Evaluation of multimodal EEG-fNIRS neurofeedback for motor imagery

Camille Muller[1], Thomas Prampart[1], Elise Bannier[1,2], Isabelle Corouge[1], Pierre Maurel[1]

[1]*Univ. Rennes, Inria, CNRS, IRISA, Rennes, France*
[2]*CHU Rennes, Department of Radiology, Rennes, France.*

camille.muller@inria.fr

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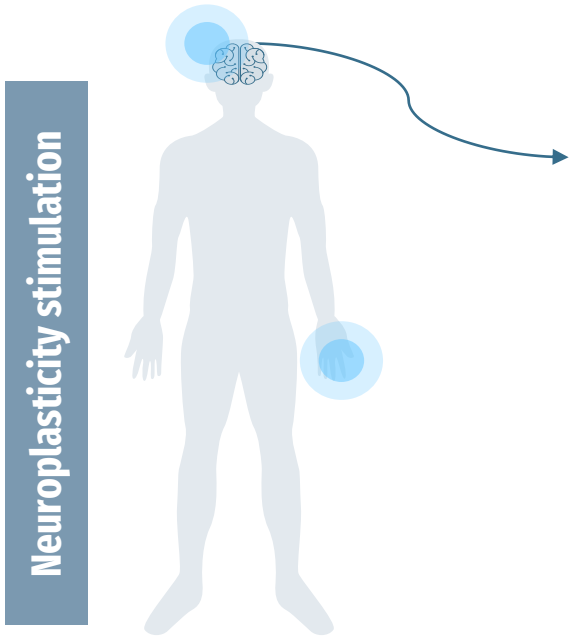
Multimodal neurofeedback for post-stroke rehabilitation

Context: Post-stroke upper-limb (UL) rehabilitation



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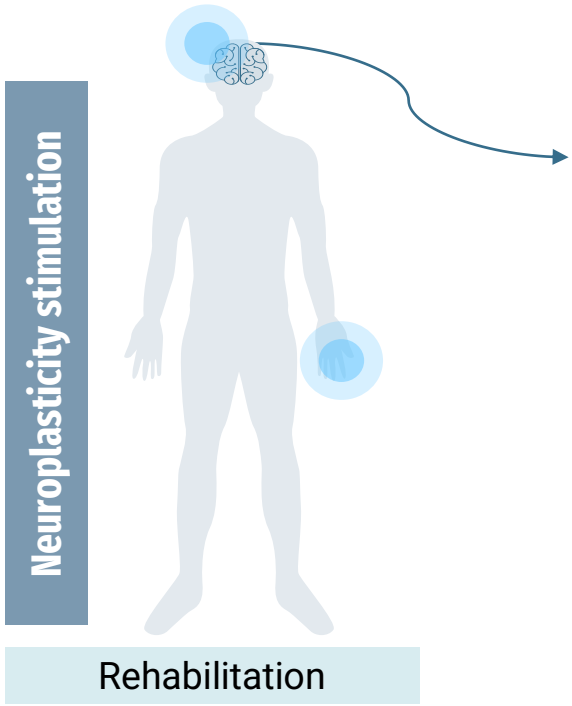

Rehabilitation: **Counteract ipsilesional hemisphere lack of activation**
(Floël, 2014; Teo et al., 2016)

Neurofeedback (NF) + Motor imagery* (MI)

- Targeting the lesioned area *(Jackson et al., 2003)*
  => Activation of motor areas *(Hanakawa, 2008)*
- ↑ motor recovery *(Le Franc et al., 2022;* Bai et al., 2020)

*Motor imagery (MI) - *mental representation of an action without engaging its actual execution (Jeannerod, 1999)*

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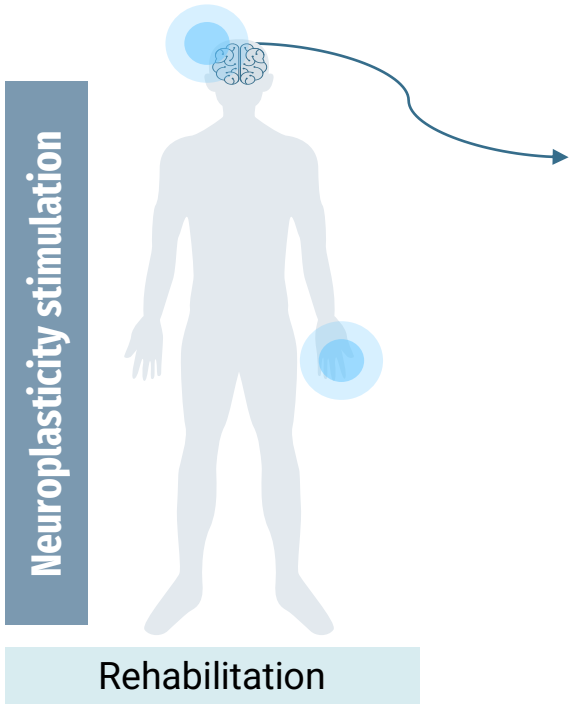

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Optimising NF for MI: **Neuroimaging methods feasible + as accurate as possible**

Multimodal EEG + fNIRS

- Practical for rehabilitation
- Information of brain related activity in post-stroke
  (Muller et al., 2024; Delorme et al., 2019; Yang et al., 2019)

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Can multimodal neurofeedback improve its efficiency ?

Multimodal imagery for NF?

fMRI + EEG

Ciccarelli et al., 2023

- May enhance brain rehabilitation techniques
- Complementary bio-signals
- Electric brain activity and BOLD
- Potential therapeutic effects

Limitations of fMRI: position, contraindications, cost, movement, …

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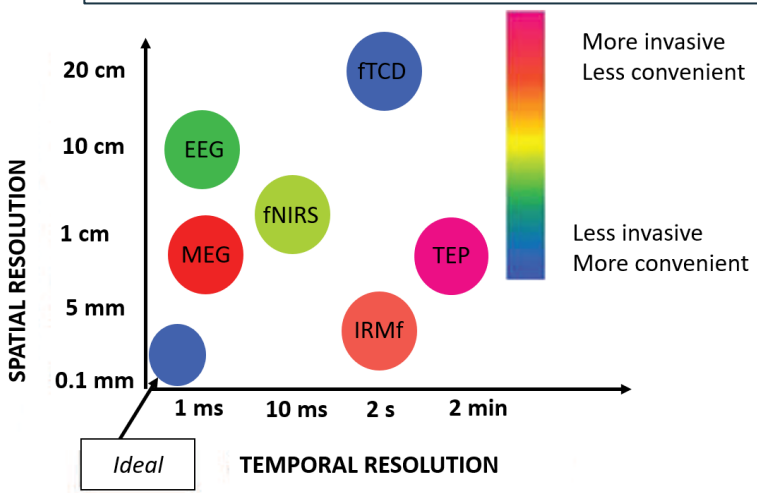

Figure adapted from Parasuraman et Caggiano, 2005 ; Mandrick 2013 ; Chiarelli et al., 2018

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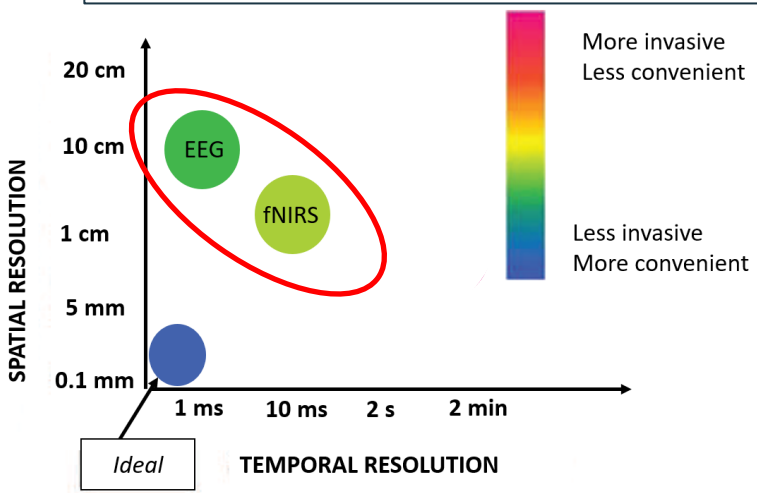


Interest for methods

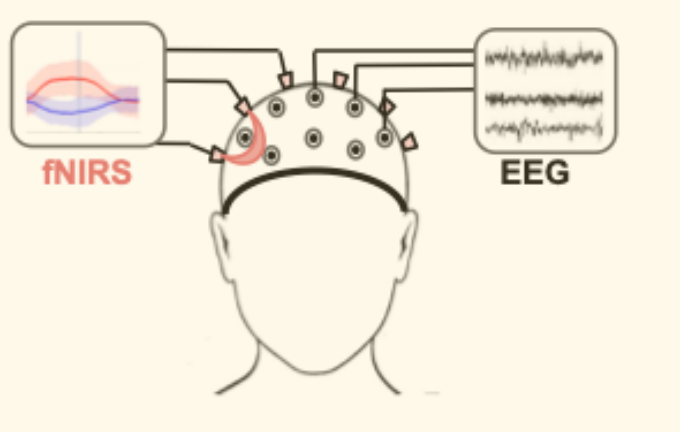
- ❑ Non invasive
- ❑ Easy to use
- ❑ Portable
- ❑ Allowing combined practice
- ❑ Affordable cost

Figure adapted from Parasuraman et Caggiano, 2005 ; Mandrick 2013 ; Chiarelli et al., 2018

Multimodal neurofeedback with fNIRS-EEG

Advantages of EEG and fNIRS combination

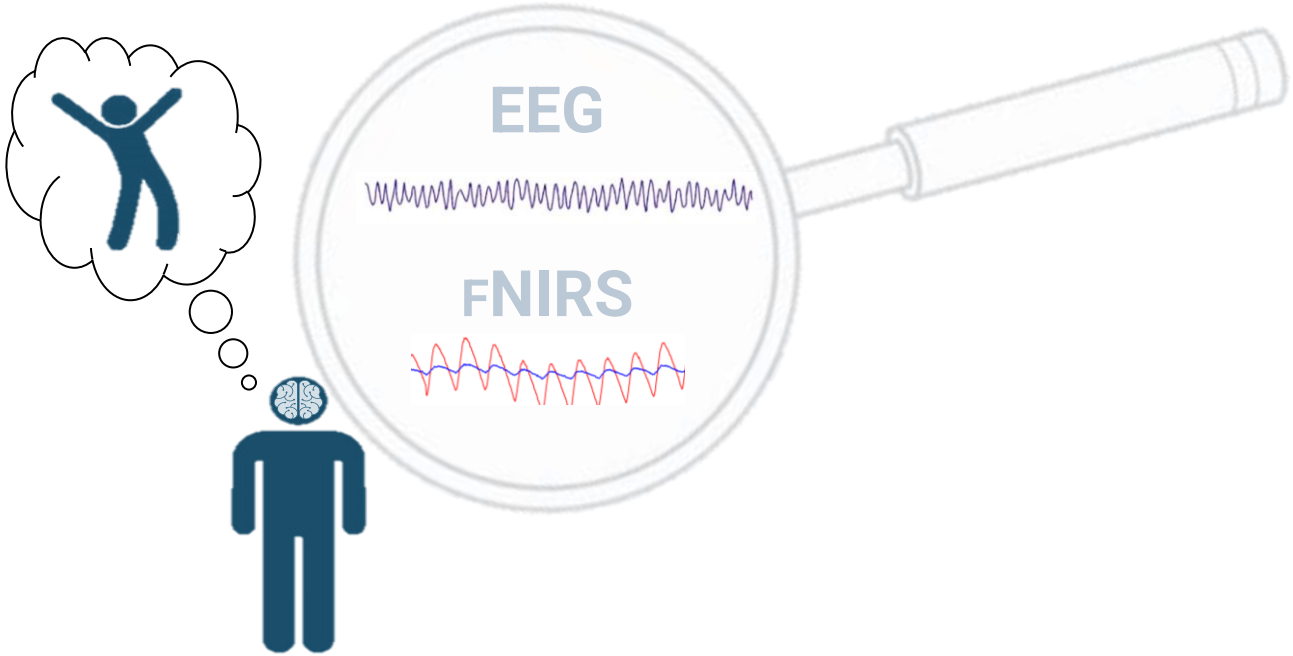
- Provide complementary information *(Hong et al., 2018)*
- Better spatio-temporal mapping
- No signal contamination
- Possibility of an ecological use => improving the clinical application
- Already often combined applications other than NF



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

To our knowledge, none study has associated fNIRS + EEG for NF-MI for post-stroke UL motor rehabilitation

Evaluate the benefits of multimodal EEG-fNIRS neurofeedback (NF) for motor imagery (MI)



Population

Objective : evaluate the effects of multimodal NF with EEG and fNIRS

Healthy subjects (N = 30)

- + 18 yrs.
- Right-handed
- No neurological disease
- No UL orthopedic issue

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1 session of NF

Initial tests

MI abilities (KVIQ, *Malouin et al., 2015)*

NF training

- NF calibration
- 3 conditions in randomized order
  * EEG only
  * fNIRS only
  * EEG + fNIRS
- Feedback about the strategies and feelings of control for each condition

Inclusions in progress, 6 subjects included

EEG and fNIRS combined implementation

EEG (ActiChamp, Brain Products)	32 channels
fNIRS (NIRScout XP, NIRx)	16x16 sources x detectors (+8 short-channels)

Implementation complexity

- ✓ Record the same brain areas (NF of right M1)
- ✓ Install all 72 sensors
- ✓ Two different sampling rates (500 vs 6.25Hz)
- ✓ Extract the brain activity with the same software

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- fNIRS 16 sources
- fNIRS 16 detectors
- fNIRS channels
- fNIRS short-channels

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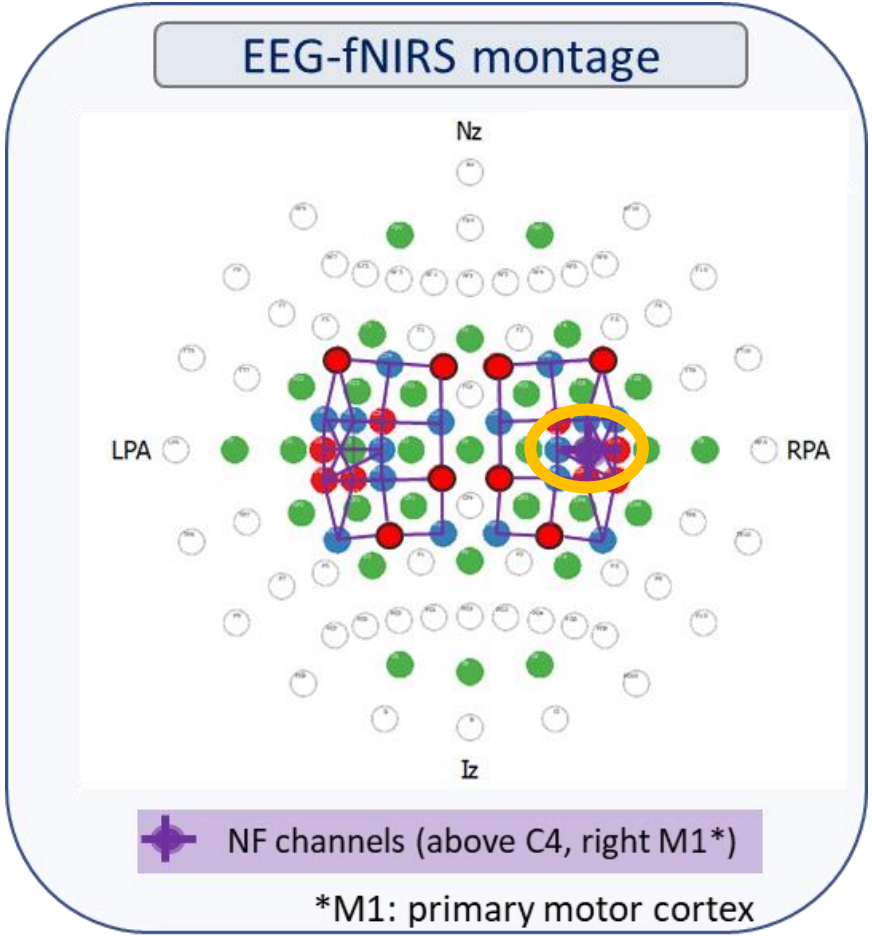
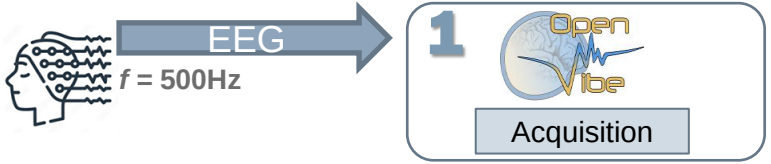
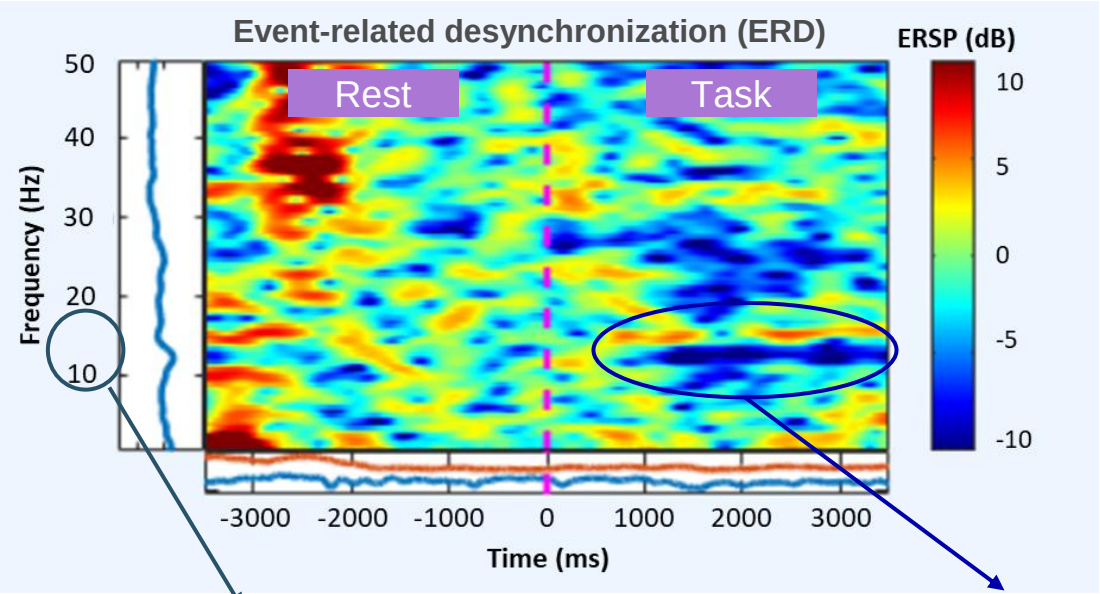




Movement desynchronization (%) (ERD, *Perronnet et al., 2020)*



EEG

f = 500Hz

1 Acquisition

EEG

2 Pre-processing

- Reference to Fz
- Filter (8-13Hz)
- Spatial filter (Laplacian around C4)
- Signal epoching: 1s every 0.25s
- Moving average: 4 epochs

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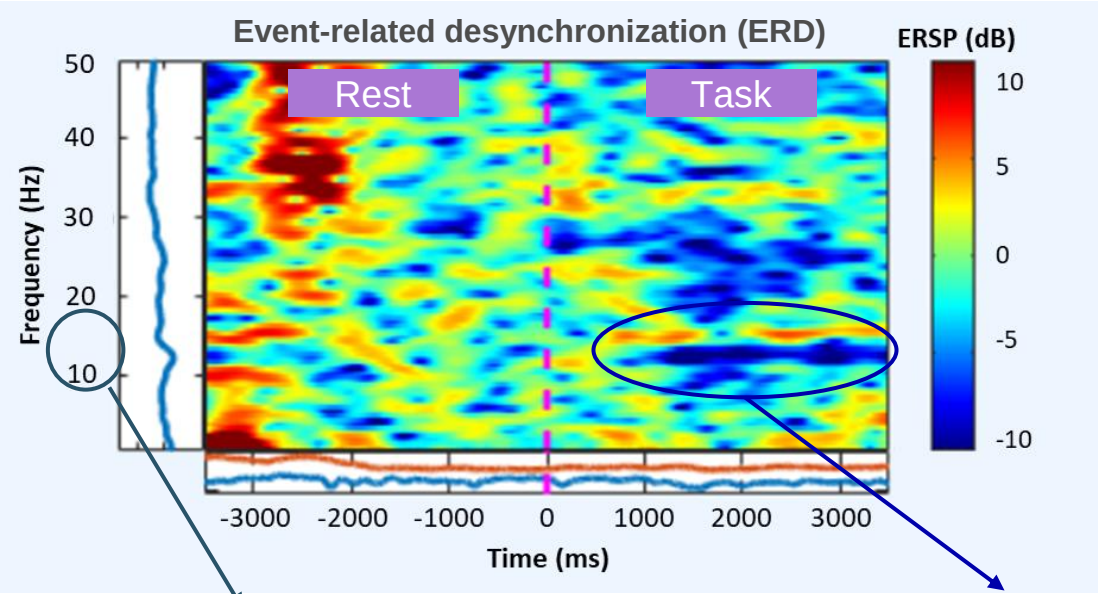

Alpha rhythm – 8-13Hz

Power decrease

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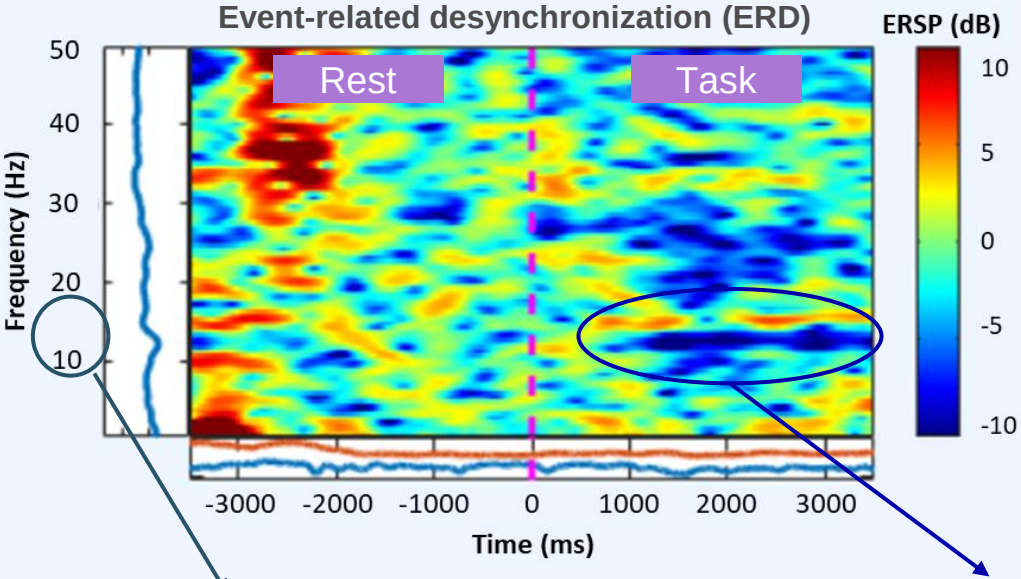


Alpha rhythm – 8-13Hz

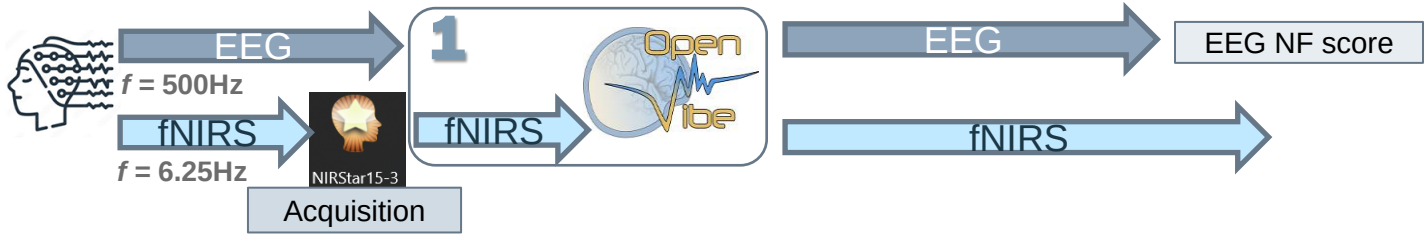
Power decrease

3 EEG NF score

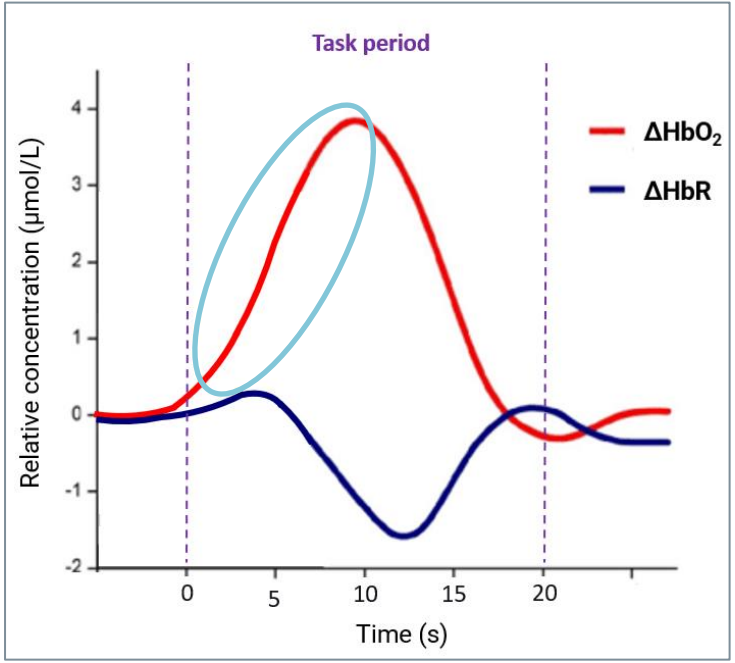
$$\text{Ratio ERD} = \frac{(pTask - pRest)}{pRest} * 100$$

$$\text{EEG NF score} = \frac{Ratio\ task}{Ratio\ calibration*} * 100$$

**Ratio calibration* representing the 30th percentile of the ratios obtained during a calibration session

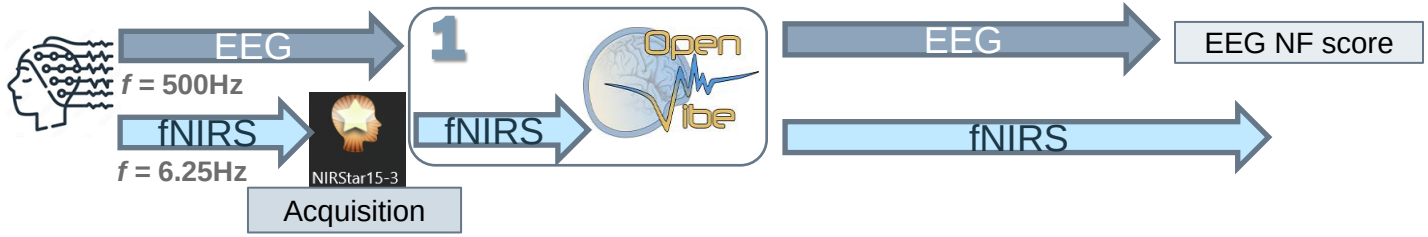


Variations of ΔHbO_2 (Δμmol) *(Godet et al., 2023)*

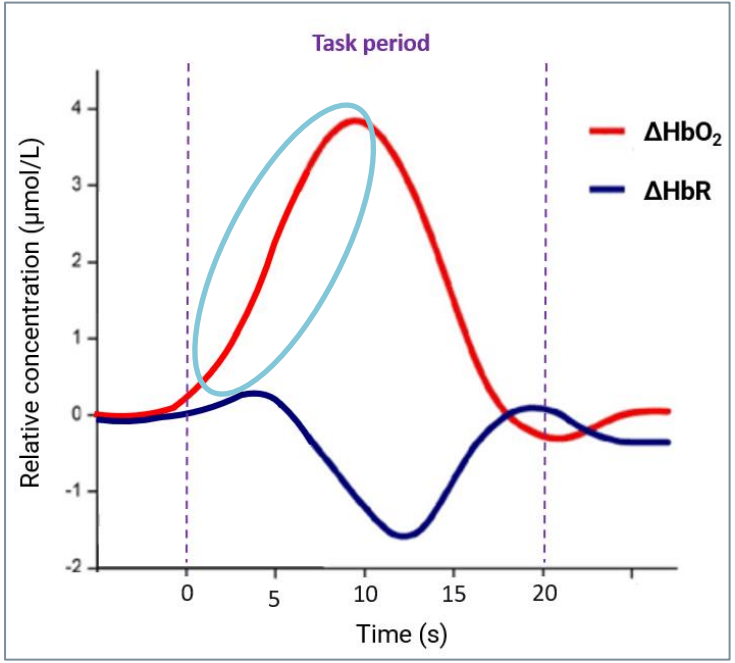


Oxygenated blood (HbO_2)

Deoxygenated blood (HbR)



Variations of ΔHbO_2 ($\Delta\mu mol$) *(Godet et al., 2023)*



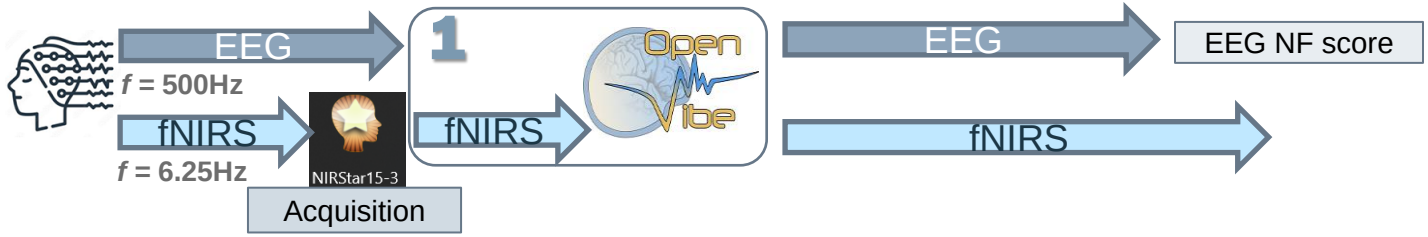
Oxygenated blood (HbO_2)

Deoxygenated blood (HbR)

Pre-processing 2

- Conversion from raw intensity to OD*
- Short-channel correction
- Conversion from OD to HB states
- Filter (0.01-0.09Hz)
- Signal epoching: 0.96s every 0.48s
- Moving average: 3 epochs

*OD: Optical density



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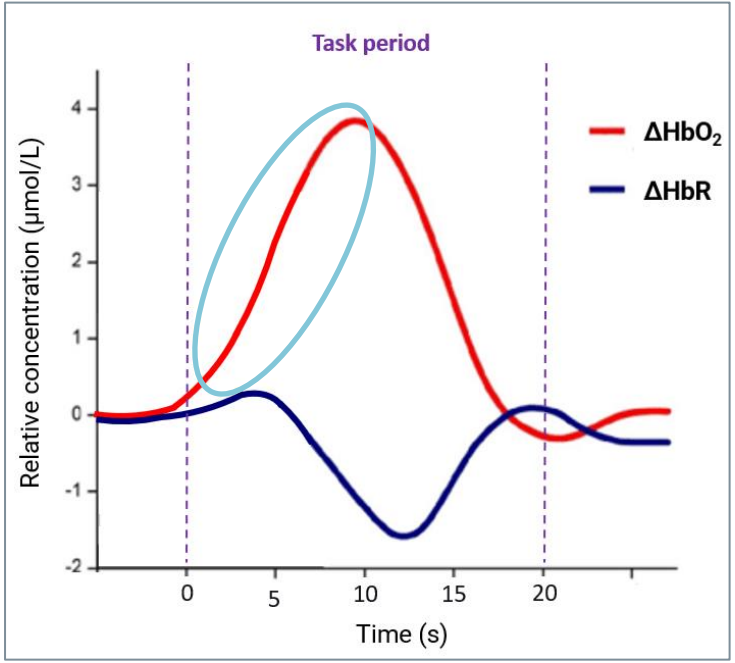

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fNIRS NF score 3

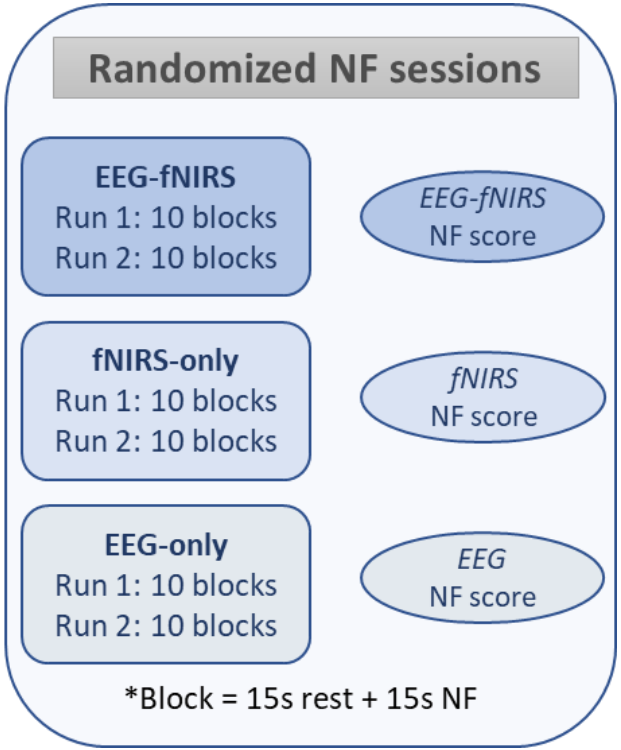
$$\text{Diff } HbO_2 = Task(HbO_2) - Rest(HbO_2)$$

$$\text{fNIRS NF score} = \frac{Diff\ task}{Diff\ calibration*} * 100$$

**Diff calibration* representing the 30th percentile of the difference obtained during a calibration session

*OD: Optical density

Neurofeedback design



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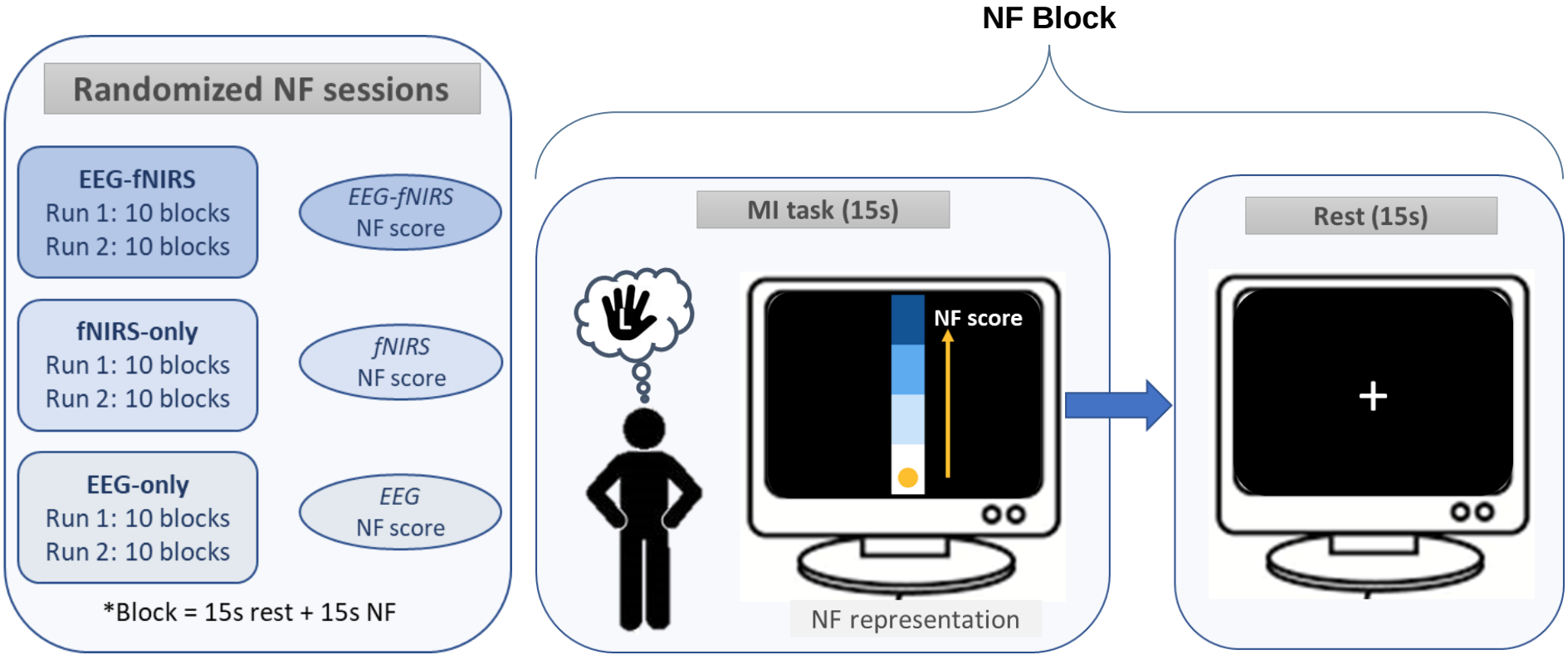
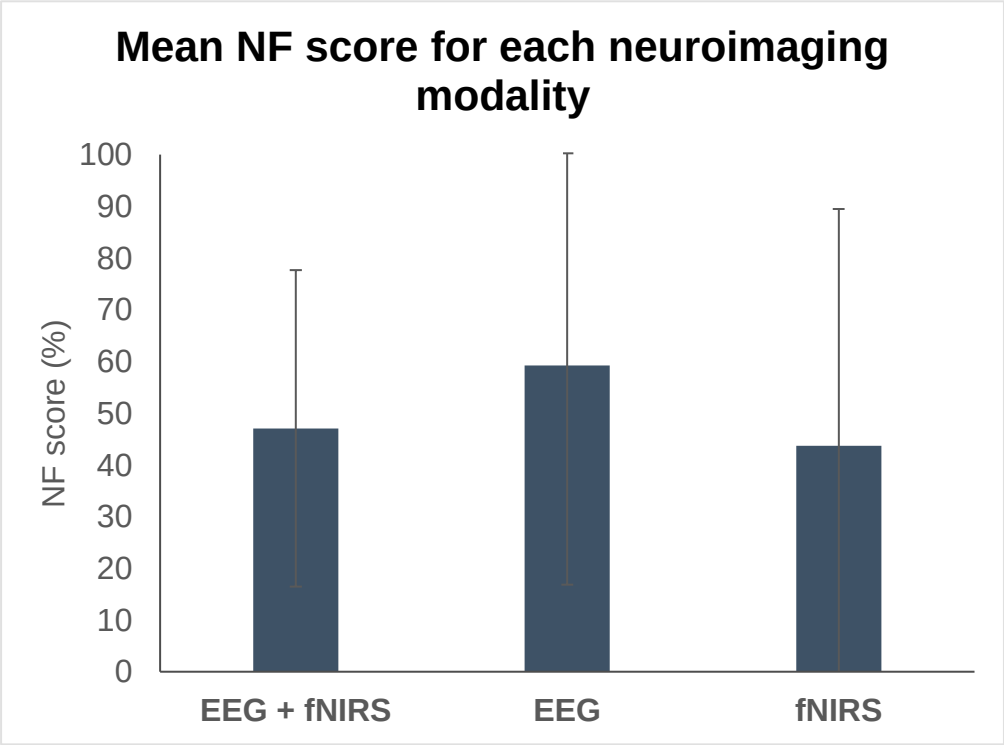


Online brain activation

*Gauge controlled in every condition for all participants**

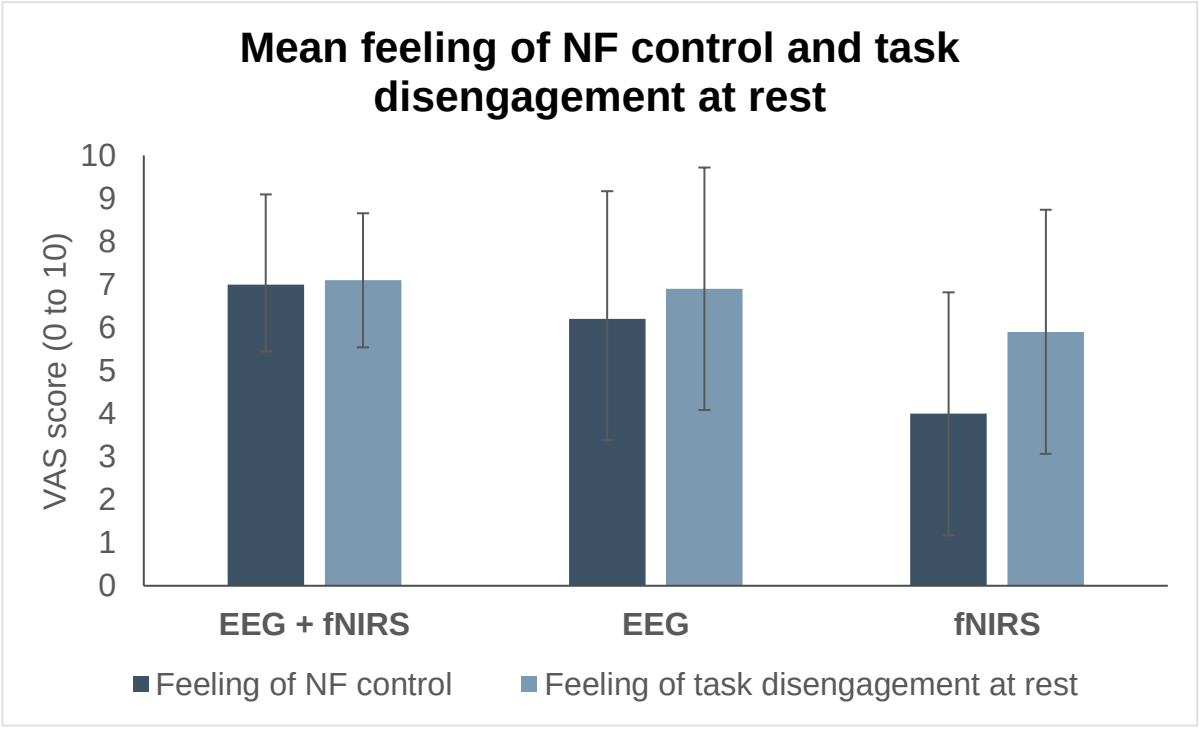
**Preliminary results (6 subjects)*



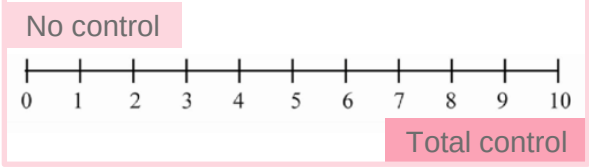
- EEG-NF score higher than two other conditions (fNIRS-alone and EEG-fNIRS)
- EEG-fNIRS-NF score higher than fNIRS-NF alone

NF control

**Preliminary results (6 subjects)*



Visual analogue scale (VAS, Hayes and Patterson 1921)



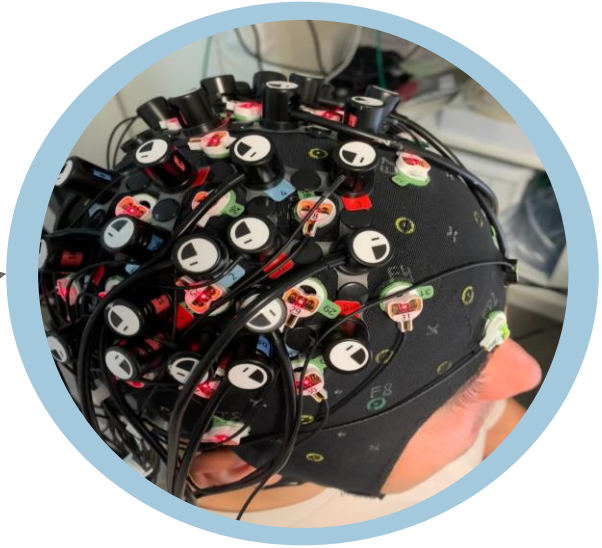
EEG + fNIRS NF condition:

- Feeling **of control of the ball** movement higher and feeling of **ability to disengage** from the MI task during rest periods higher

Multimodal NF with fNIRS and EEG

Feasability

- EEG-fNIRS-NF platform dealing with real-time signals with a dedicated software (OpenViBE)
- Joint recording of EEG and fNIRS of same brain regions *(Yang et al., 2019; Fazli et al., 2016)*
- Timing of installation and online quality of signals
- Successful NF in every condition for each subject (Buccino et al., 2016)



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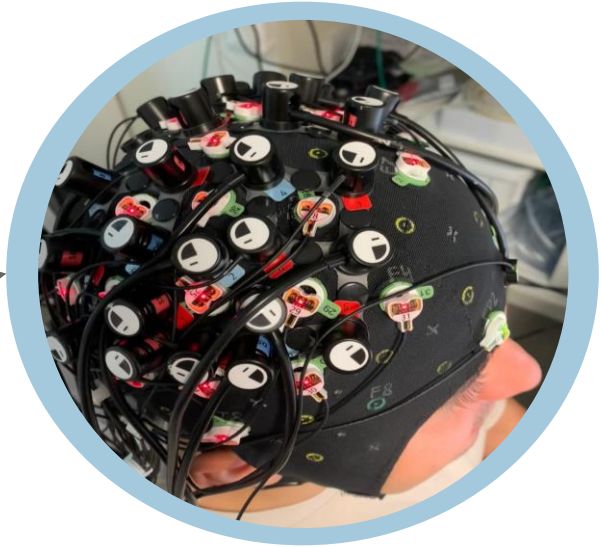

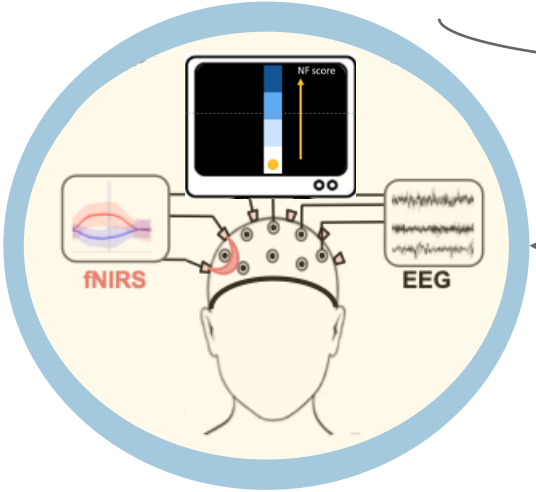

Benefits of the combination

- Preliminary results
- Feeling of NF control in favor of combined feedback
- *Hypothesis : smoother feedback*

Ongoing part

Inclusion

- Inclusion of the complete cohort
- Healthy subjects: 6/30

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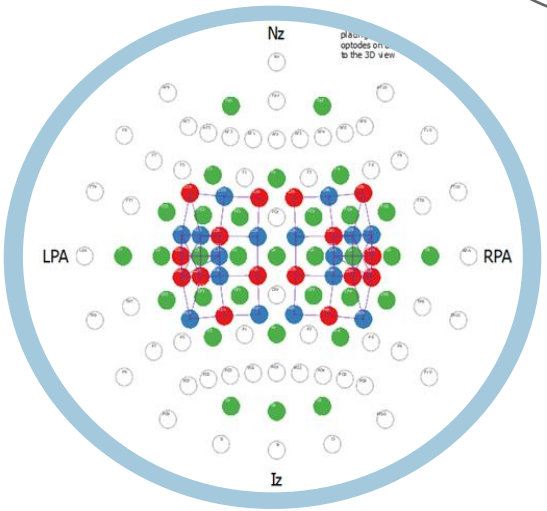

Offline analyses

- Analyze the global brain activity related to the NF session in function of the neuroimaging modality
- Extraction of brain activity (M1, SM1, PM, SMA, left and right)
- Parameters extracted

fNIRS	Mean, Max, Min, T2P **for HbO^2 and HbR**
EEG	**ERSP** (ERS and ERD)

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