PEPERONI : Portable and Personalized Neurofeedback for Stroke Rehabilitation

Pierre Maurel

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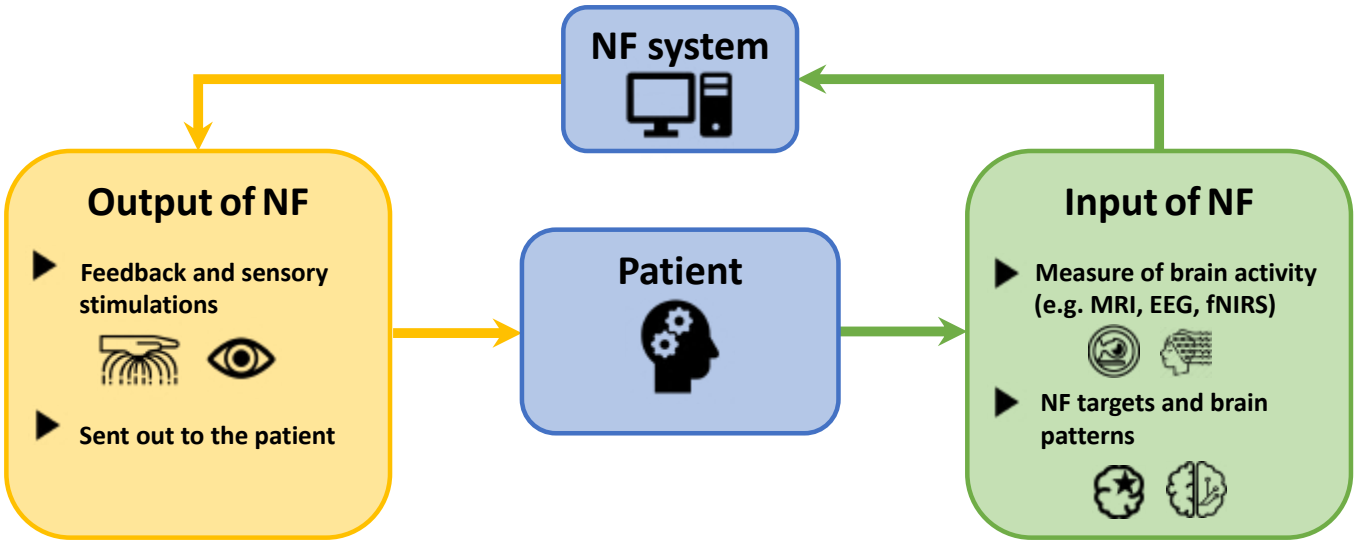
18/11/24

Neurofeedback

Neurofeedback

→ consists in presenting a subject with a stimulus directly related to his/her current brain activity

- can be used to teach subjects to regulate their own brain functions



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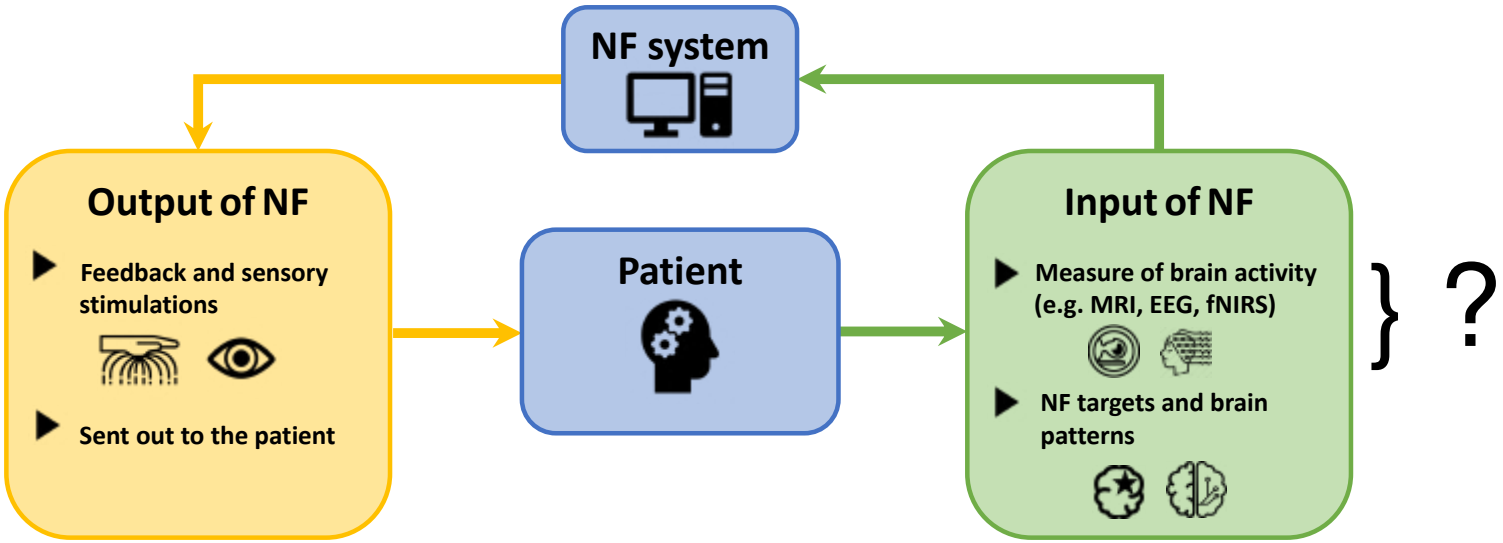
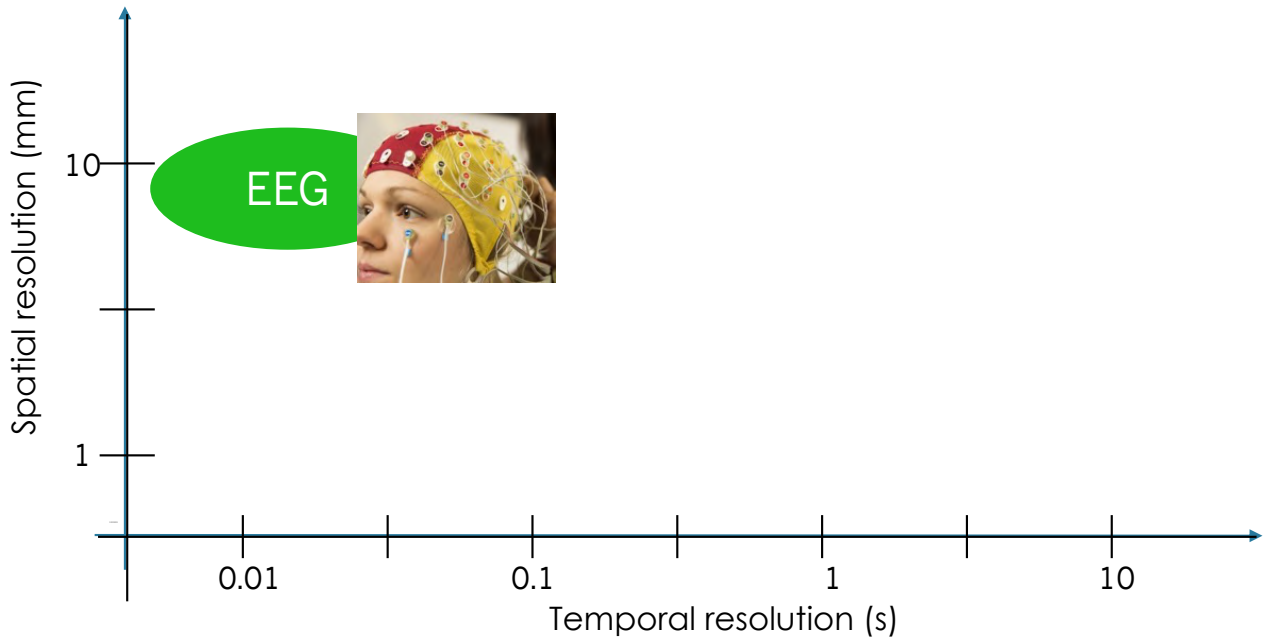


Neurofeedback: How to measure brain activity ?

- **Electroencephalography (EEG)** $\rightarrow$ portable, cheap, main modality used by clinical practitioners, but low spatial resolution



Neurofeedback: How to measure brain activity ?

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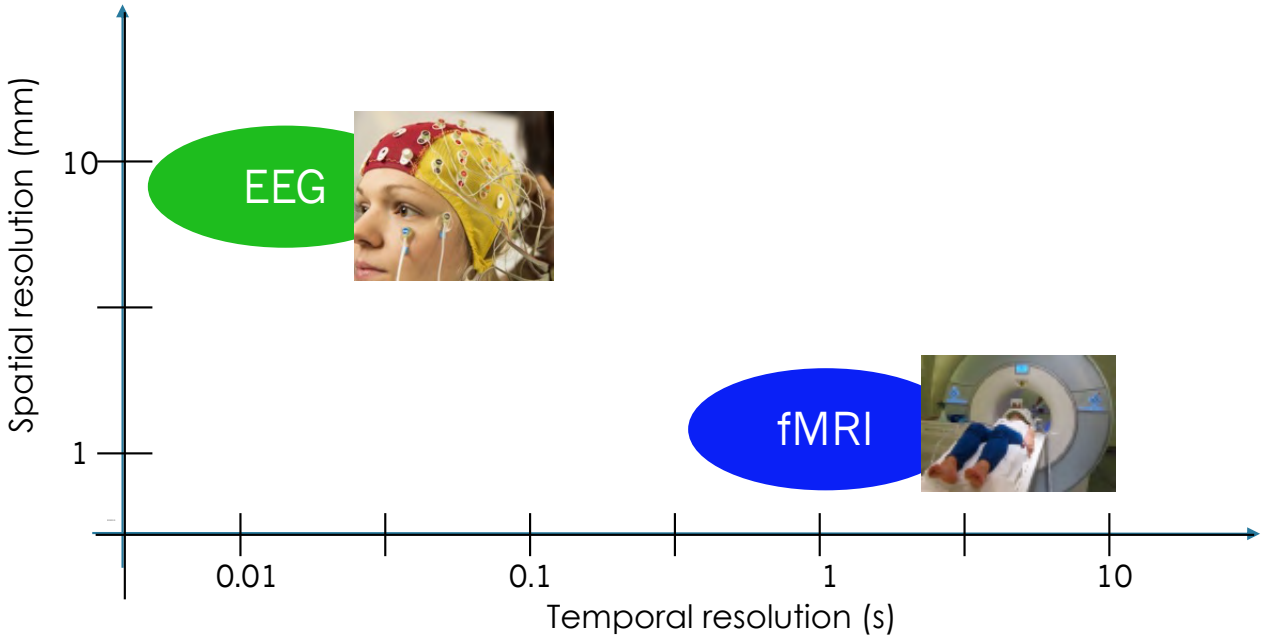
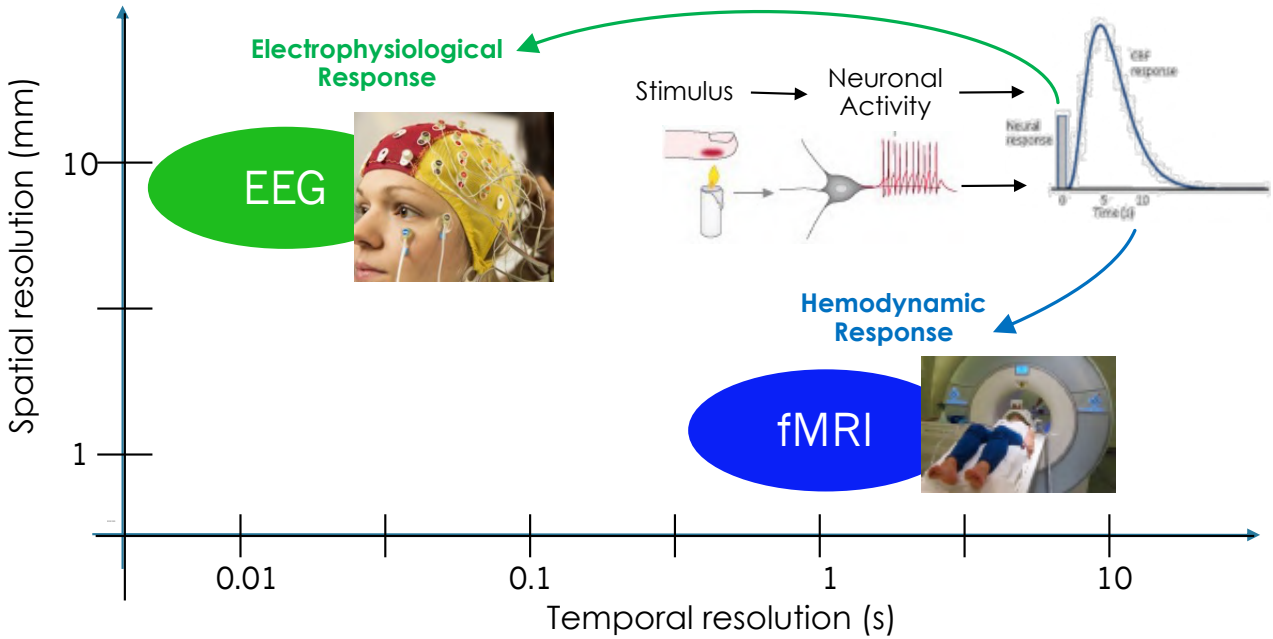
- **functional MRI** → high spatial resolution & possibility to image deep brain structures, but low temporal resolution

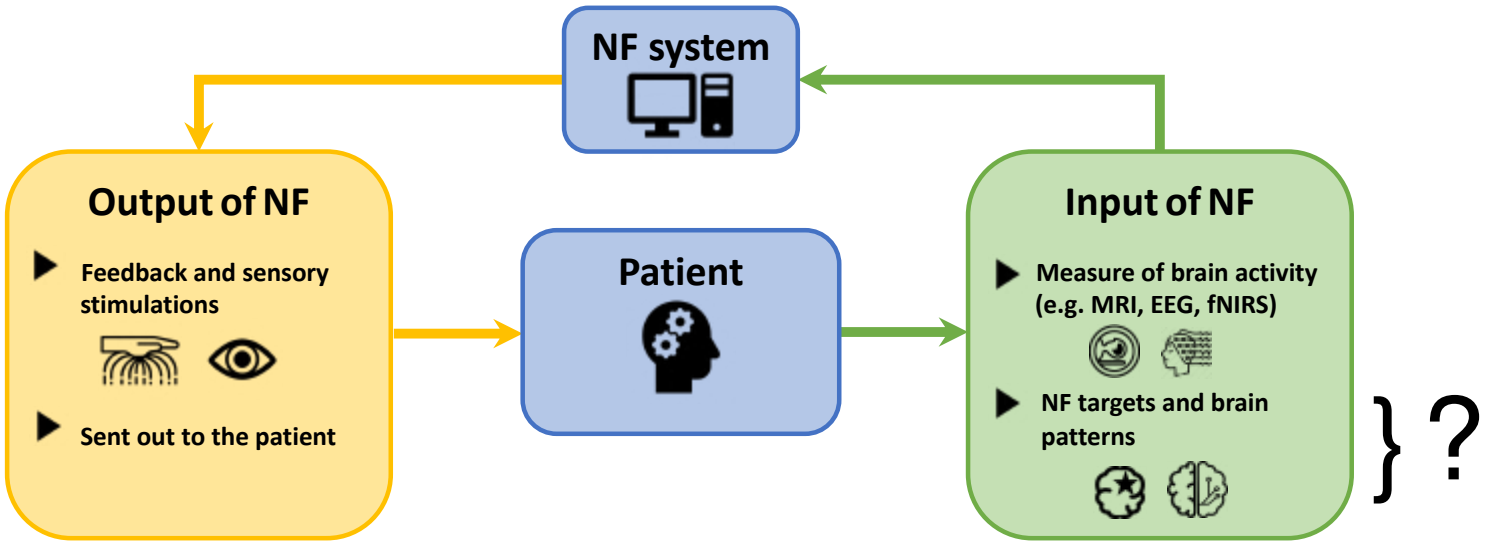


Neurofeedback: How to measure brain activity ?

- **Electroencephalography (EEG)** → portable, cheap, main modality used by clinical practitioners, but low spatial resolution
- **functional MRI** → high spatial resolution & possibility to image deep brain structures, but low temporal resolution
- Capture two different (but related) information

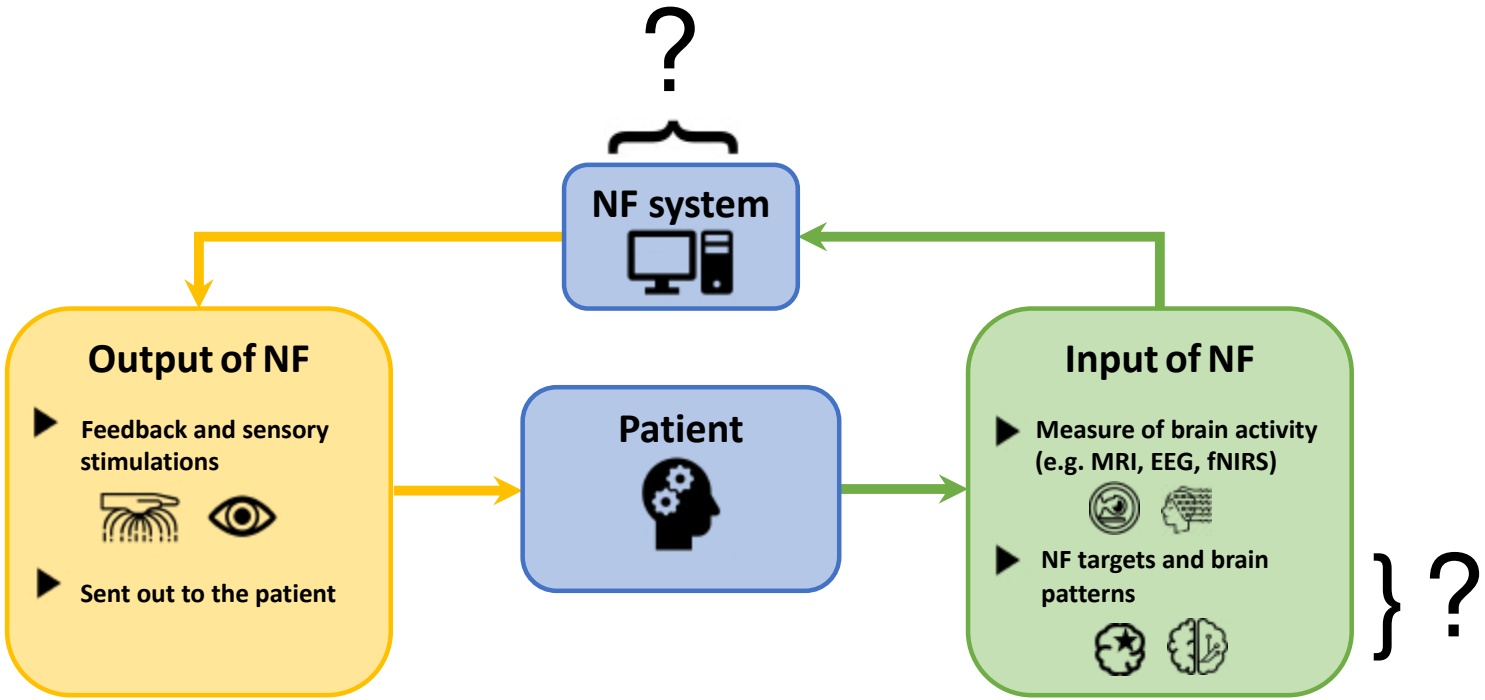


Neurofeedback: How to create the stimulus ?



- Which "target" ? depends on the objective, and the instructions given.
  - Brain activity in the motor area $\leftrightarrow$ "move your left hand"
  - Alpha waves $\leftrightarrow$ "close your eyes and relax"
  - Amygdala activity $\leftrightarrow$ "Think about something that makes you happy"

Neurofeedback: How to create the stimulus ?



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  - Alpha waves $\leftrightarrow$ "close your eyes and relax"
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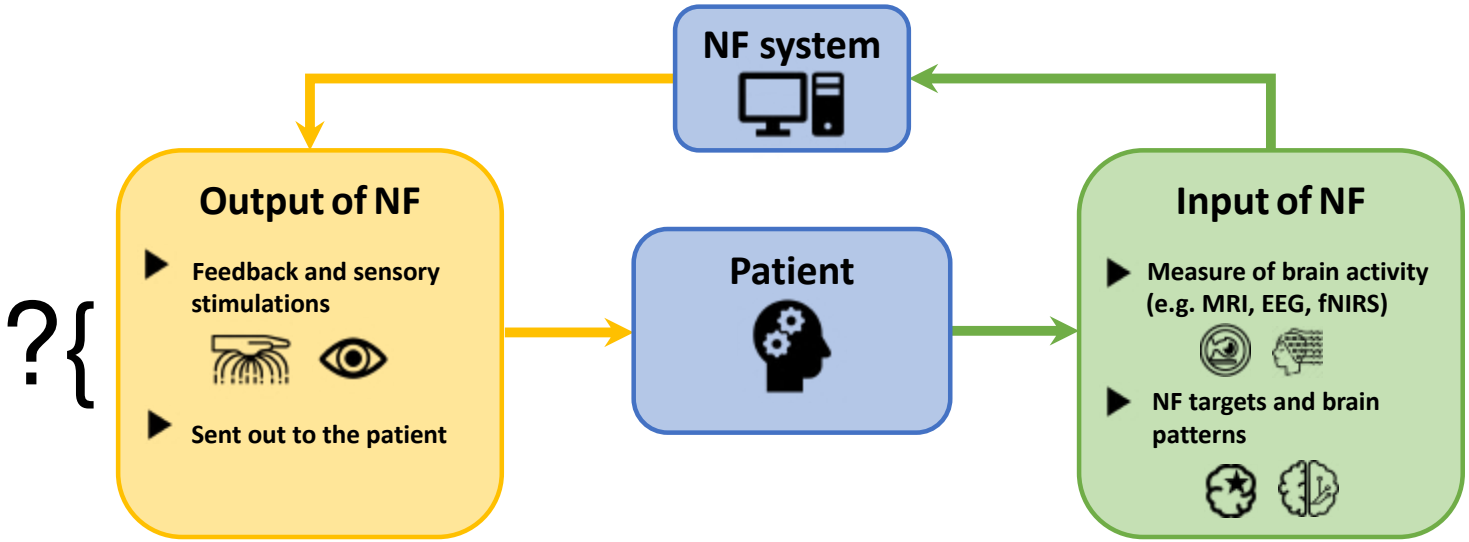
- How to compute neurofeedback scores ? Real-time processing
  - several options depending on the target
  - continuous ? discrete ?

Neurofeedback: What type of feedback ?



- Classically → visual feedback, gauge-like 
- More sophisticated visual feedback
- Auditory feedback
- Tactile feedback

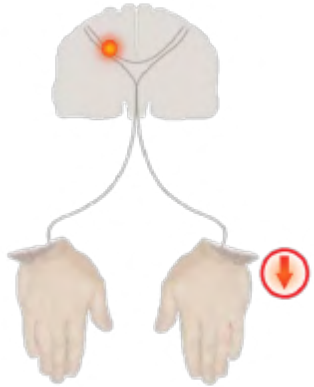
Stroke Rehabilitation

- Leading cause of adults acquired disability

  (Lecoffre et al., 2017)

- 60% of stroke survivors $\rightarrow$ upper-limb paresis, without useful grip, major impact on independence

  (Nakayama et al., 1994)



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- Leading cause of adults acquired disability

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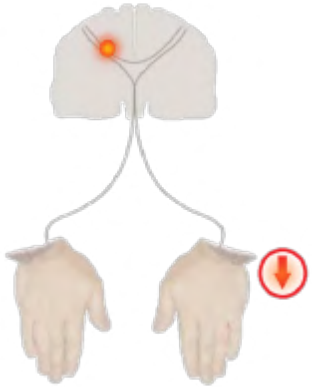
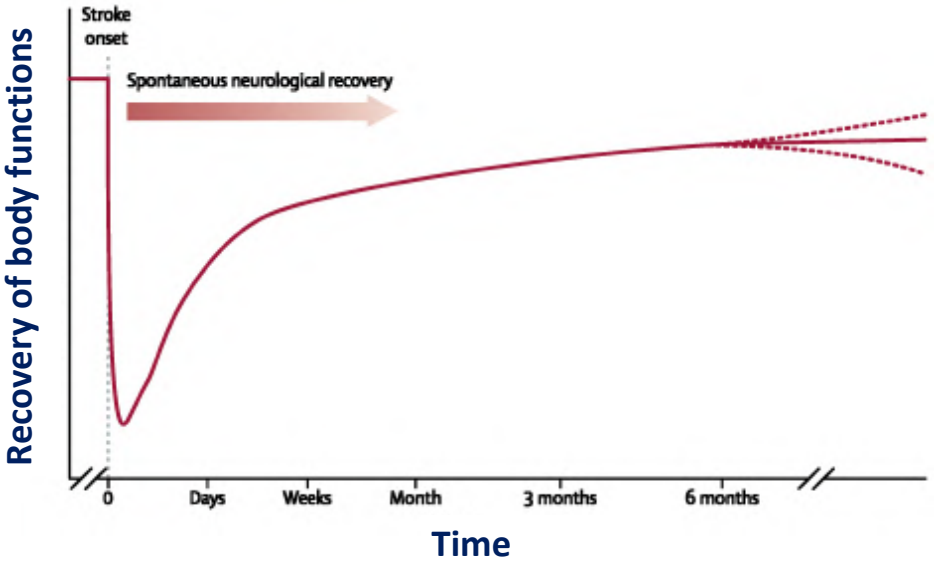
- Recovery limited after one year



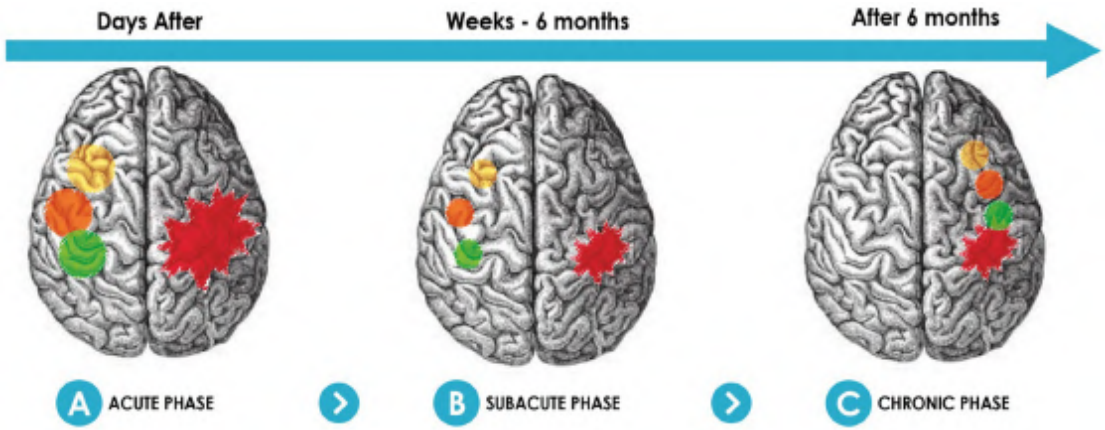


(Langhorne et al, 2011)

(S.Butet)

Neurofeedback for Stroke Rehabilitation

- Physiological recovery mechanism in brain motor areas after stroke



(Le Franc et al. 2022)

→ **Neurofeedback to guide brain plasticity by rewarding a recovery of ipsilesional activation**

Neurofeedback for Stroke Rehabilitation

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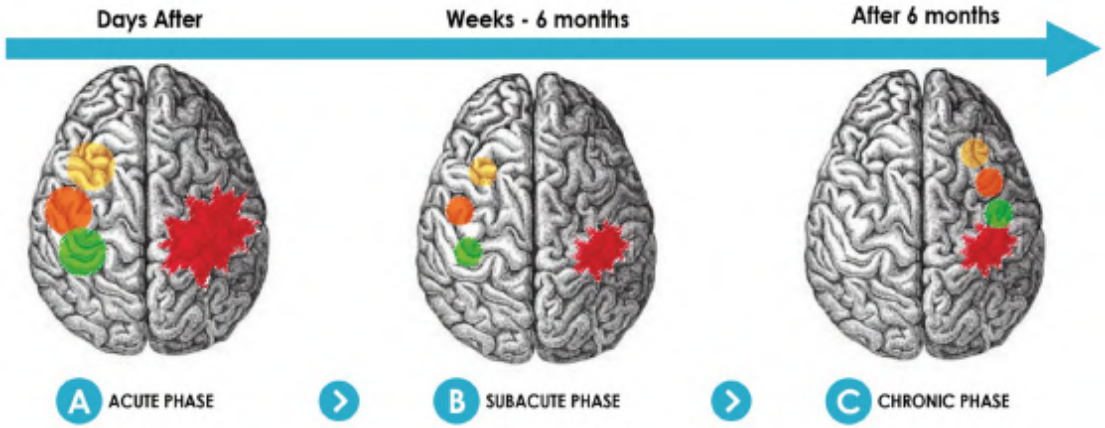
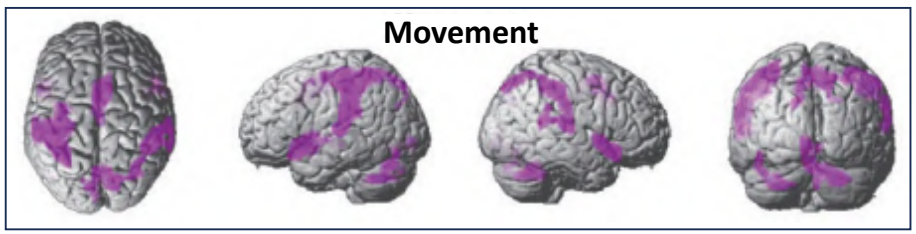
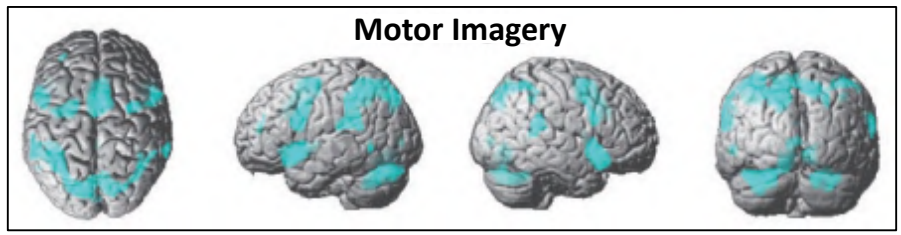


(Le Franc et al. 2022)

→ **Neurofeedback to guide brain plasticity by rewarding a recovery of ipsilesional activation**

- Motor imagery (recommended post-stroke, similar brain activity)
  (Monteiro et al. 2021)



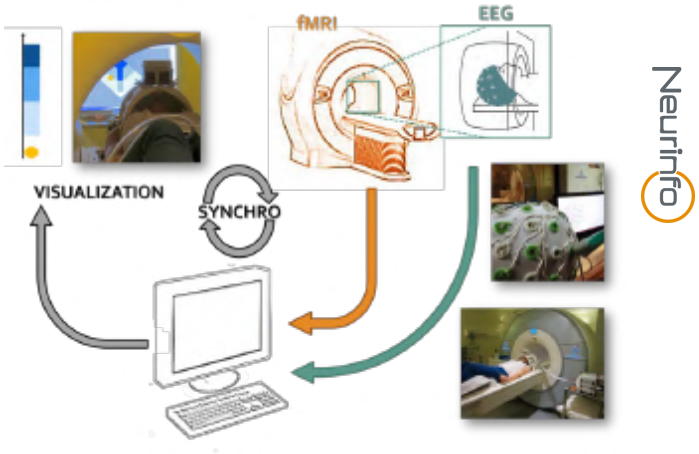


T.Hanakawa et al. 2008, *Motor Planning, Imagery, and Execution in the Distributed Motor Network: A Time-Course Study with Functional MRI*

Context : an EEG-fMRI NF Platform

↪ *How to Build a Hybrid NF Platform Combining EEG and fMRI*, Mano et al., 2017

- Second system worldwide to perform bimodal EEG-fMRI NF
- objective : take advantage of the respective qualities of each modality



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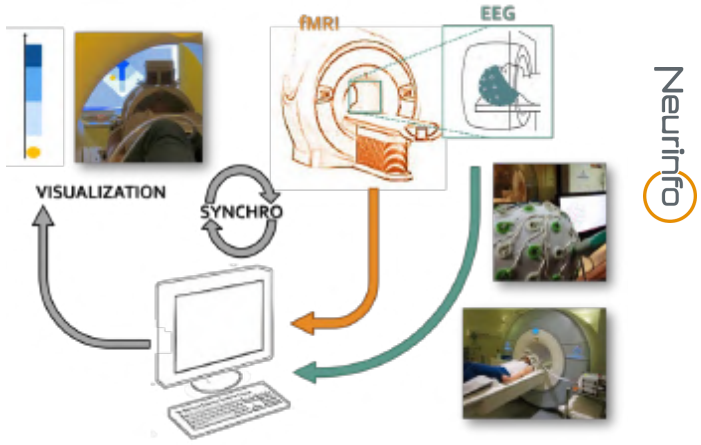
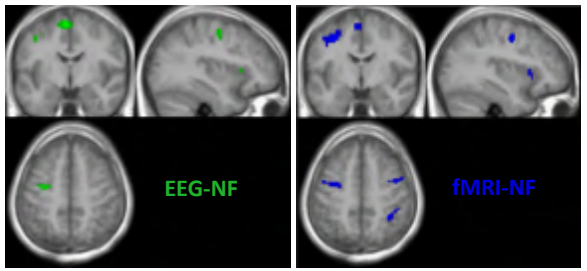
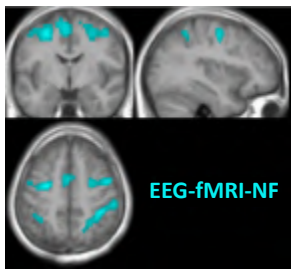


↪ *Unimodal vs Bimodal EEG-fMRI NF of a Motor Imagery Task*, Perronnet et al., 2017

- First studies on healthy subjects
- Simultaneous EEG-fMRI-NF provides stronger, bigger and more widespread activations



Unimodal NF



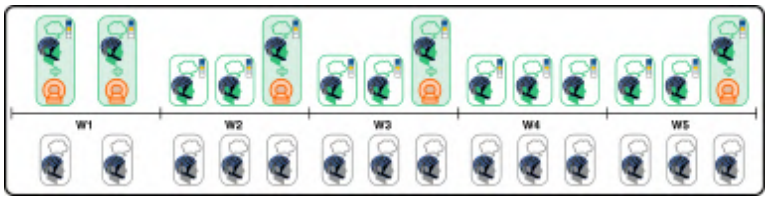
Bimodal NF

Randomized Controlled Trial, Chronic Stroke Patients

↪ *EEG-fMRI Neurofeedback versus Motor Imagery after Stroke, a Randomized Controlled Trial*, Butet, Fleury et al., 2024

30 chronic stroke patients → 14 sessions over 5 weeks

- Neurofeedback group → **5 bimodal EEG-fMRI-NF**, 9 EEG-NF
- Motor Imagery group → 14 motor imagery sessions, without NF

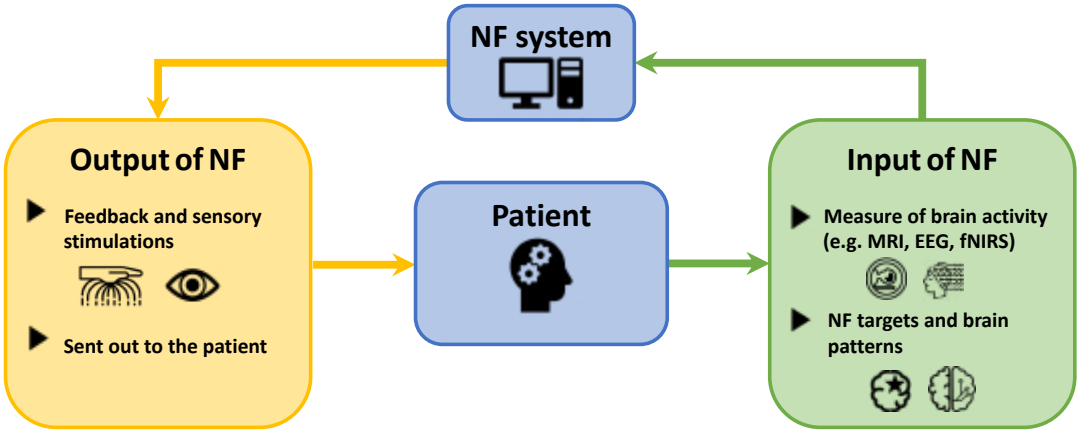


Results on Fugl-Meyer Motor Score:

- **NF group** → **significant improvements**, MI group → no significant gains
- **$8/15$ participants in the NF group** showed clinically significant recovery (increase ≥ 4 points), $3/15$ in the MI group

PEPERONI

Portable and Personalized Neurofeedback for Stroke Rehabilitation



PEPERONI

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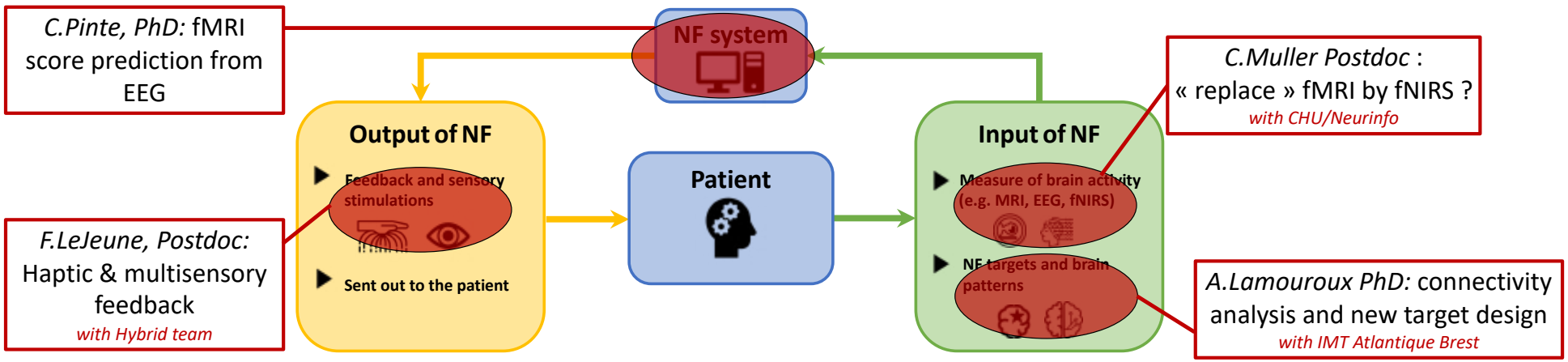

Consortium

- **Empenn U1228 (Inria/Inserm/CNRS/UR1)**
  - Elise Bannier, IR CHU
  - Julie Coloigner, CR CNRS
  - Isabelle Corouge, IR Univ.Rennes
  - Pierre Maurel, PR Univ.Rennes
  - Camille Muller, PostDoc
- **HYBRID Team (Inria/IRISA)**
  - Anatole Lécuyer, DR Inria
  - Marc Macé, CR CNRS
  - Léa Pillette, CR CNRS
  - François Le Jeune, PostDoc
  - Thomas Prampart, IR Inria
- **BRAin Team (Lab-STICC UMR CNRS / IMT Atlantique)**
  - Nicolas Farrugia, MCF IMT
  - Giulia Lioi, MCF IMT
  - Alix Lamouroux, PhD
- **Rehabilitation Dept. CHU Rennes**
  - Isabelle Bonan, PU-PH
  - Simon Butet, MD

PEPERONI: more Personalized, WP 1.1

Goal 1 $\rightarrow$ *"Personalized"* (= adapted to patient profile)

Alix Lamouroux
PhD student

WP 1.1 Brain Connectivity & Neurofeedback
Personalize NF marker with connectivity features

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WP 1.1 Brain Connectivity & Neurofeedback
Personalize NF marker with connectivity features

Objectives

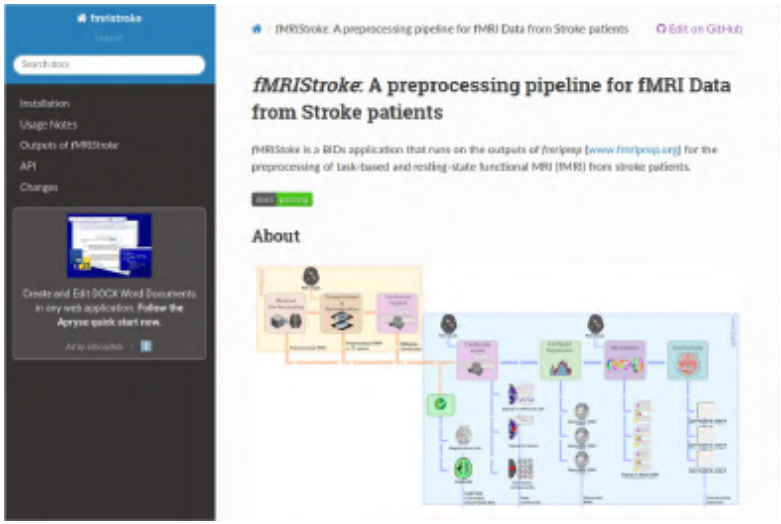
- $\rightarrow$ How to optimally study brain connectivity in stroke patients ?
- $\rightarrow$ Investigate the impact of neurofeedback on brain connectivity
- $\rightarrow$ Propose new neurofeedback targets based on connectivity

WP 1.1 → Alix Lamouroux

fMRI Preprocessing - Stroke

Provide a tool to the community to process and analyse stroke data

- Help the community converge on preprocessing pipeline for stroke data
- **Software under review in** : Journal of Open Source Software



Converge on an “ideal” pipeline for stroke

- **Paper submitted to Imaging Neuroscience :** “Benchmarking preprocessing pipelines for rs-fMRI data in stroke patients: the impact on functional connectivity and behavioral prediction”

WP 1.1 → Alix Lamouroux

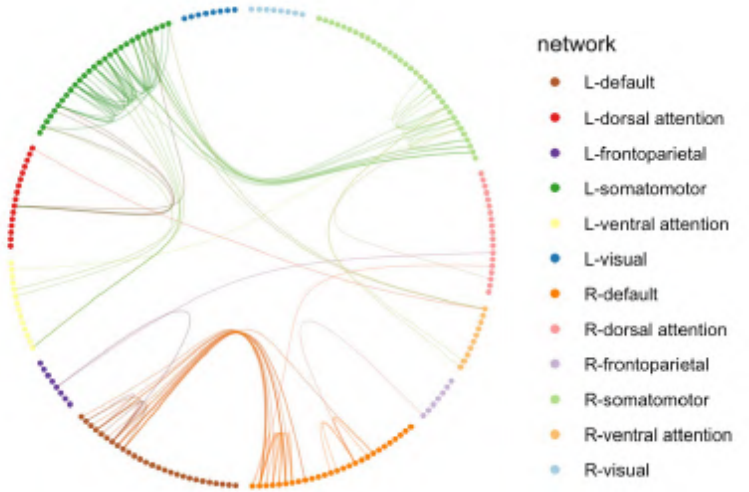
Impact of Neurofeedback on connectivity

↪ Ongoing work on RCT data (chronic stroke patients)

Analysis of connectivity changes due to intervention - Preliminary results

- **Significant connectivity changes found in NF group** in two components (Motor and DMN)
- No significant changes in Motor Imagery group

A. NF group - Significant connections



B. NF group - Mean Connectivity

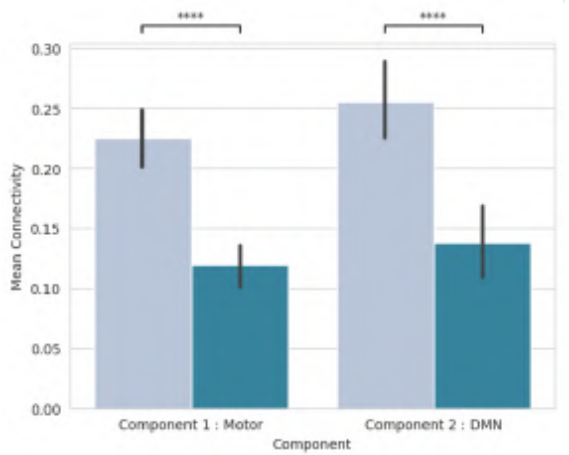


Figure 1 : A. Significant differences Pre vs Post in NF group found with NBS (Network Based Statistics). **B.** Mean connectivity in the two components.

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François Le Jeune
Postdoc

WP 2.2 Multisensory neurofeedback
Adapt the feedback to the patient and the task

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Adapt the feedback to the patient and the task

Objectives

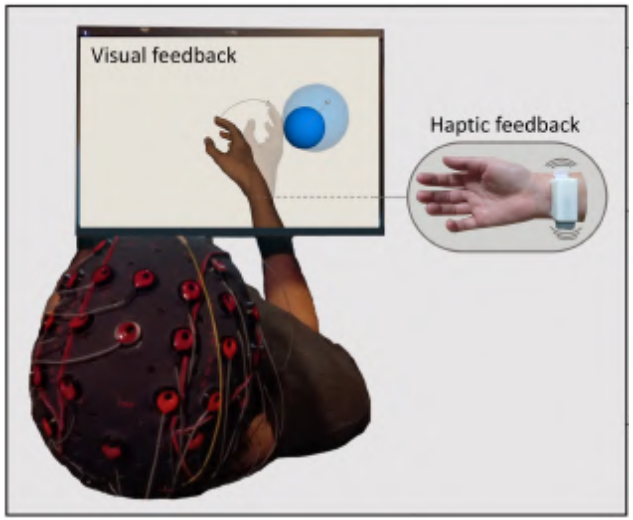
- $\rightarrow$ Current systems: mostly visual feedback.
- $\rightarrow$ Adapted feedback: reduce the time required to learn to control the system and their brain activity, increase chance of success
- $\rightarrow$ Adaptation depending on: personal characteristics of users, evolution of their results

WP 1.2 → François Le Jeune

Visuohaptic feedback for acute stroke patients

↪ YUWIN : earlY Upper Limb Rehabilitation WIth EEG-Neurofeedback After Stroke

Investigate **visuohaptic neurofeedback** in **early stage** sensorimotor rehabilitation on clinical **recovery scores** and **neuromodulation**



44 acute post-stroke patients

22 **REAL** Neurofeedback

22 **SHAM** (yoked) Neurofeedback

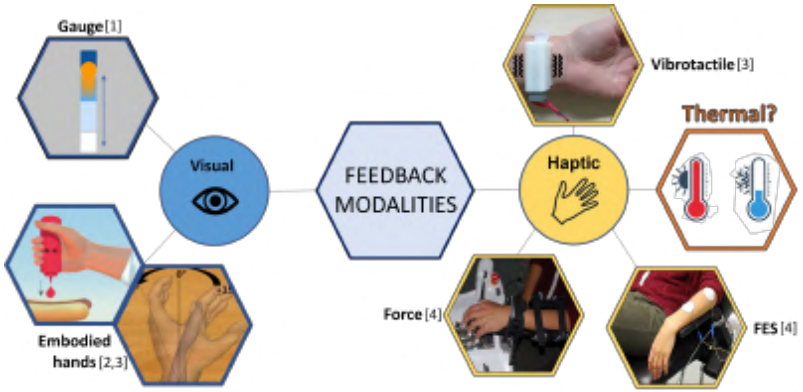
9 patients have completed the protocol so far

WP 1.2 → François Le Jeune

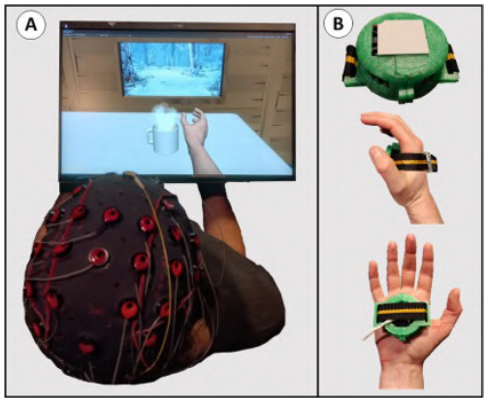
Insights on Thermal Neurofeedback

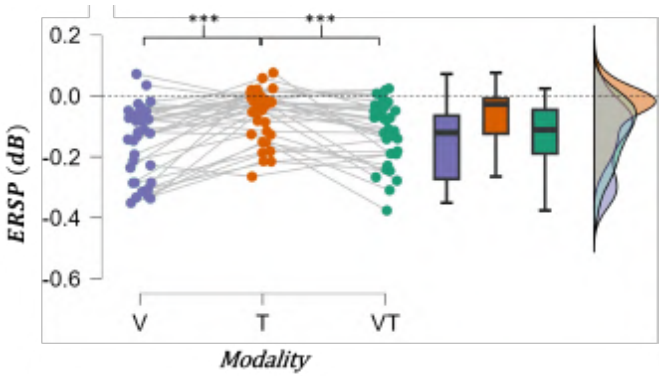
↪ new haptic feedback based on thermal variation

STATE OF THE ART



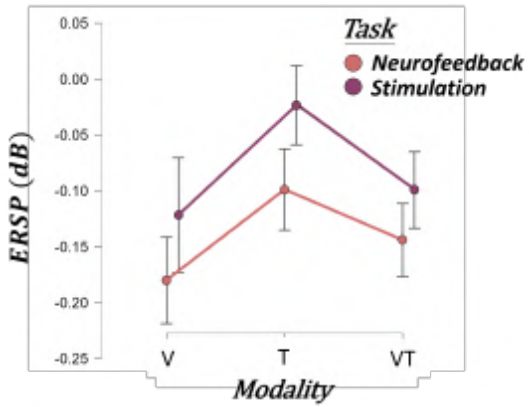
SETUP





PRELIMINARY RESULTS

- Performances with T < V or VT
- Performances with VT ≈ V
- V & VT benefit from **action observation**



Graz BCI Conference 2024, CORTICO 2024, rtFin 2024

PEPERONI: more portable, WP 2.1

Goal 2 $\rightarrow$ *"Portable"* (= less reliance on MRI)

Caroline Pinte
PhD student
(not funded by CominLabs)

WP2.1 Improving portability of bi-modal NF
predicting fMRI NF scores from EEG signals

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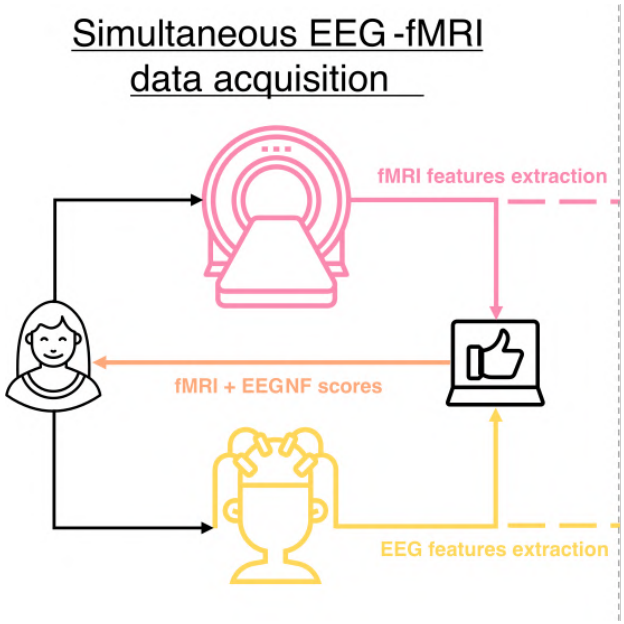

Image : C.Pinte

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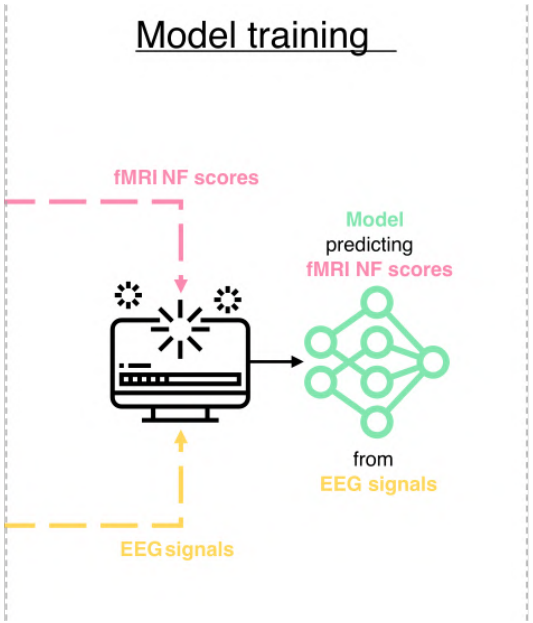

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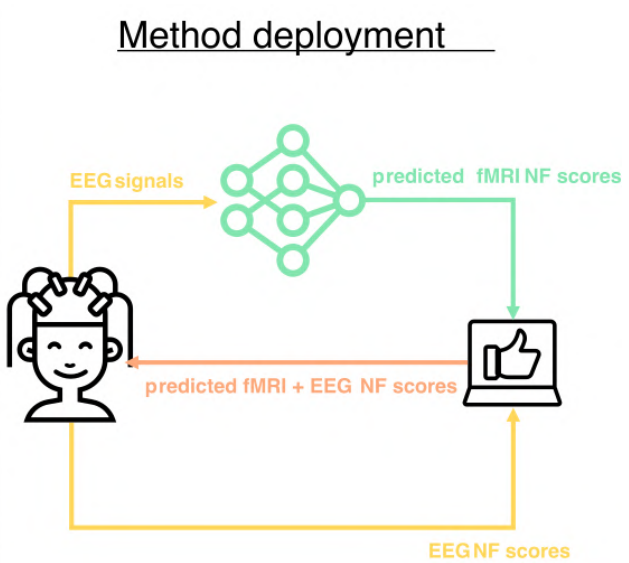

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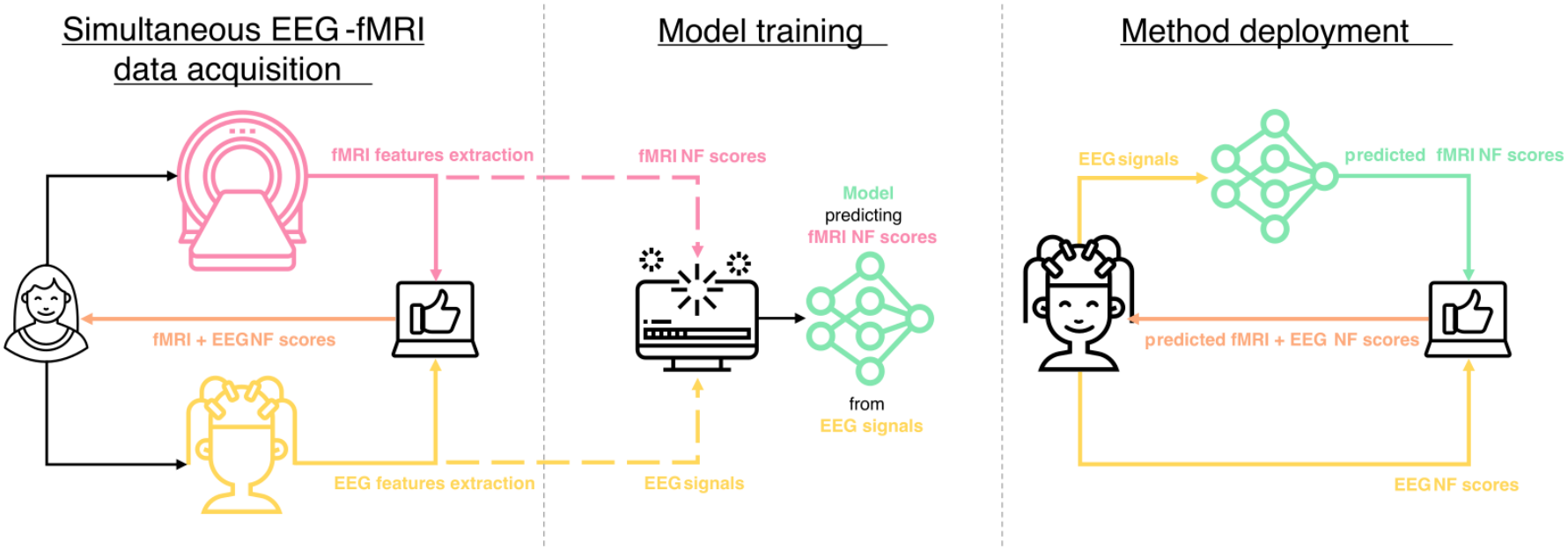

Image : C.Pinte

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Camille Muller
Postdoc

WP2.2 EEG-fNIRS neurofeedback
"replace" fMRI by fNIRS ?

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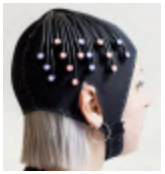
Camille Muller
Postdoc

WP2.2 EEG-fNIRS neurofeedback
"replace" fMRI by fNIRS ?

Objectives

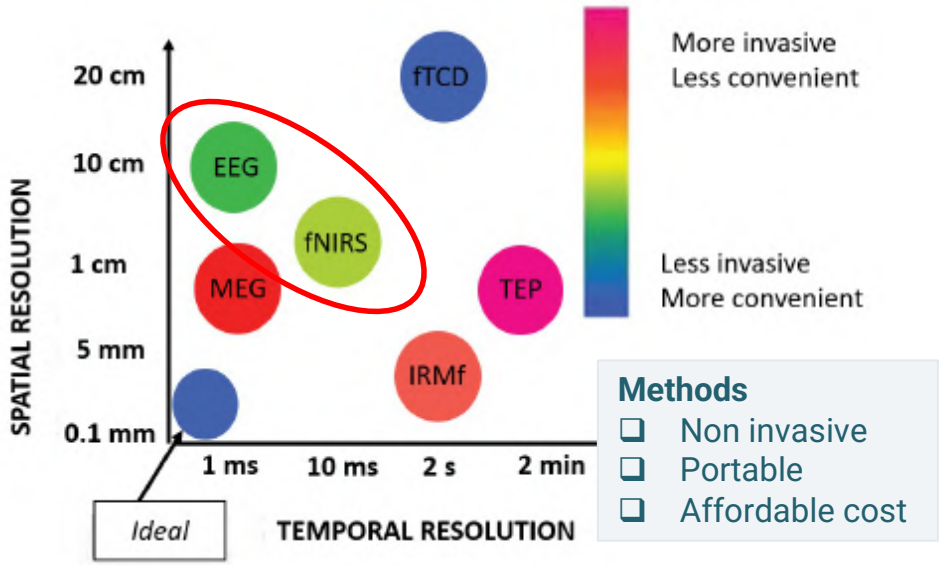
- $\rightarrow$ fNIRS : Functional near-infrared spectroscopy 
- $\rightarrow$ fNIRS and fMRI measure the hemodynamic response
- $\rightarrow$ Propose a new EEG-fNIRS NF acquisition protocol
- $\rightarrow$ Validation on healty subjects
- $\rightarrow$ Design a proof-of-concept study on stroke patients

WP 2.2 → Camille Muller

EEG-fNIRS neurofeedback

Advantages of EEG and fNIRS combination

- Provide complementary information *(Hong et al., 2018)*
- Better spatio-temporal mapping
- No signal contamination *(Fazli et al., 2012)*
- Possibility of an ecological use => improving the clinical application *(Buccino et al., 2016)*
- Existing combined applications other than NF



Combination **feasible** and **promising** for optimizing conventional motor training methods and clinical rehabilitation *(Wang et al., 2023)*

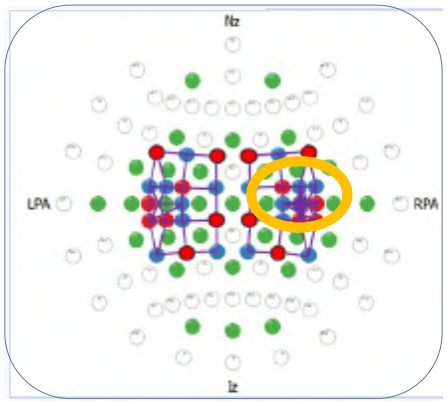
OBJECTIVE: **Evaluate the benefits of multimodal EEG-fNIRS neurofeedback for motor imagery**

WP 2.2 → Camille Muller

EEG-fNIRS neurofeedback

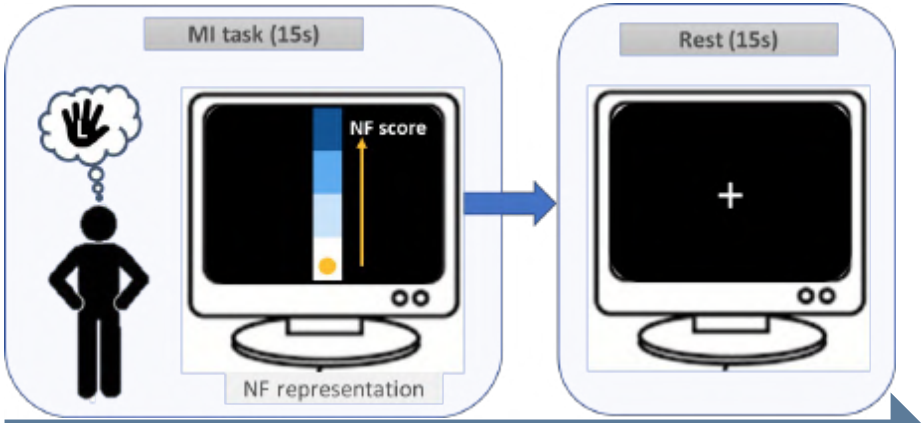
↪ Hybrid acquisition system & real time processing unit (with T.Prampart)

↪ Ongoing study on healthy subjects



EEG and fNIRS joint recording

- NF above right primary motor cortex



NF training

- 3 conditions in randomized order
  * EEG-based NF / fNIRS-based NF / EEG + fNIRS based NF

Preliminary results:

- EEG-fNIRS-NF platform dealing with real-time signals with a dedicated software (OpenViBE)
- NF controlled in all conditions
- Feeling of NF control in favor of combined feedback

Ongoing work:

- 7/30 subjects included (healthy, right-handed)
- Publication of the method
- Analyze the global brain activity related to the NF session in function of the neuroimaging modality

rtFin 2024

Thank you for your attention