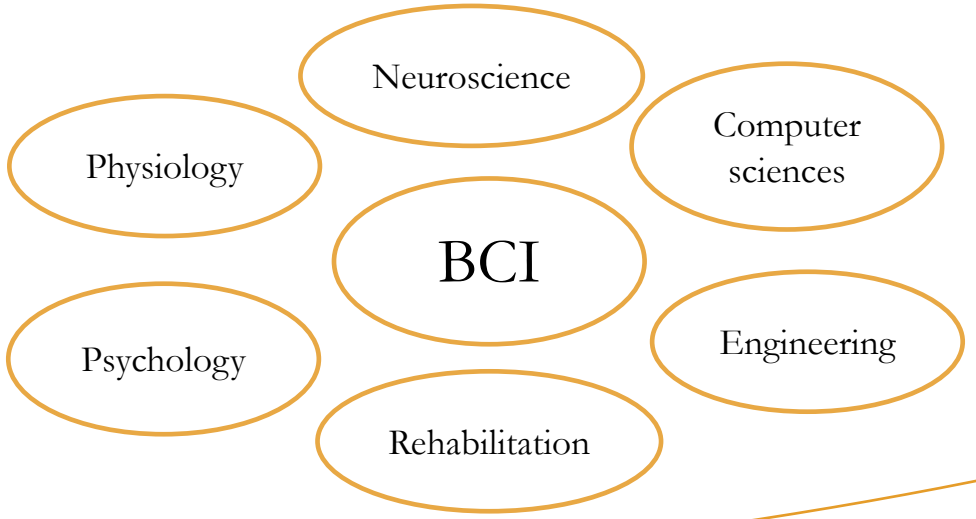
WHAT ARE BCIS, AND HOW DO THEY WORK? A GUIDED TOUR!

Arthur Desbois & Marie-Constance Corsi

Inria NERV team, Paris Brain Institute

Context



Today

1970

1st implanted BCI

3 research groups

2000

> 30k publications
6-8 research groups

2005

> 50k publications
> 100 research groups

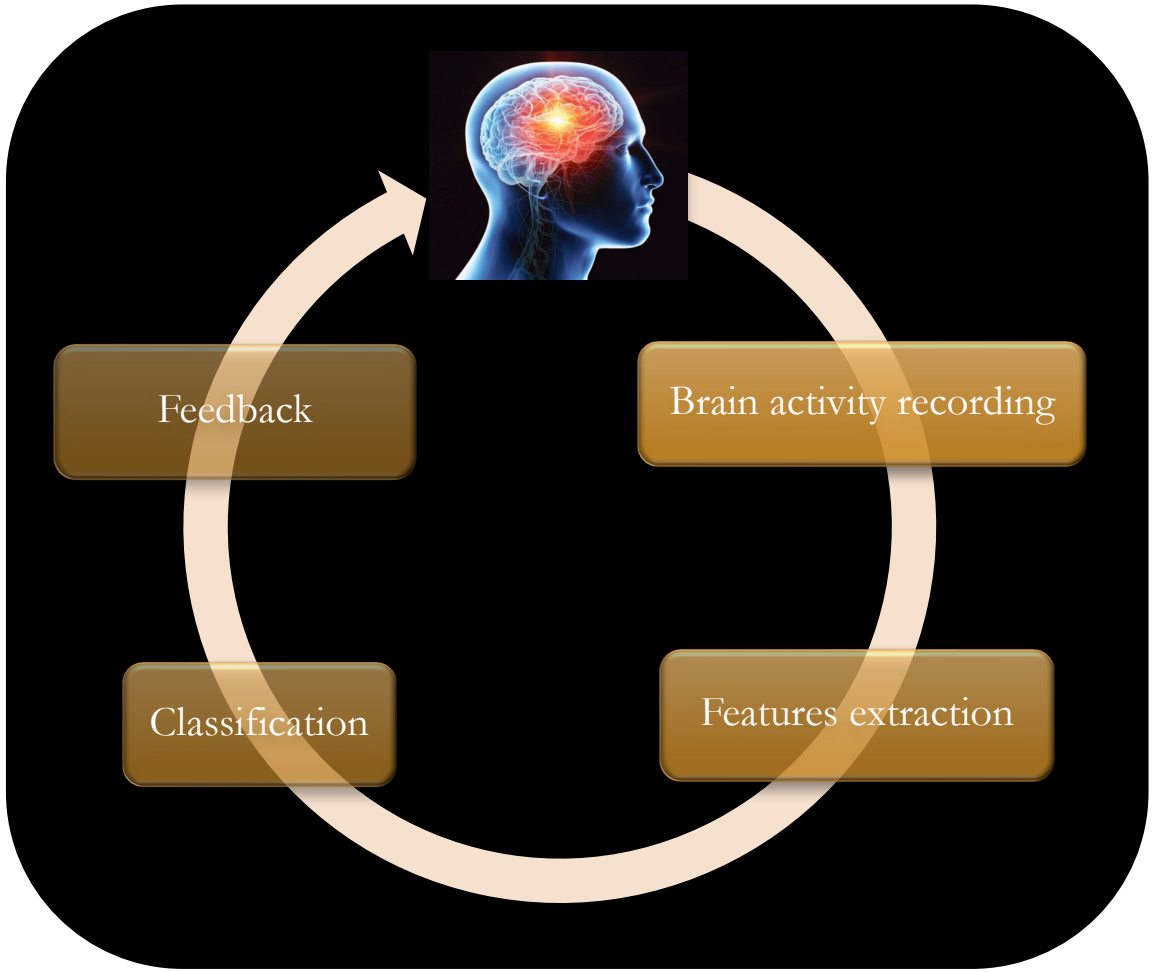
Commercialization of devices oriented to general public

2010

Emotiv, US

my Brain Technologies

Behind the magic…



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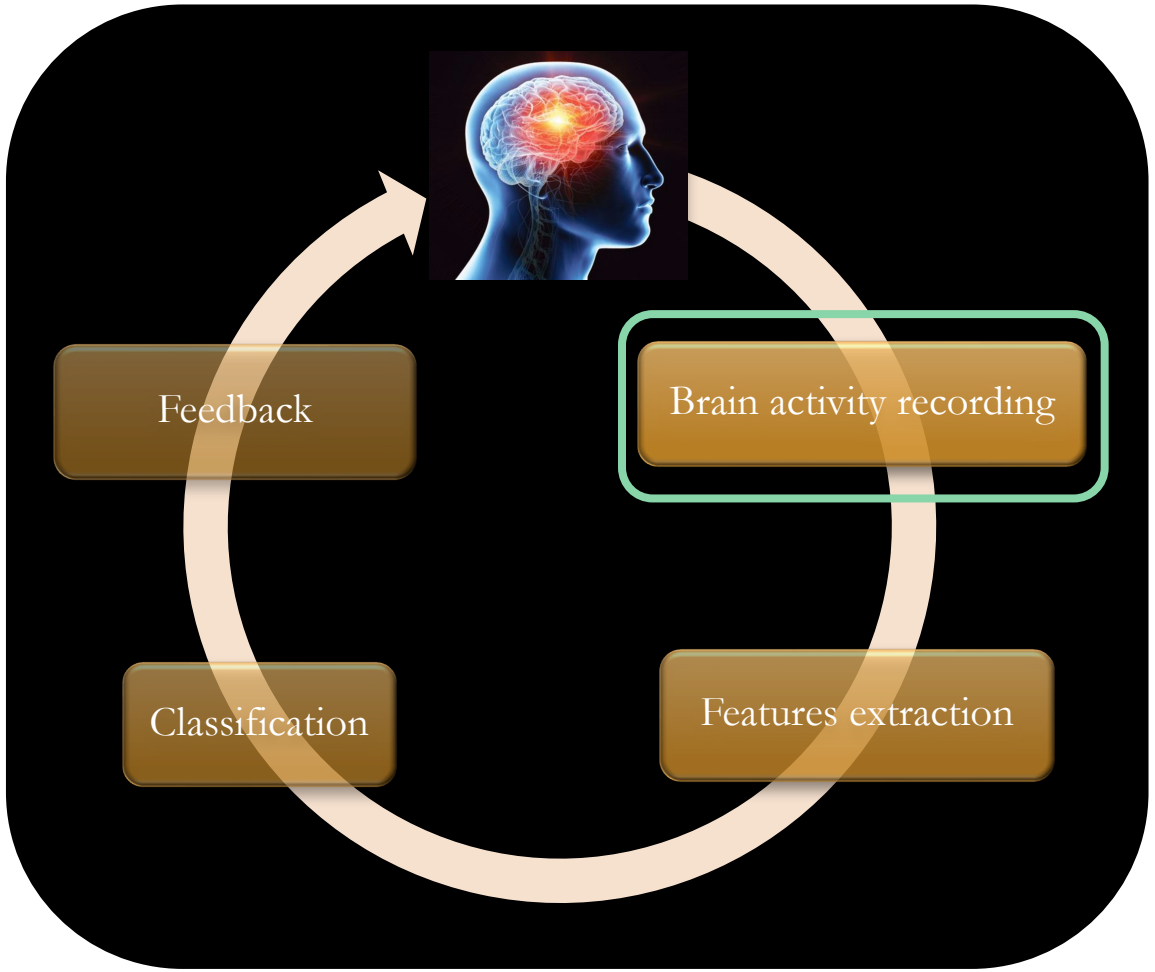
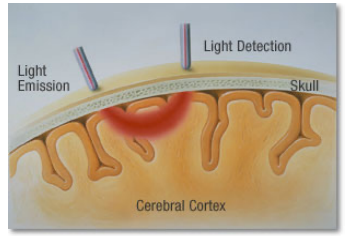


Non-invasive tools

EEG

NIRS



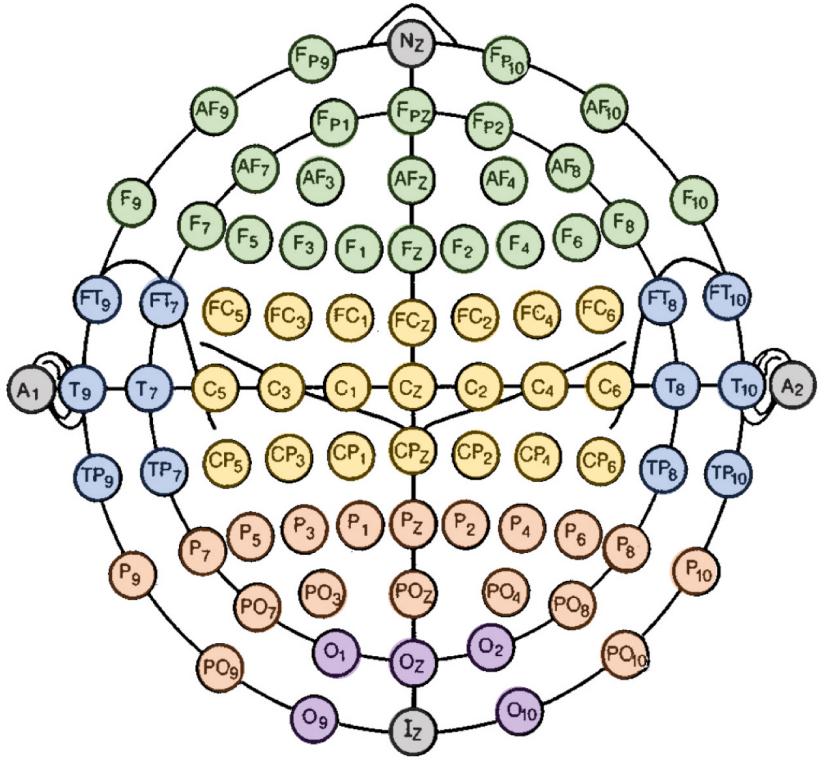
Near Infrared Spectroscopy
(Fazli et al, 2012)

MEG

fMRI

Functional MRI
(Sitaram et al, 2009)

Brain recording – EEG instrumentation

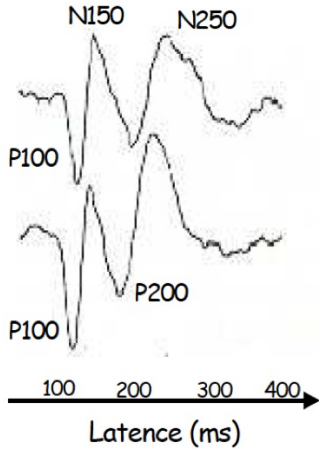


Adapted from (Corsi, 2023)

Brain recording w/ M/EEG – Evoked responses

Nomenclature: the latency, the amplitude, the shape and the polarity

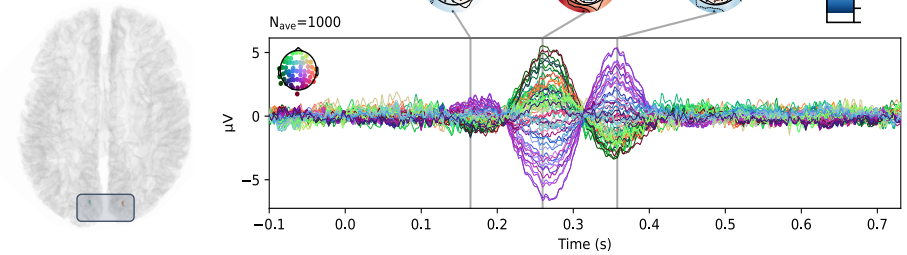
- Nxxx: one negative wave @ xxx ms (EEG)
- Pxxx: one positive wave @ xxx ms (EEG)
- Mxxx: one wave @ xxx ms (MEG)



Adapted from [Campagne, 2014]

Components

- Early components (exogenous): related to stimulus characteristics
- Late components (endogenous): related to the task, to the subject's stat



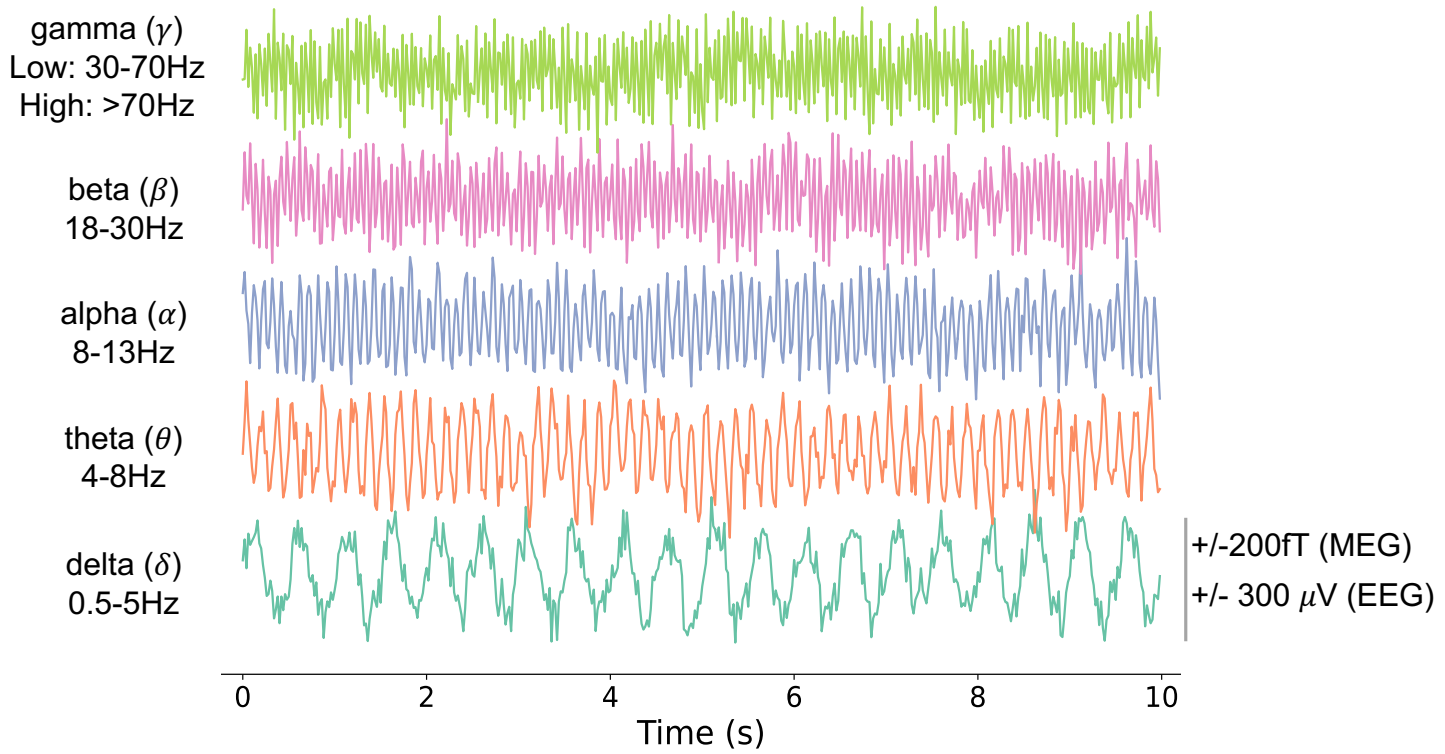
Adapted from [Corsi, 2023]

BCI application: P300 Speller

Brain recording w/ M/EEG – Oscillatory activity

Spontaneous activity, characteristics:

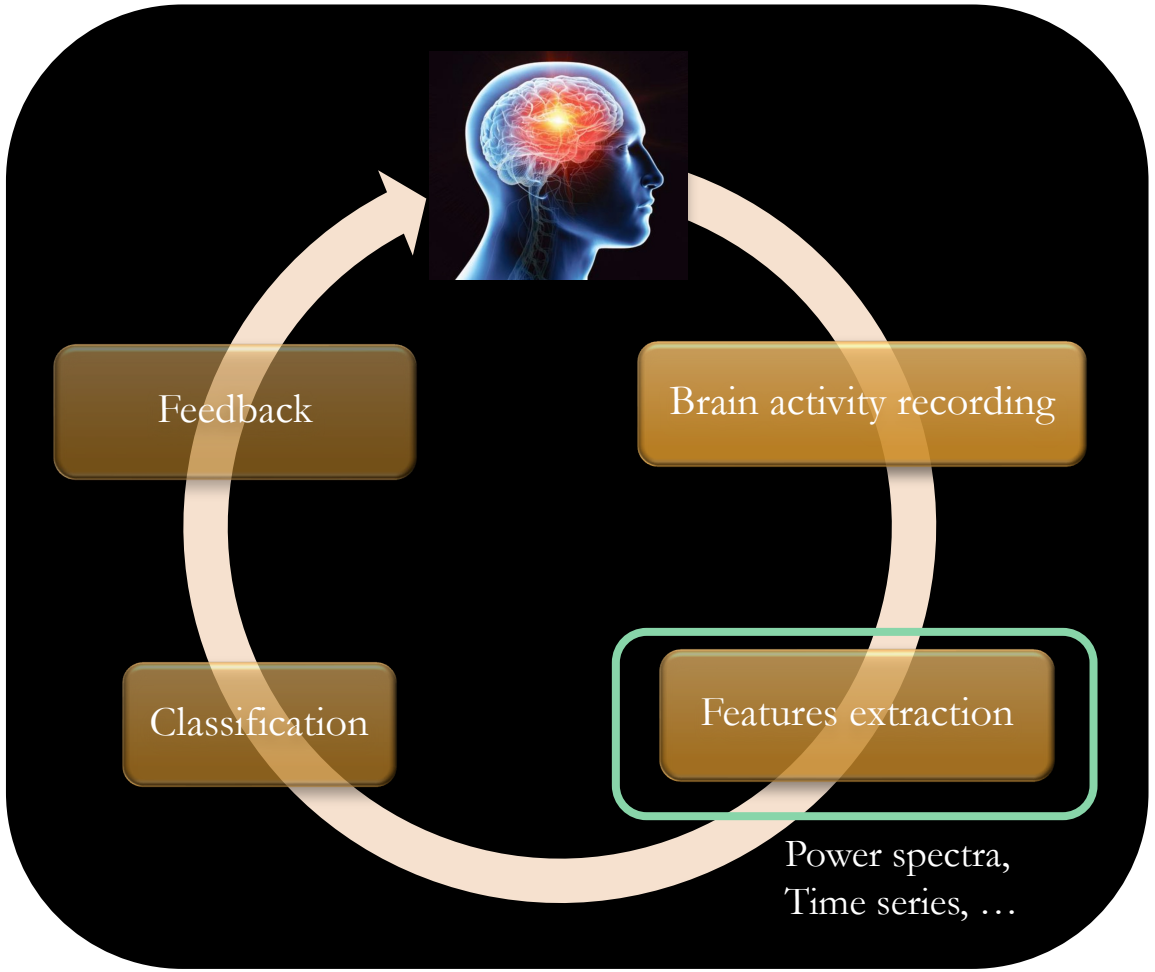
- Frequency
- Amplitude
- Shape
- Localization
- Psychopsychological context
- Duration
- Vanishing

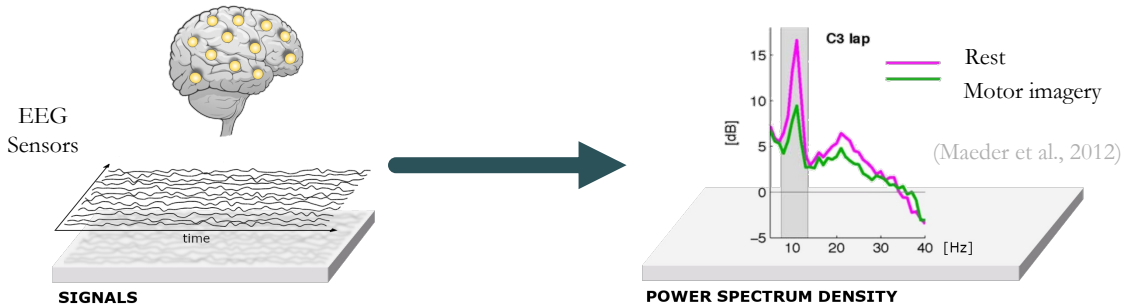


Adapted from [Corsi, 2023]

BCI application: motor-imagery based BCI

Behind the magic…

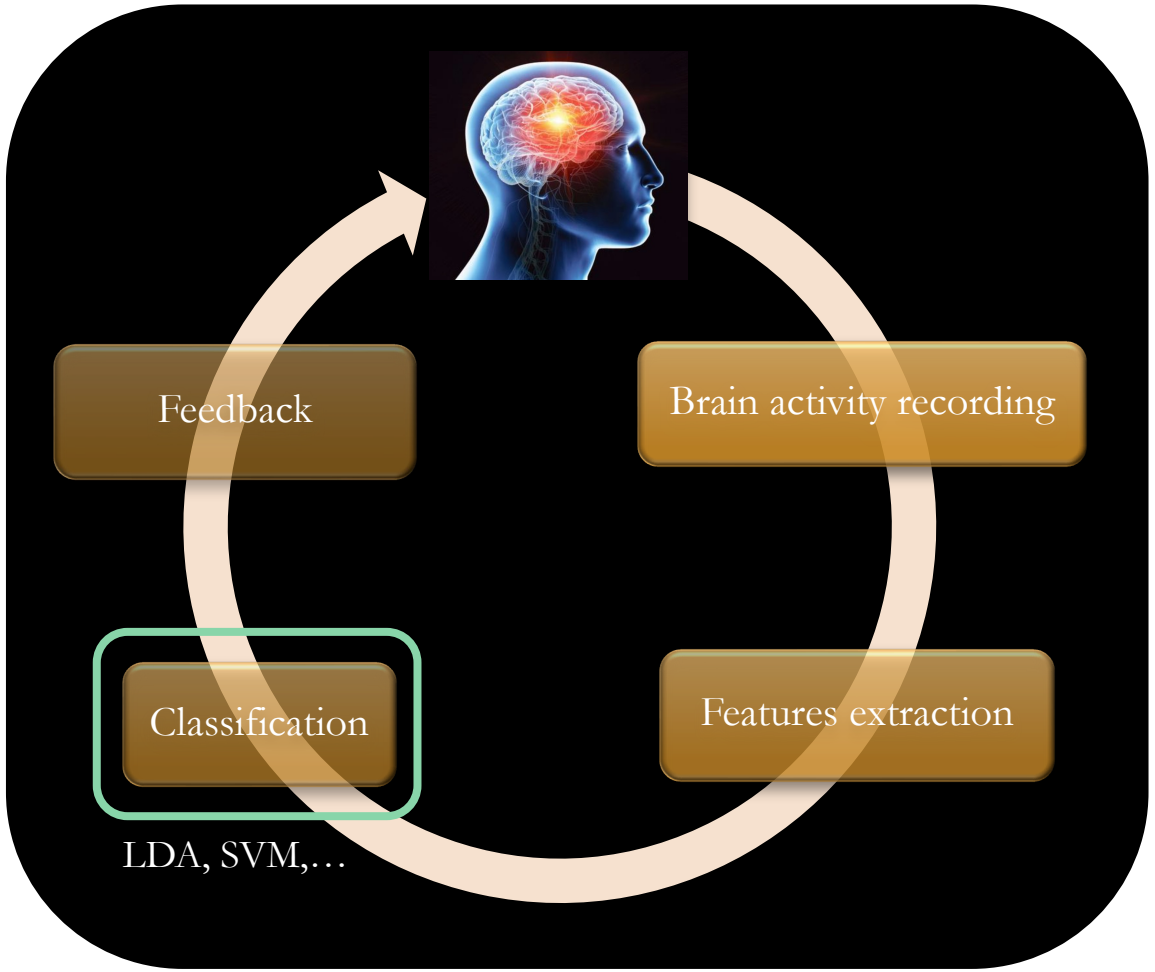


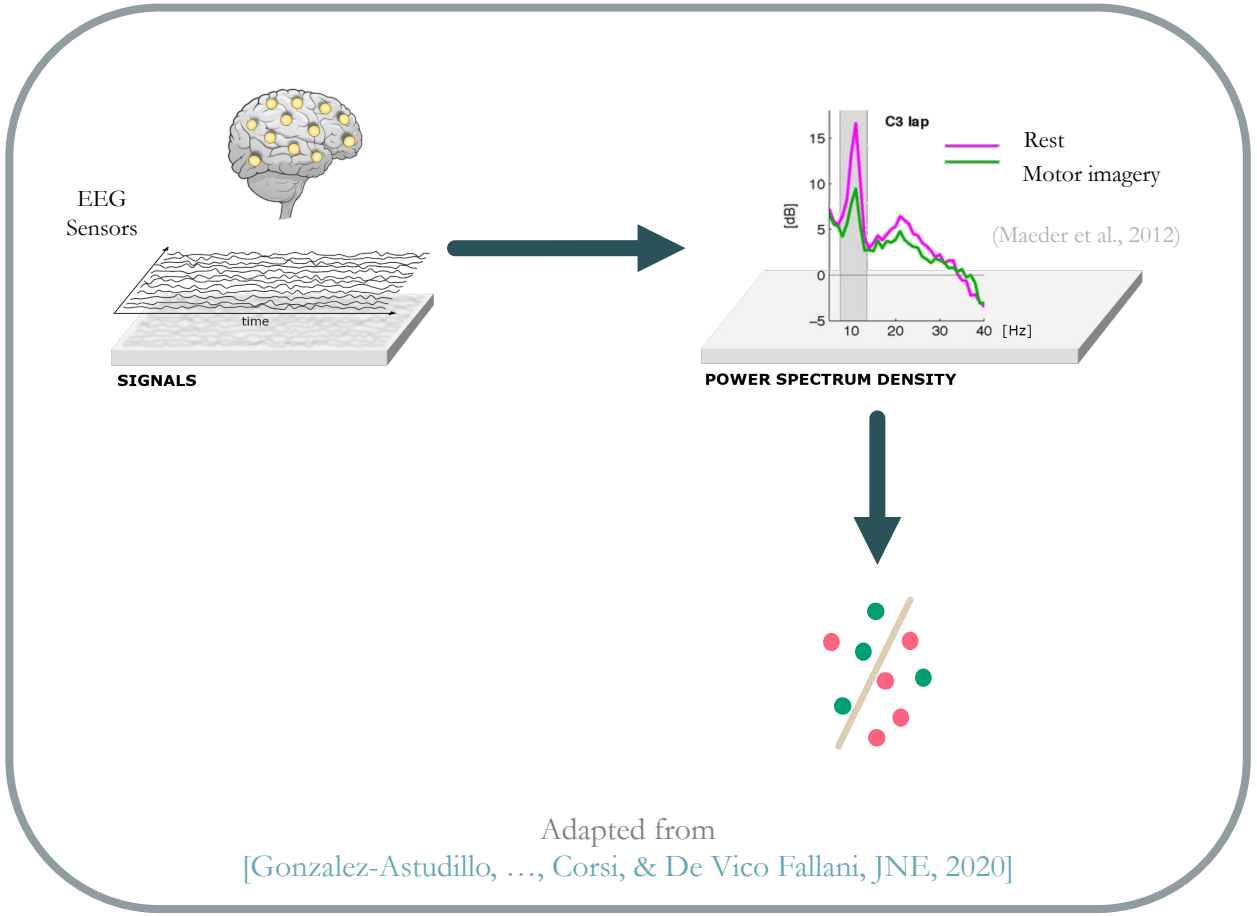


(Maeder et al., 2012)

Adapted from
[Gonzalez-Astudillo, …, Corsi, & De Vico Fallani, JNE, 2020]

Behind the magic…





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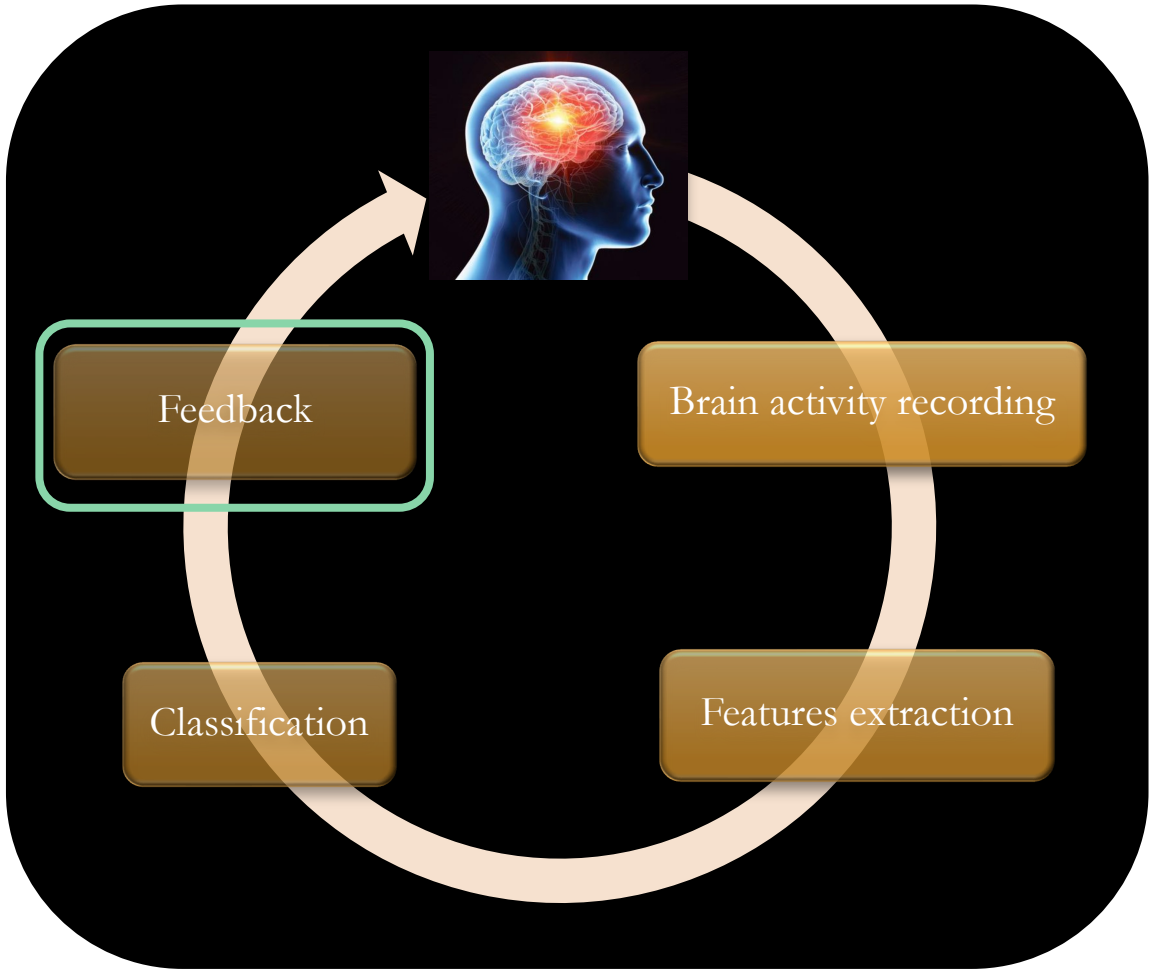
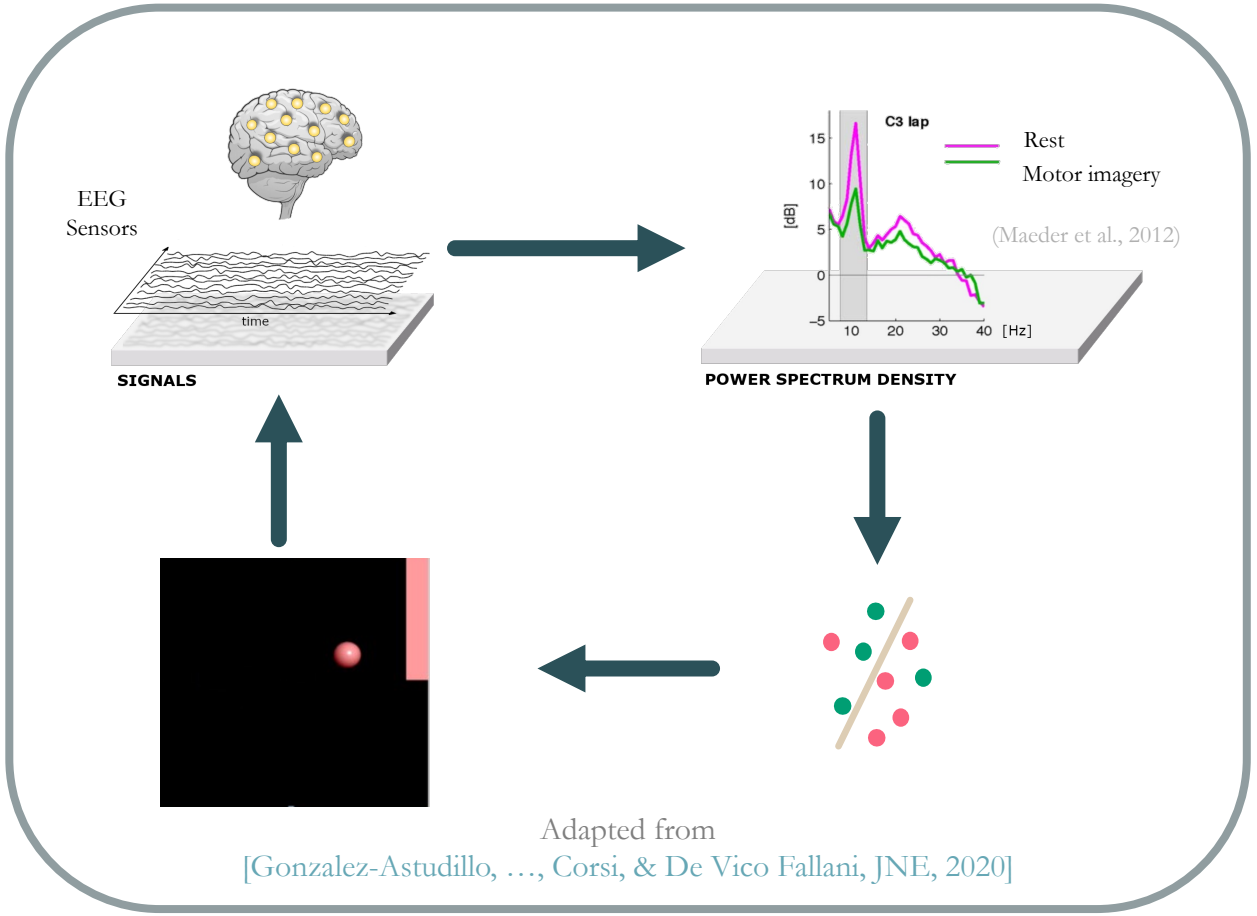


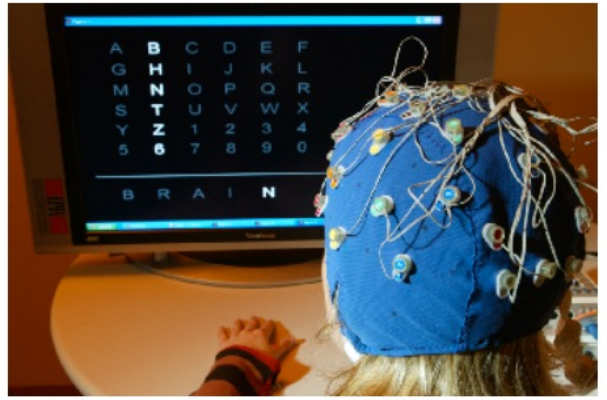


Adapted from
[Gonzalez-Astudillo, …, Corsi, & De Vico Fallani, JNE, 2020]

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)

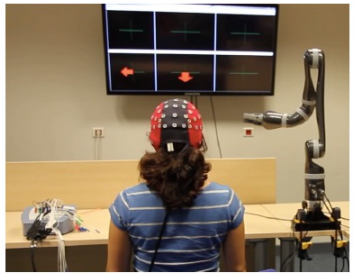


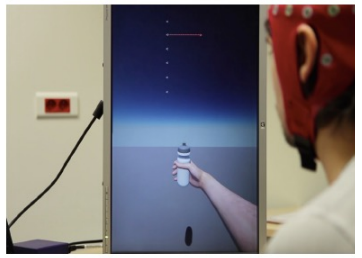
BCI & communication

- 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)

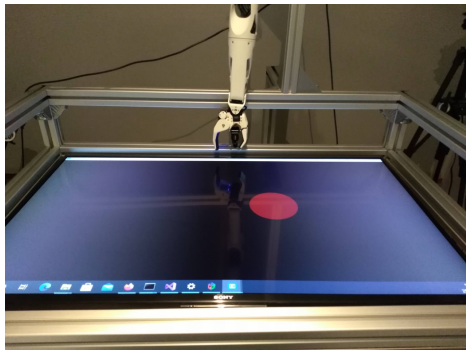
Examples of BCI research and clinical applications

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





LORIA projects
Courtesy of S. Rimbert

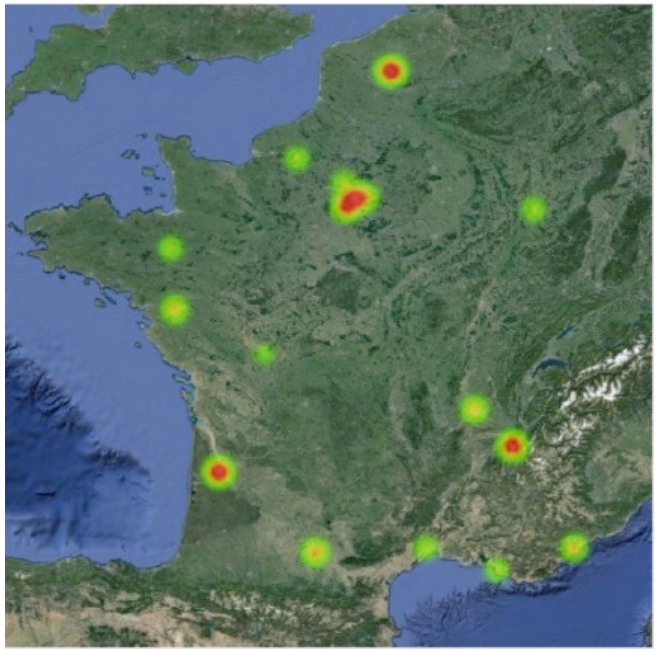


ARAMIS projects
Courtesy of T. Venot

Examples 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)

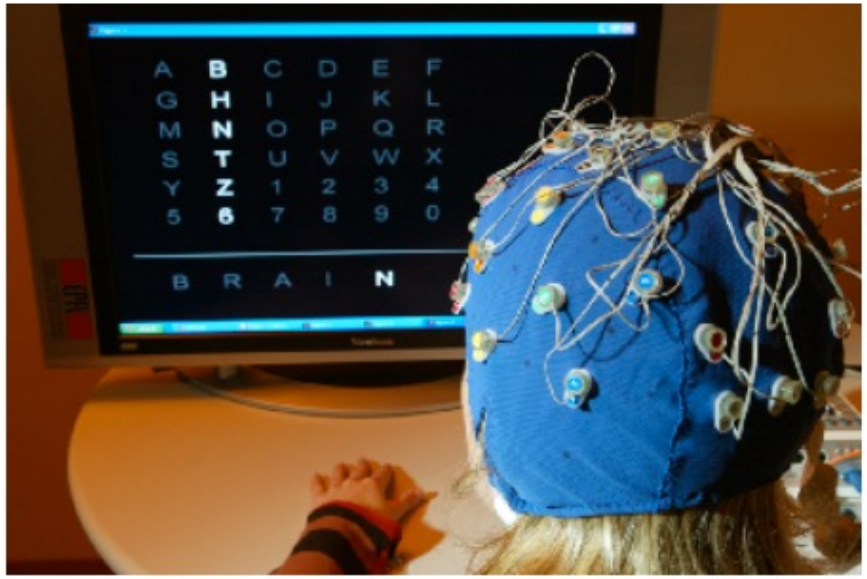
- Most salient disciplines:
  - EEG Signal Processing & Machine Learning
  - Clinical Neuroscience
  - Human-Computer Interaction & BCI
  - Computational Neuroscience
  - Invasive BCI research
  - Ethics



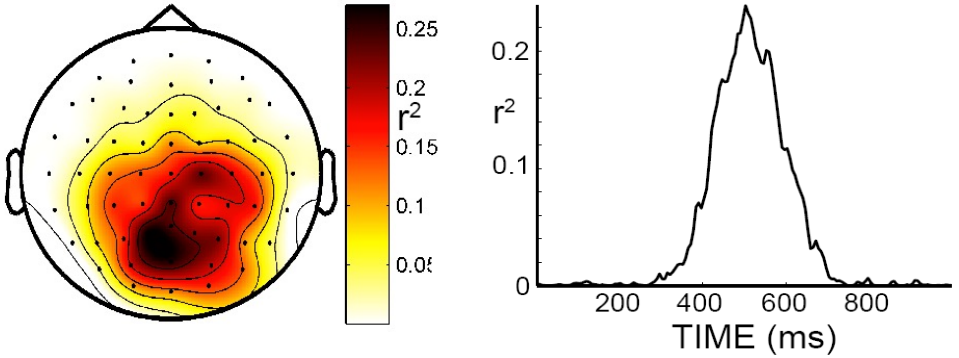
BCI labs localization in France

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

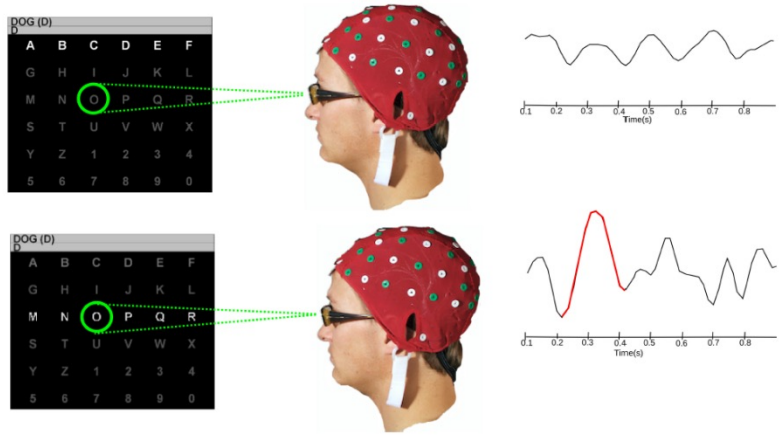
Different types of BCI – P300 Speller



P300 Speller

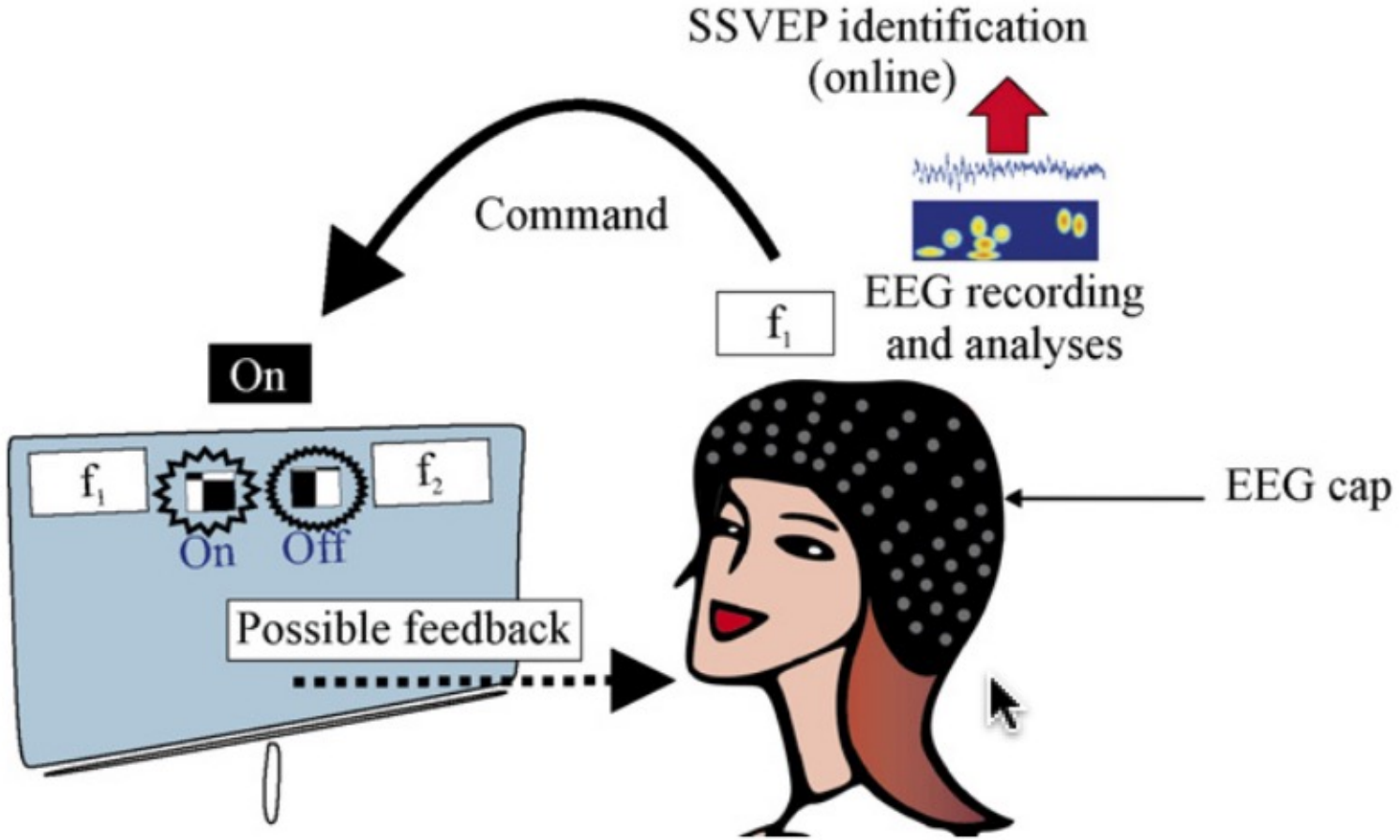


Illustrations from BCI2000 website



Adapted from [Lotte et al, 2015]

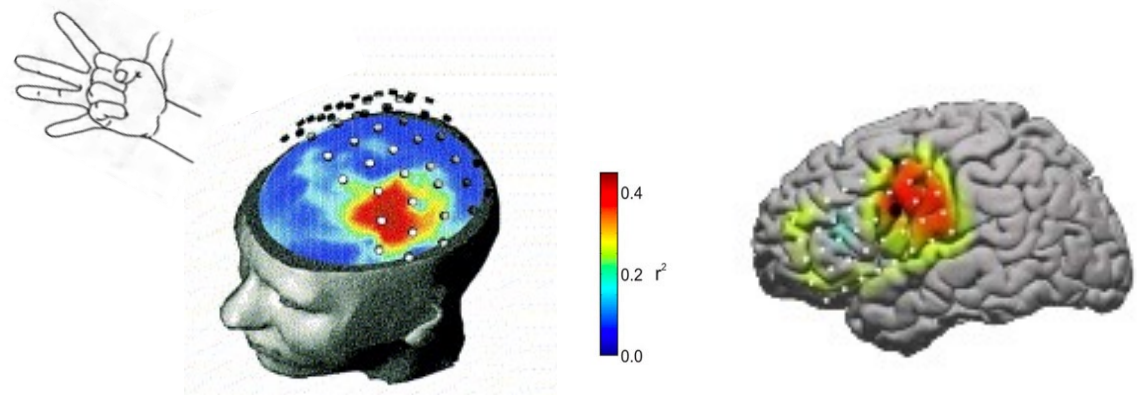
Different types of BCI – Visual epoked potential



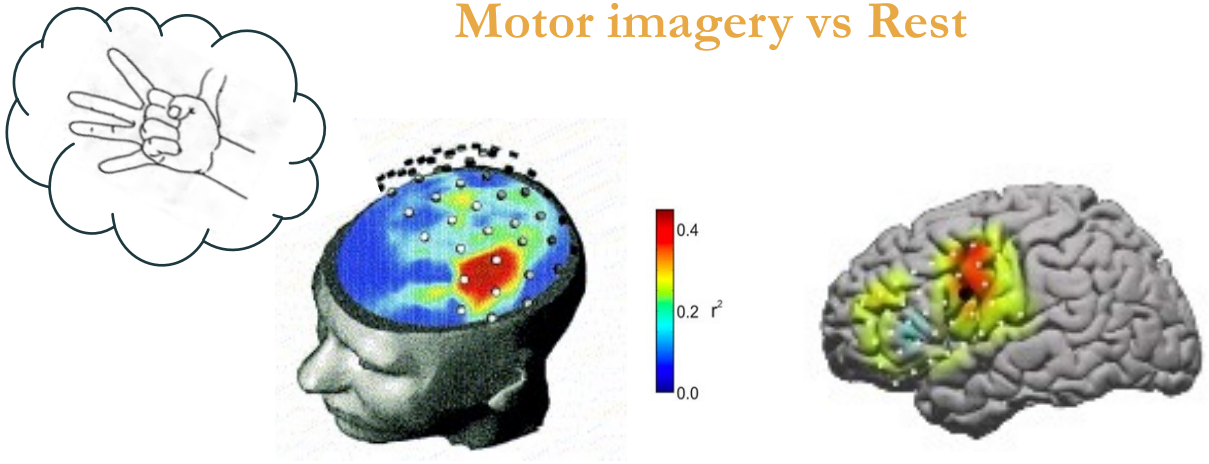
(Vialatte et al, 2010)

Different types of BCI – Motor imagery

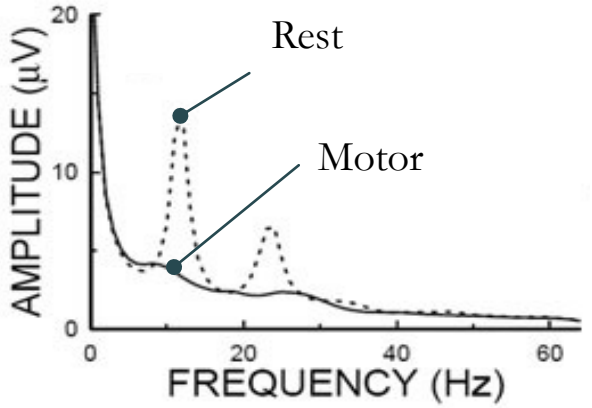
Motor execution vs Rest



Motor imagery vs Rest



Power decrease



Desynchronization effect
(Pfurtscheller et al, 1999)

Underlying idea

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

AN EXAMPLE OF BCI EXPERIMENT

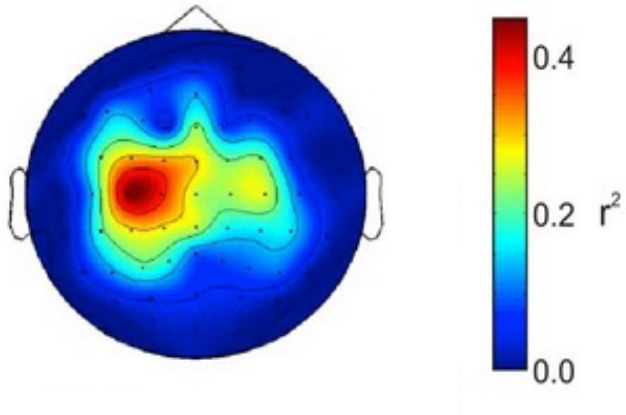
Motor imagery – Mu-beta rhythms

Behavioral properties

- Movement / preparation for movement : Event-related desynchronization (ERD) (Pfurtscheller, G, Lopes da Silva, FH, 1999)
- With relaxation/post-movement period : ERS

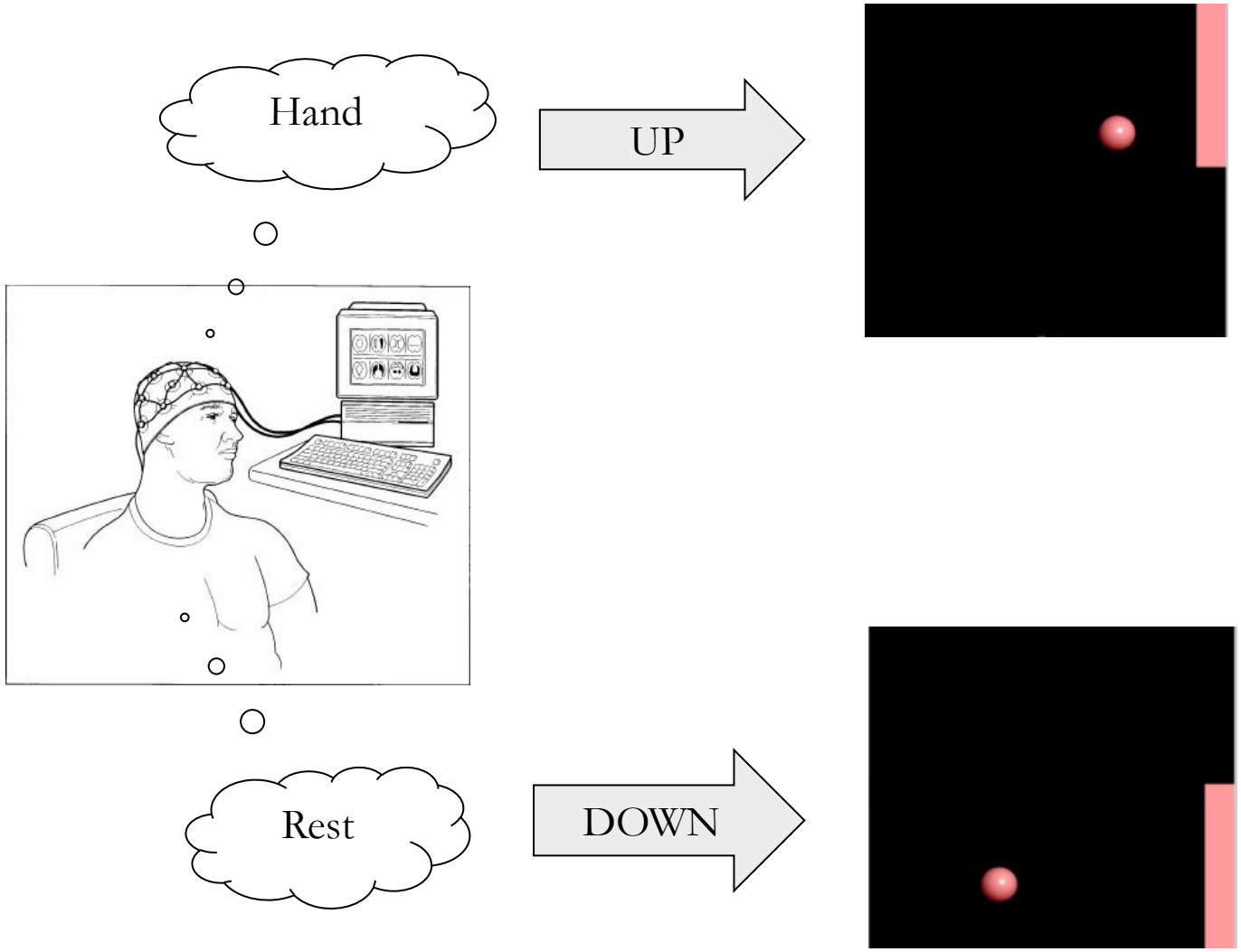
Why using it in BCI ?

- Mu/Beta activity modulation by motor-imagery, a way to communicate
- Use of power spectra
- To establish this communication :
  - Spatial selection
  - Frequency selection



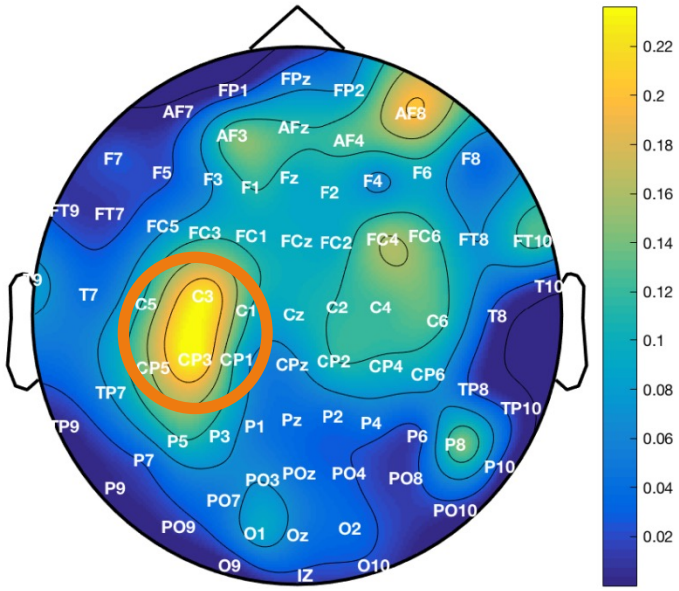
Illustrations from BCI2000 website

Motor imagery – In practice

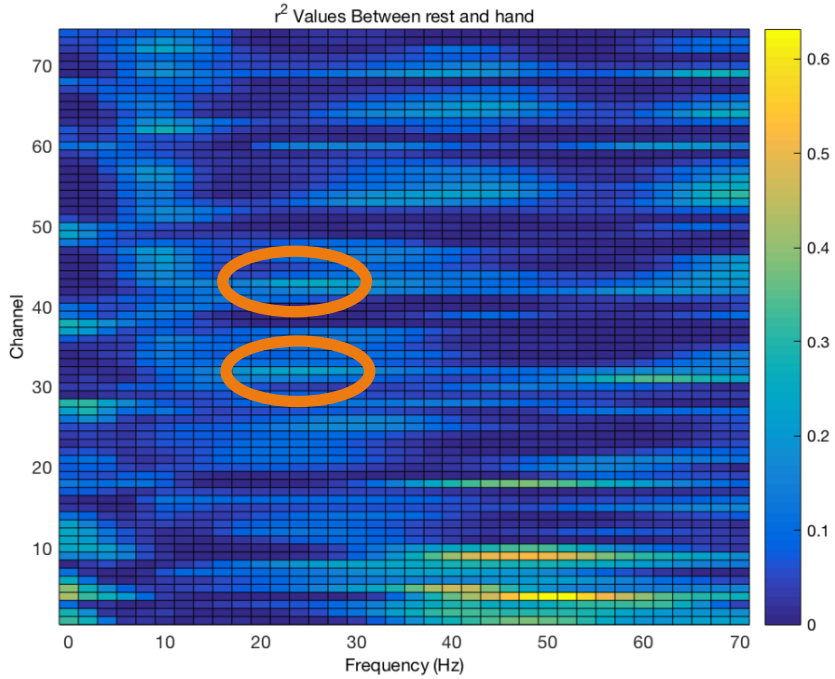


Motor imagery – In practice

@ 10Hz

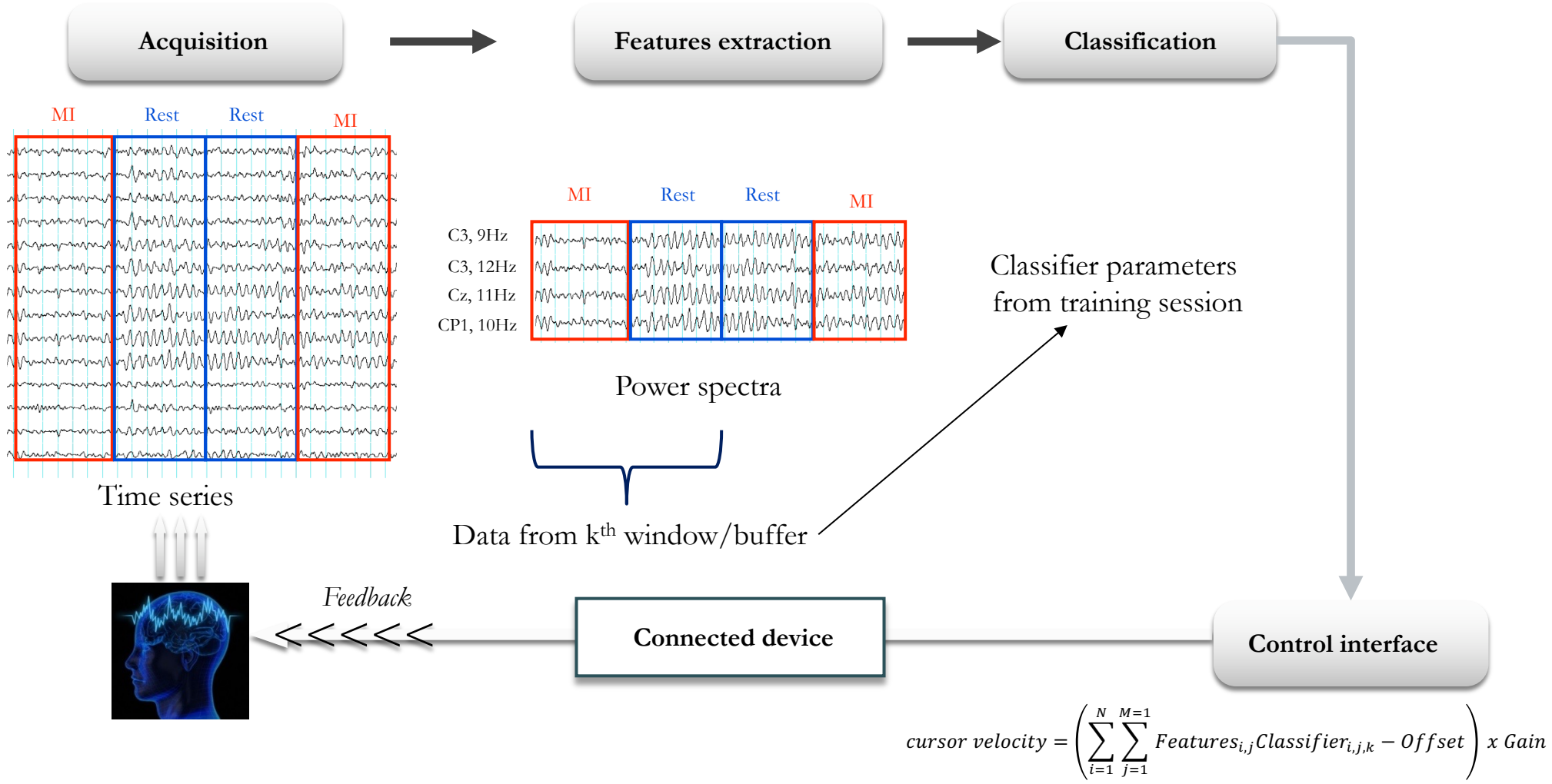


r^2



r^2

Motor imagery – In practice



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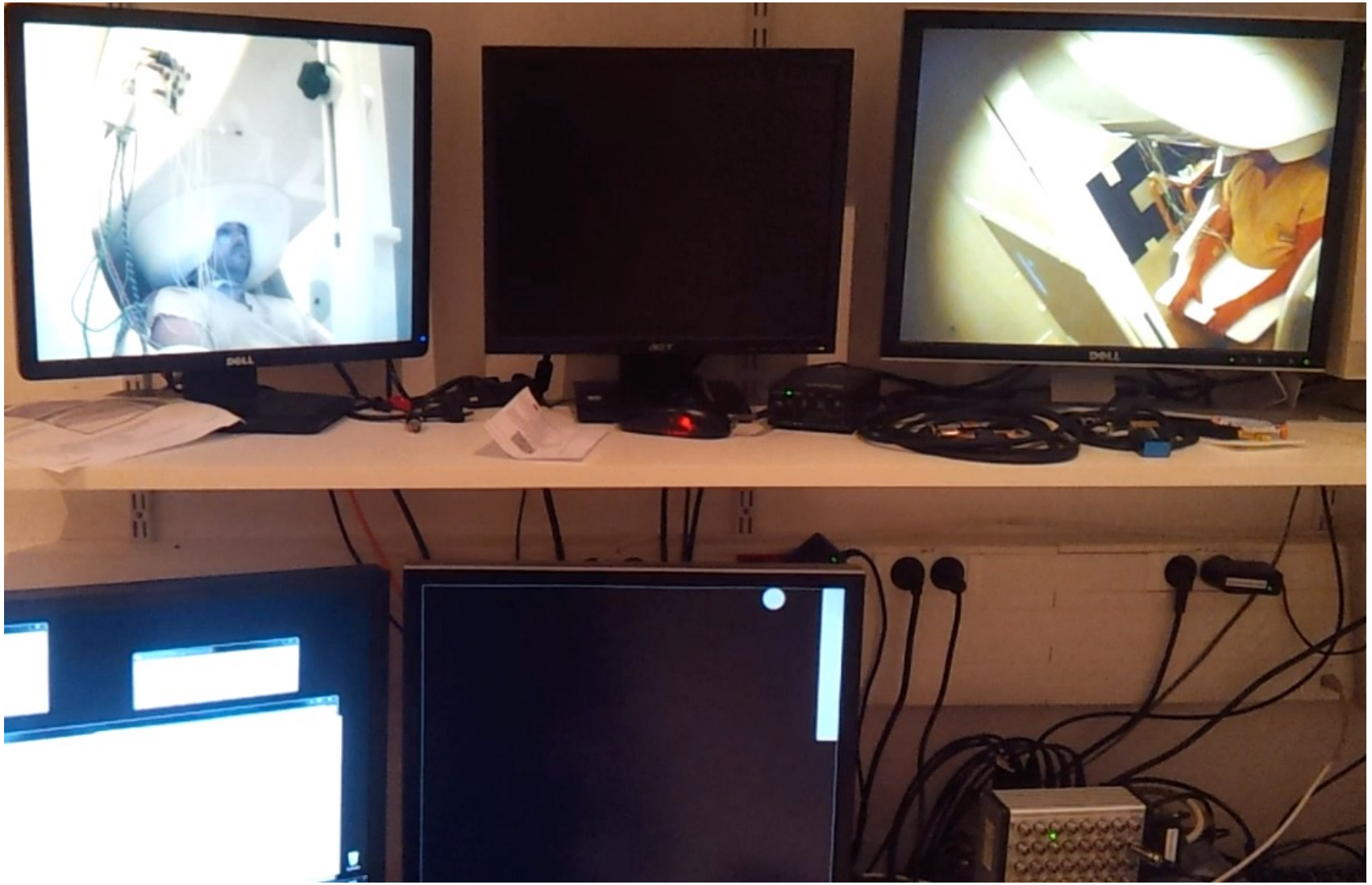
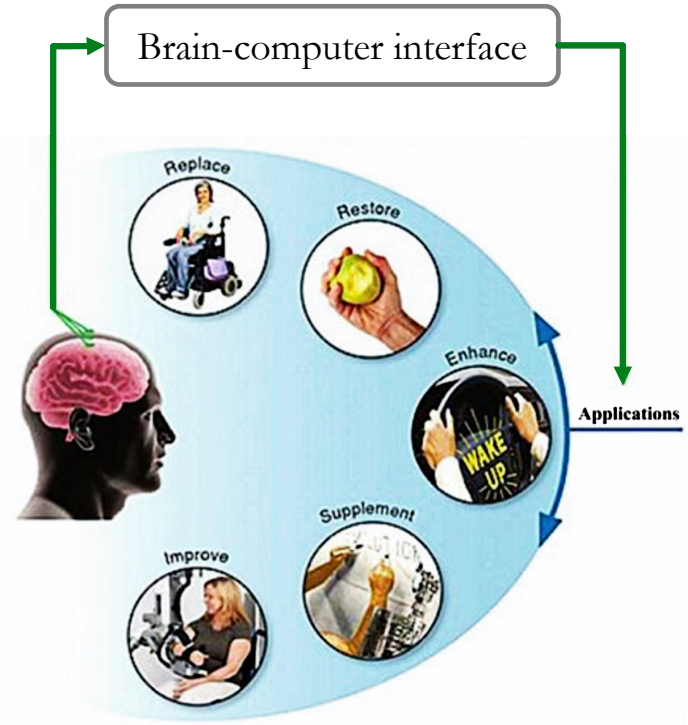
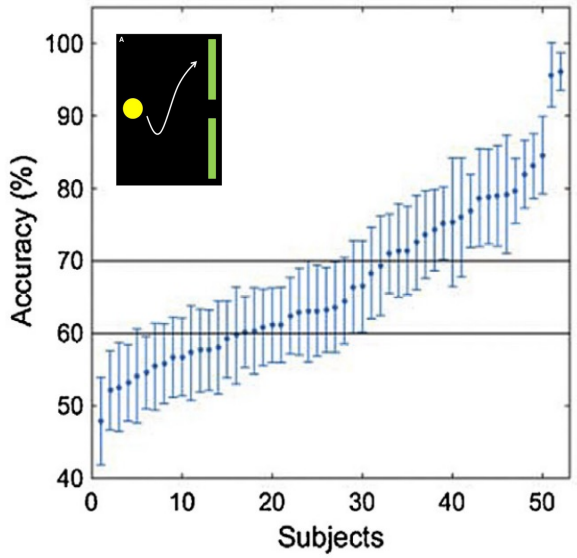


BCI inefficiency challenge

Great potential



Poor usability



(Ahn & Jun, 2015)

Problem: Current BCIs fail to detect the mental intentions in ~30% of users –

BCI inefficiency (Thompson, 2018)

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

Classification algorithms – classical methods

Type	Examples of methods used in BCI
Linear classifiers	- Linear Discriminant Analysis (LDA) and its regularized version - Support Vector Machine (SVM)
Neural networks (NN)	- Multi-Layer Perceptron (MLP)
Non-linear Bayesian classifiers	- Bayes quadratic classifiers - Hidden Markov Models (HMMs)
Nearest neighbour classifiers	- k-Nearest Neighbour (kNN) - Mahalanobis distance classifiers
Classifier combinations	- Boosting - Voting - Stacking

Current challenges:

- Low signal-to-noise ratio of EEG signals
- Non-stationarity over time of EEG signals
- Inter/intra-subject variabilities
- Limited amount of training data for calibration
- Low reliability and performance of current BCIs

Classification algorithms – recent methods

- Adaptive classifiers
- Classification of matrices
- Classification of tensors
- Transfer learning
- Deep learning

Open challenge – small datasets

- Motivations
  - New subject/protocol – necessity to try out different experimental conditions
  - Working with patients means often short sessions to avoid tiredness and lack of motivation
  - Data change over time (non-stationay feature distributions) – cf rehabilitation training

- Methods
  - LDA variants with domain-specific regularizations [Sosulski et al, 2021]
  - Transfer learning from earlier sessions/other subjects/different tasks [Kobler et al, 2022]
  - Deep Learning and data augmentation [Rommel et al, 2022]

- Resources
  - Workshop dedicated to smal datasets (BCI meeting 2023) by. M. Tangermann – materials (slides and code)

CONCLUDING REMARKS

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

To go further…

- Tools – with many tutorials
  - Performing online experiments : OpenViBE, an Inria software
  - Open datasets to test algorithms & check their replicability: MOABB
  - M/EEG data analysis : MNE-Python
  - Classification tools : Scikit-learn
  - Extracting and selecting features in BCI: HappyFeat an Inria software

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- M/EEG
  - Chapter book
    - Origins of the signals,
    - M/EEG experiments,
    - Data analysis,
    - Features extraction & selection,
    - Brain disorders

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  - Classification tools : Scikit-learn
  - Extracting and selecting features in BCI: HappyFeat an Inria software

- M/EEG
  - Chapter book
  - Github repo
    - E/MEG data visualization,
    - Data extraction (ERD/S),
    - Classification

Thank you for your attention!

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