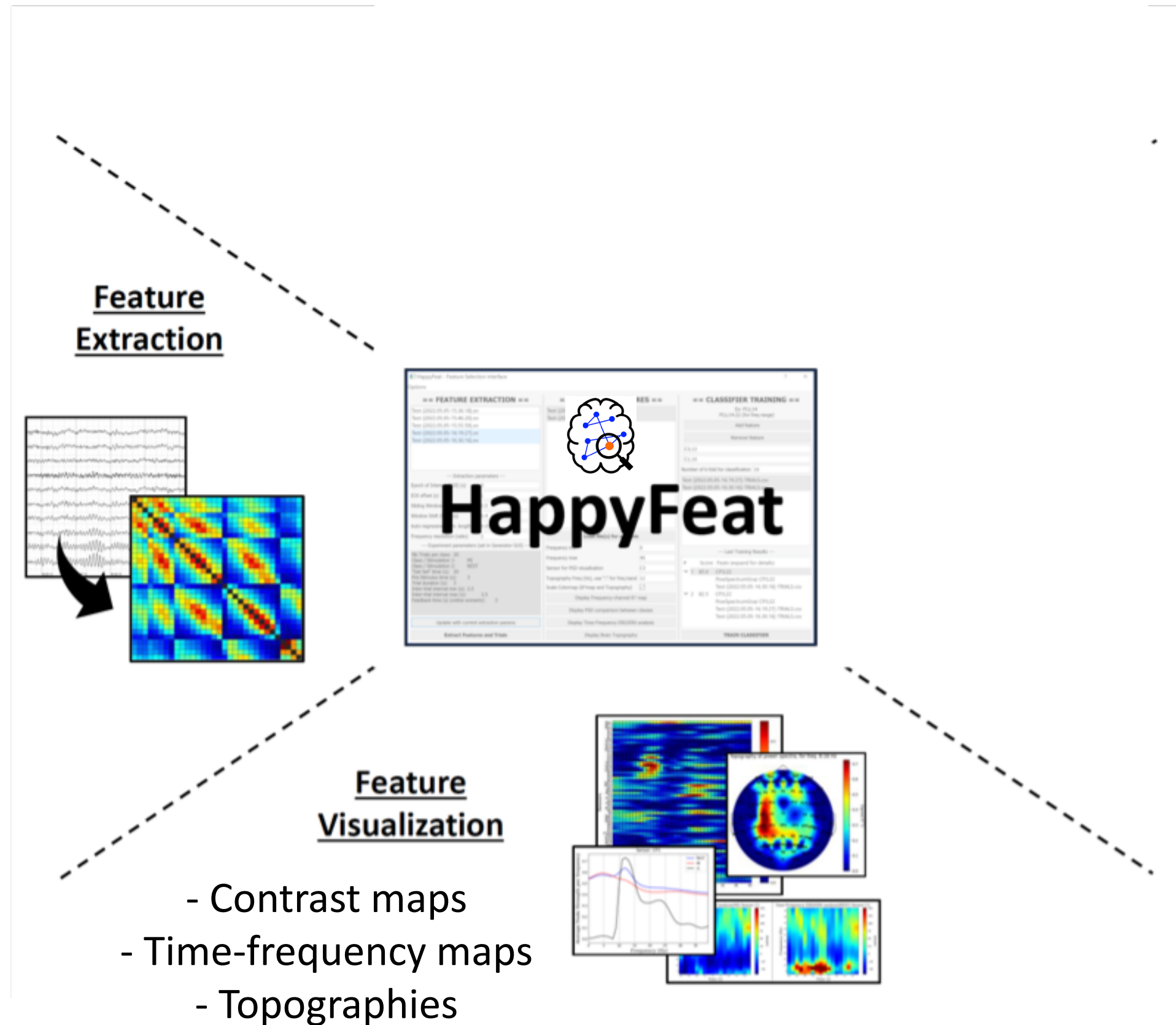
- Novel **network-based** approaches



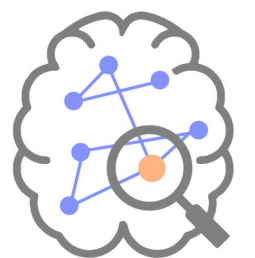
**Unlock the future**



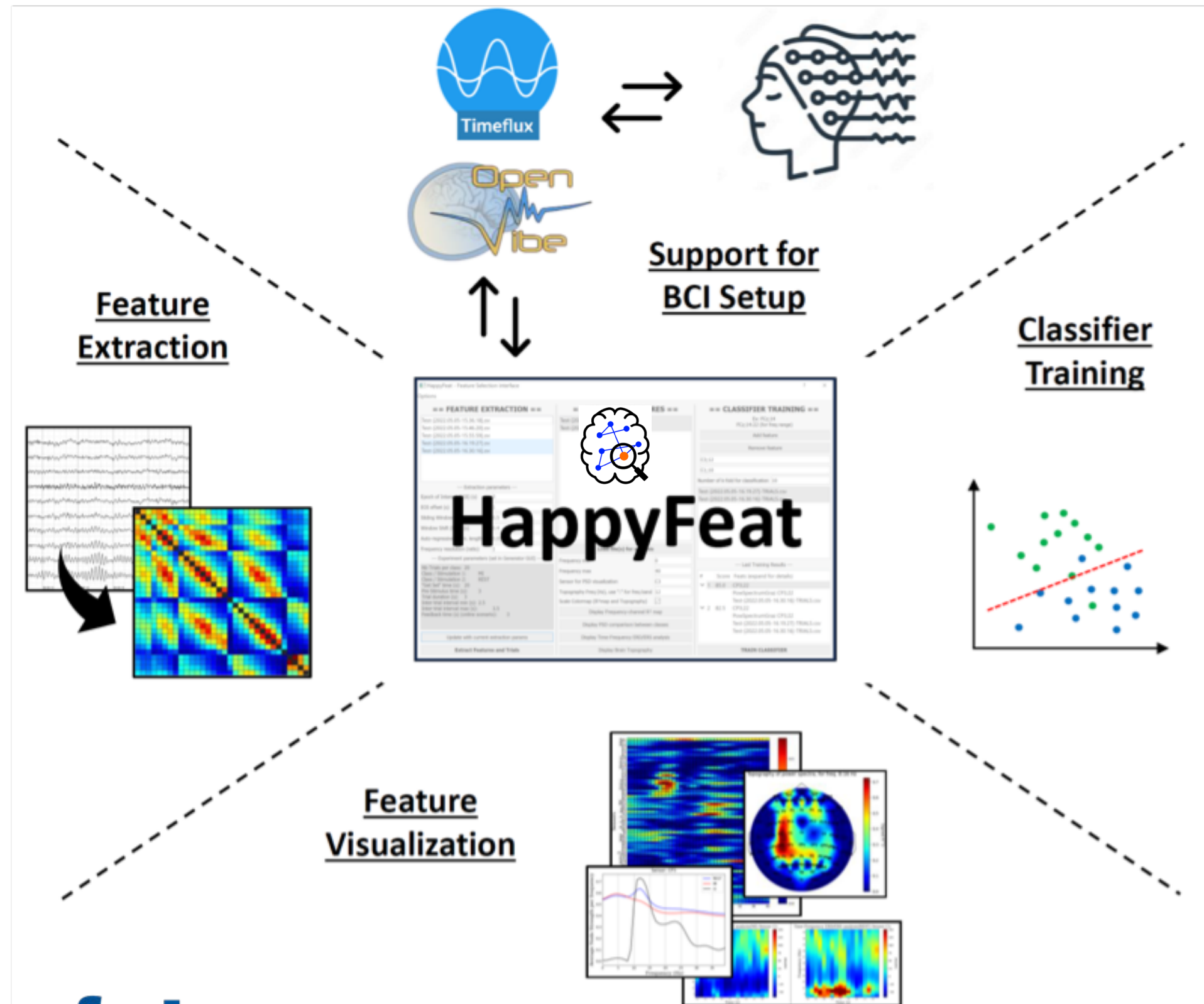
# Guiding the clinician in the features selection - HappyFeat



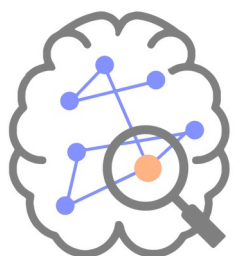
**Unlock the future**



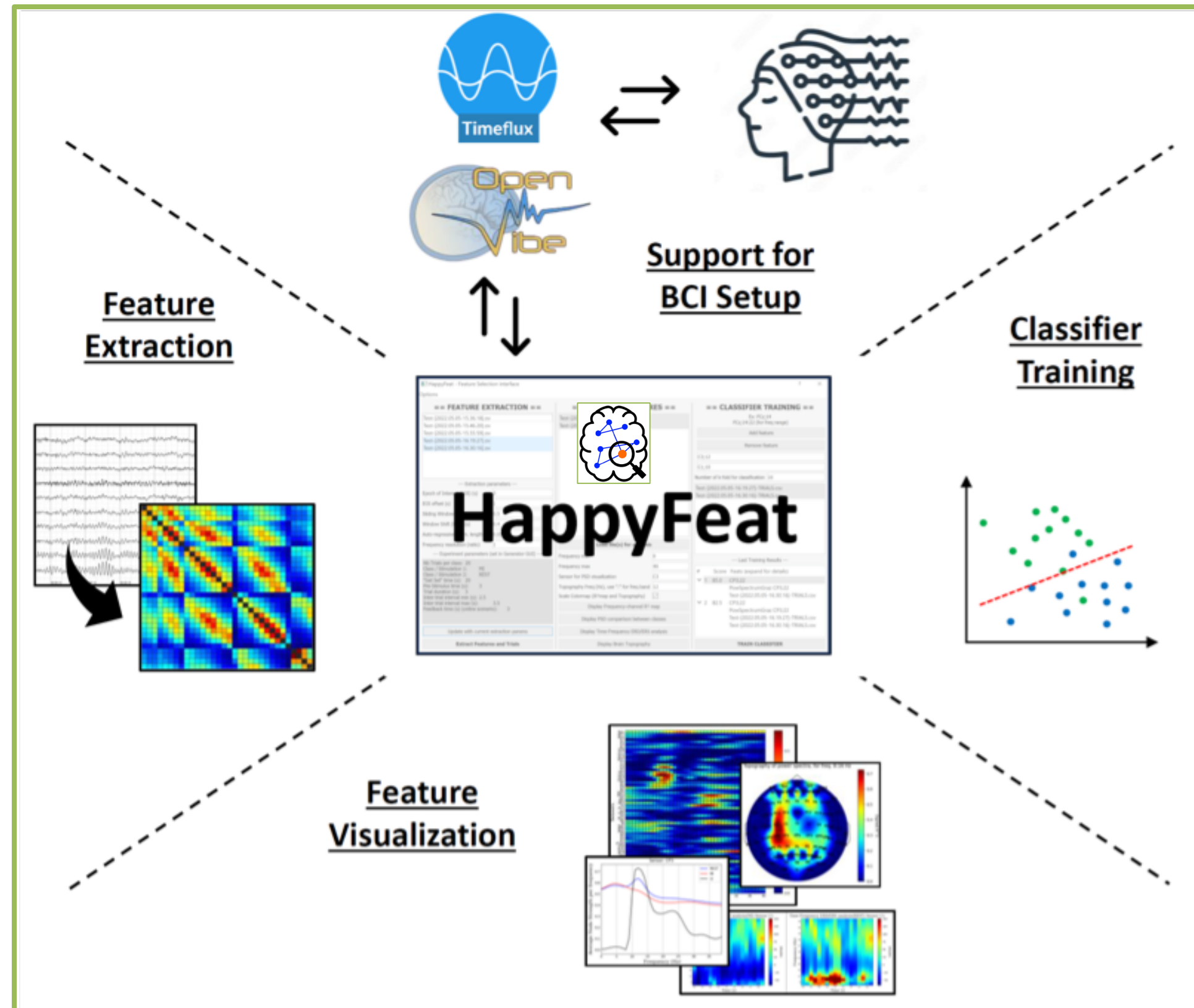
# Guiding the clinician in the features selection - HappyFeat



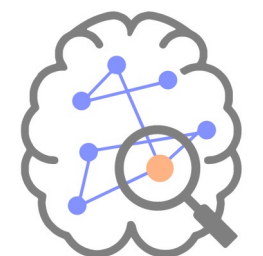
**Unlock the future**



# Guiding the clinician in the features selection - HappyFeat



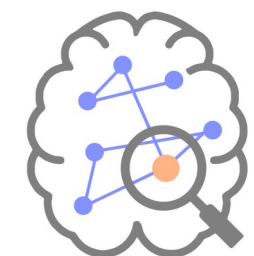
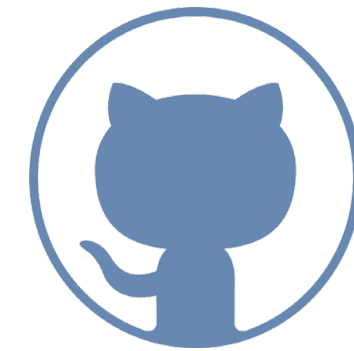
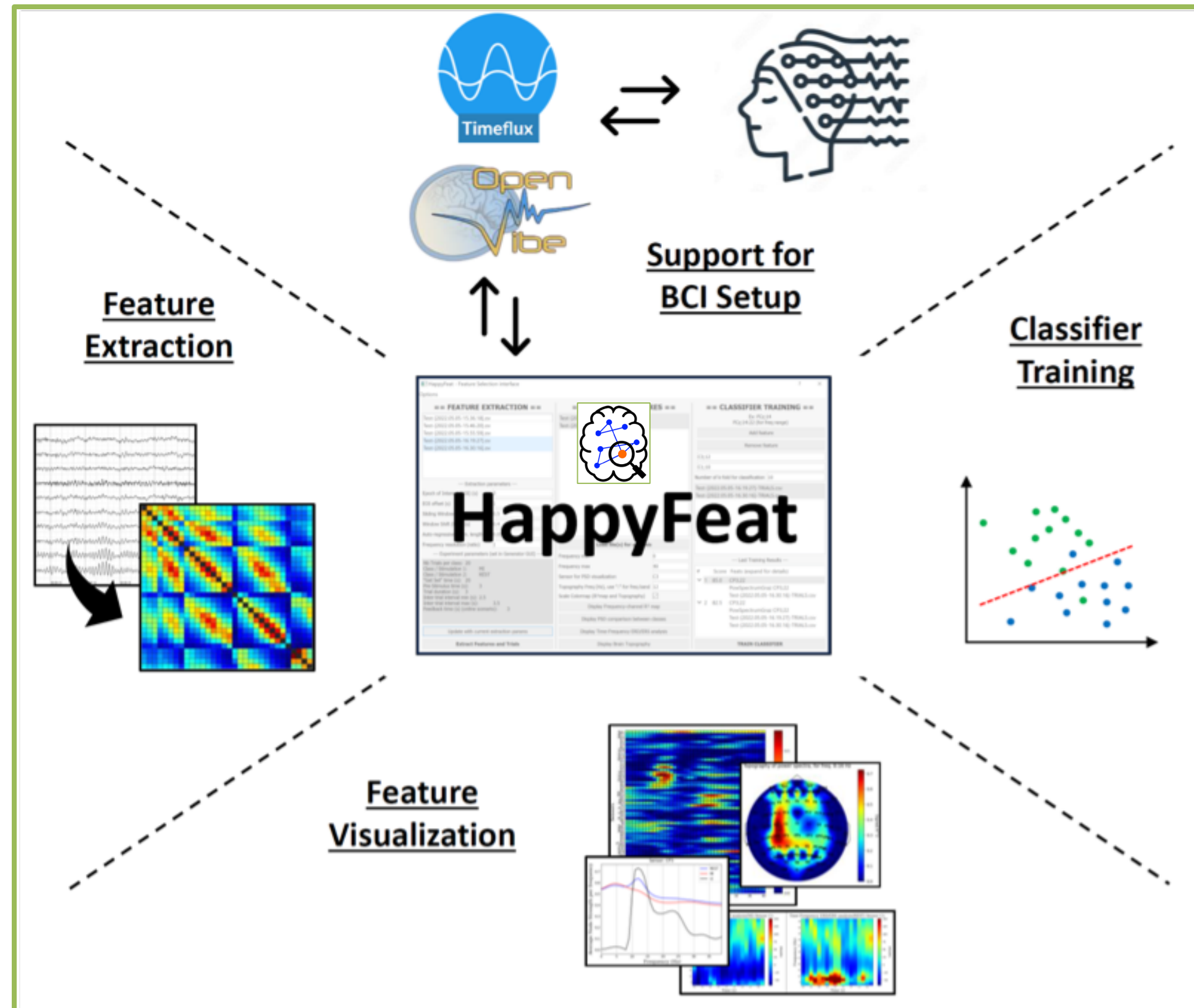
Workspace to ensure **reproducibility** and **replicability** of all the manipulations



## Unlock the future



# Guiding the clinician in the features selection - HappyFeat



**Unlock the future**

# Take home messages

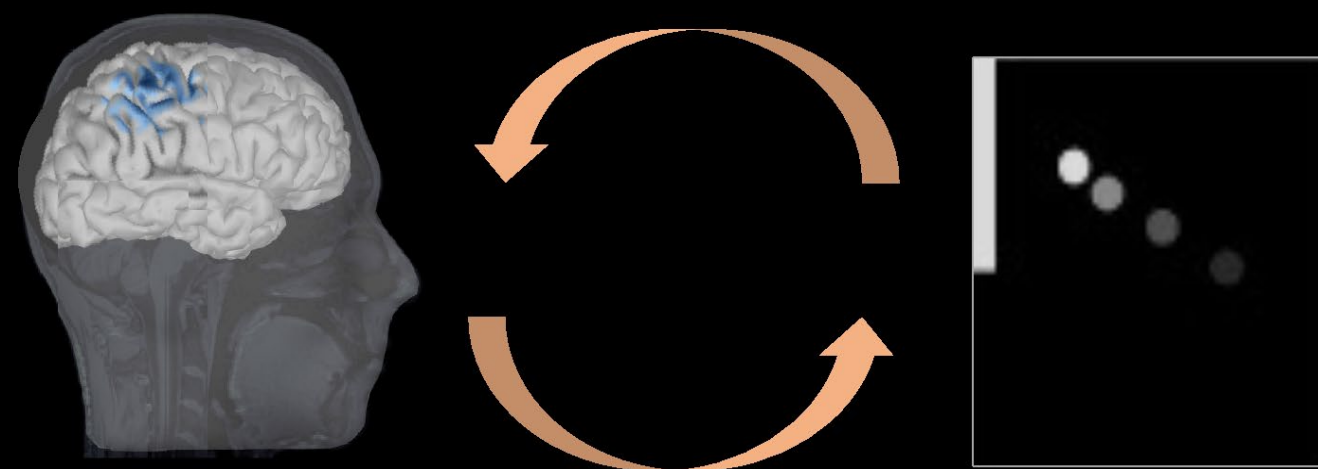
- BCI
  - Promising tool for clinical applications
  - **Multidisciplinary** domain
  - Growing interest in the last few years with the AI
- BCI learning & inter-subject variability
  - Improving the classifier / signal processing
  - Improving instructions
  - Finding (new) subject-related predictors
- Groups & events
  - International: [BCI society](#), international society
  - [Cybathlons](#): competitions to promote BCI and to test the finest algorithms with **end users!**
  - In France: [CORTICO](#), French association to promote BCI

**Unlock the future**



Forum  
**TERATEC 24**

Thank you for your attention!



[marie-constance.corsi@inria.com](mailto:marie-constance.corsi@inria.com)



MConstanceCorsi



[mccorsi](https://github.com/mccorsi)