# Can we learn from coupling EEG-fMRI to enhance neuro-feedback in EEG only?

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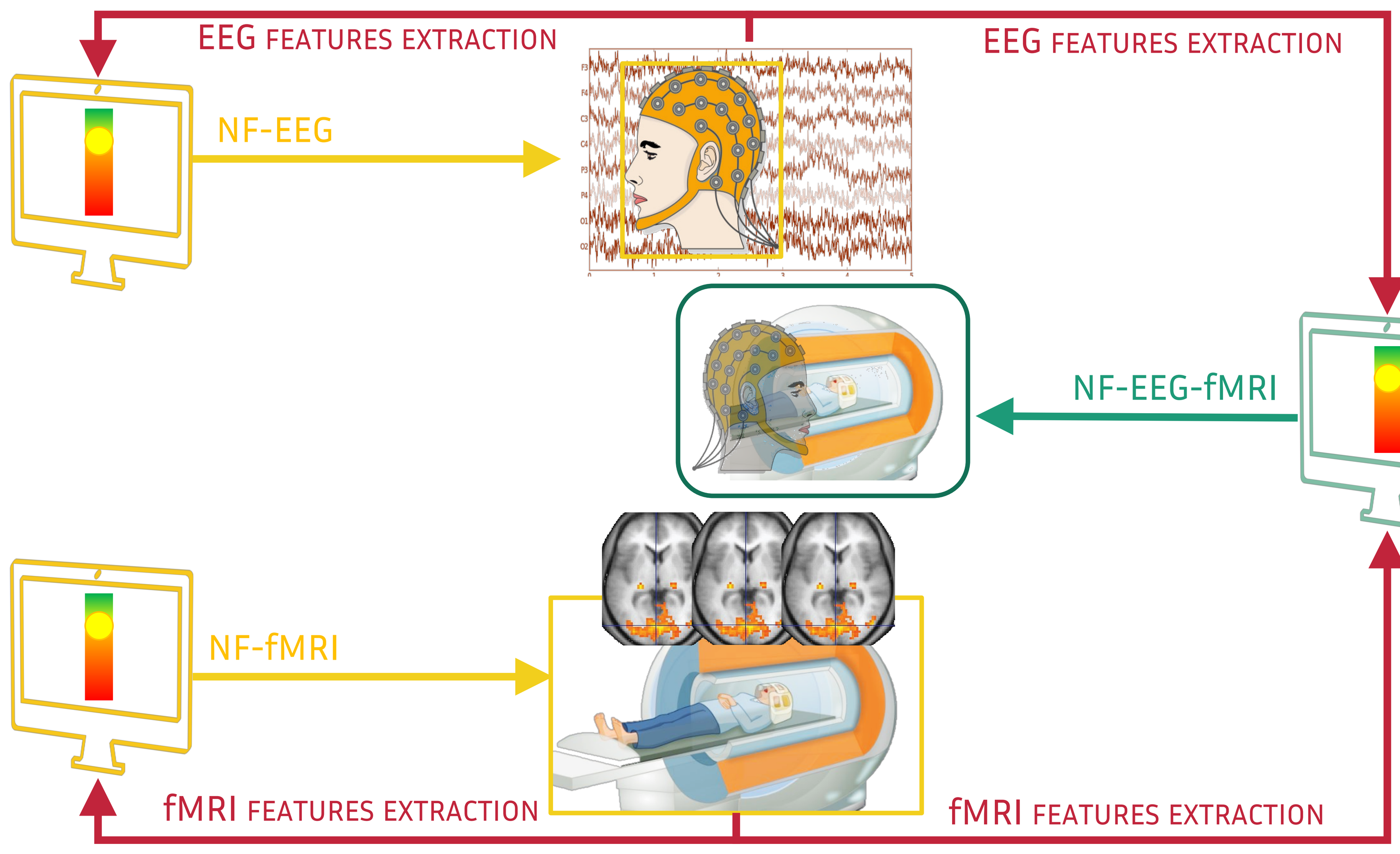
## INTRODUCTION

**Neuro-feedback (NF) :** Learn to control your brain with your brain.

EEG and fMRI, grounds solutions in the context of **brain rehabilitation** protocols.

EEG and fMRI provide complementary information.

EEG is easy ty use, fMRI is a costly and exhausting for patients modality



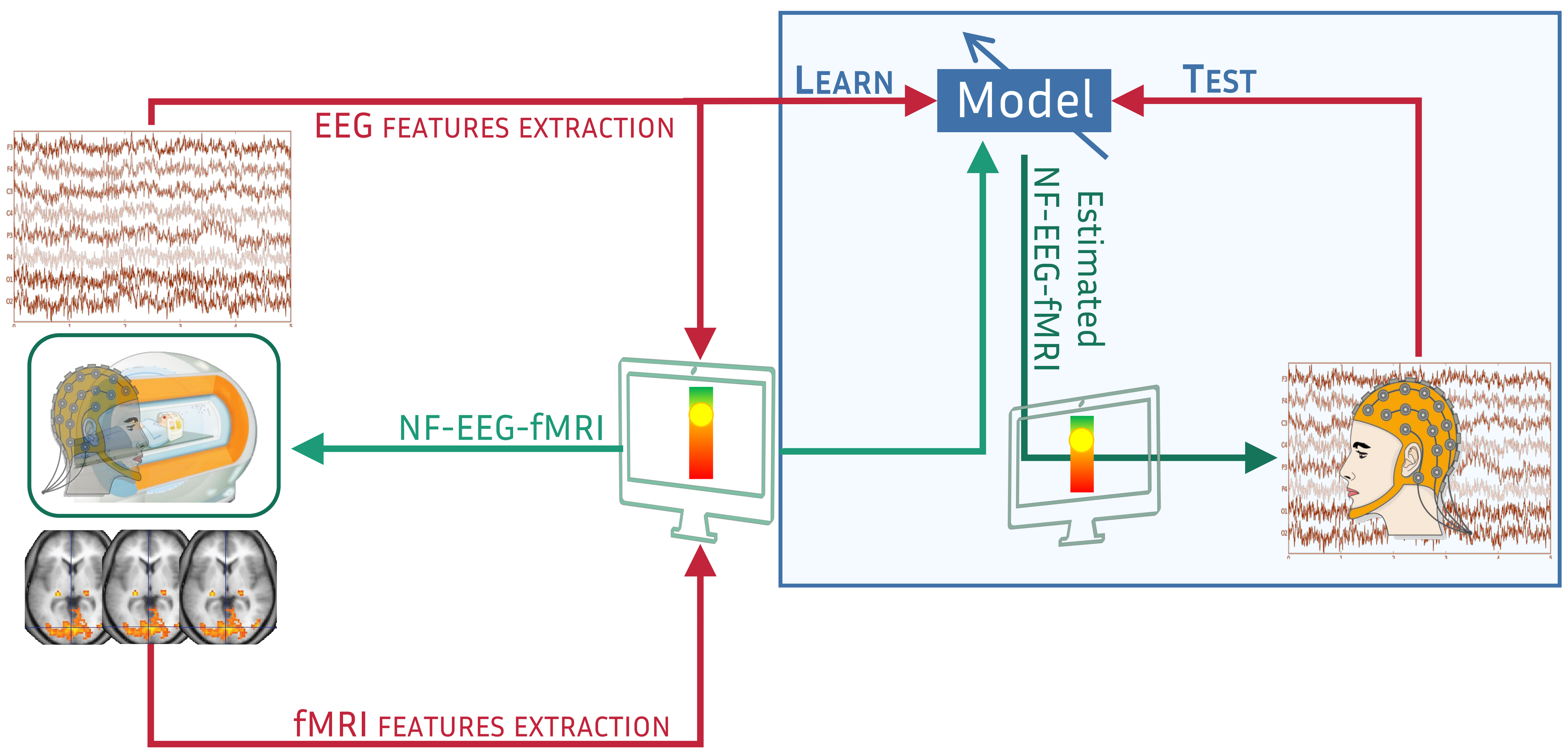

**Bi-modal NF :**

- Records and synchronises EEG and fMRI signals, in real time (Mano et al).
- Combines NF-EEG and NF-fMRI advantages
- Improve the quality of NF sessions (Perronnet et al.).
- It is not portable or easy to use, due to the fMRI modality.

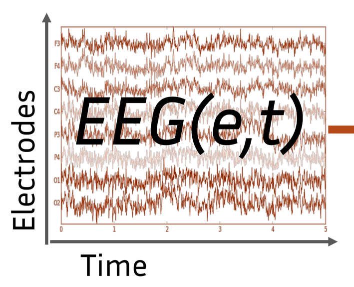
**→ Can we enhance NF in EEG only, from a previous bi-modal NF session ?**

## METHOD

**- Design and strategy :** Machine learning mechanism based on bimodal NF scores and EEG signals.



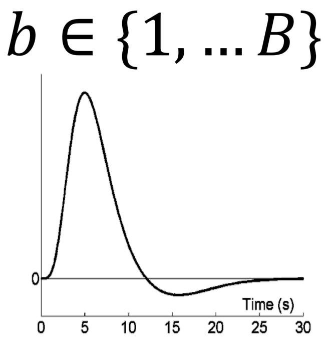

**- Model :** Non linear structured design matrix $X$




$\boldsymbol{X} = [\boldsymbol{X}_0; \boldsymbol{X}_3; \boldsymbol{X}_4; \boldsymbol{X}_5], \in \mathbf{R}^{T\times 4E\times B}$, with $\boldsymbol{X}_i \in \mathbf{R}^{T\times E\times B}$

$$X_0(t,e,b) = Freq(EEG(e,I_t),F_b)\,,\forall\, t \in \{1,\dots,T\} \text{ and } \forall\, b \in \{1,\dots B\}$$

$$\left.\begin{aligned} X_3(.,e,b) &= X_0(.,e,b) * HRF(3) \\ X_4(.,e,b) &= X_0(.,e,b) * HRF(4) \\ X_5(.,e,b) &= X_0(.,e,b) * HRF(5) \end{aligned}\right\} \begin{aligned} &\forall\, e \in \{1,\dots,E\}, \\ &\text{and } \forall\, b \in \{1,\dots B\} \end{aligned}$$




**- Optimisation :** structured sparse regularisation following 3 conditions:

1. Spatial sparsity
2. Smooth across frequency bands
3. Group selection of frequency bands.

$$\hat{\boldsymbol{\alpha}} = \arg\min_{\boldsymbol{\alpha}} \sum_{t=1}^{T} \frac{1}{2}(NF(t) - \langle \boldsymbol{X}(t), \boldsymbol{\alpha}\rangle)^2 + \underbrace{\lambda\|\boldsymbol{\alpha}\|_{21}}_{\text{Cond 1. and 2.}} + \underbrace{\rho\|\boldsymbol{\alpha}\|_1}_{\text{Cond 3.}}$$

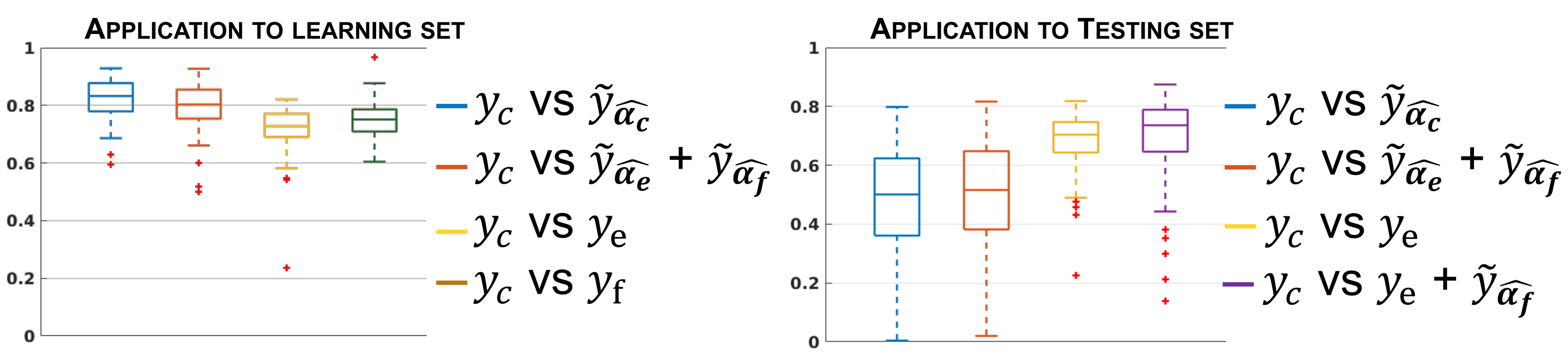
## RESULTS

**- Significant information from NF-fMRI can be captured by the model, and enhance EEG only neurofeedback.**

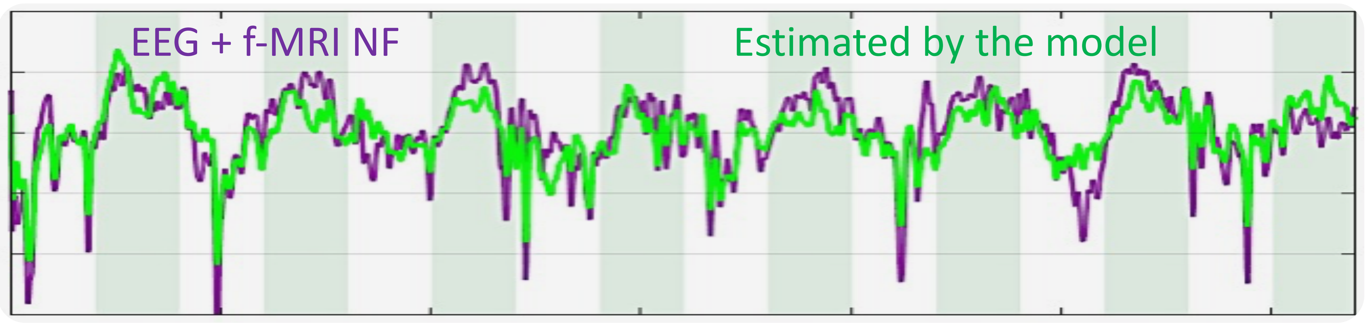
**- Prediction with NF-predictor 5 with a median correlation of 0.74**

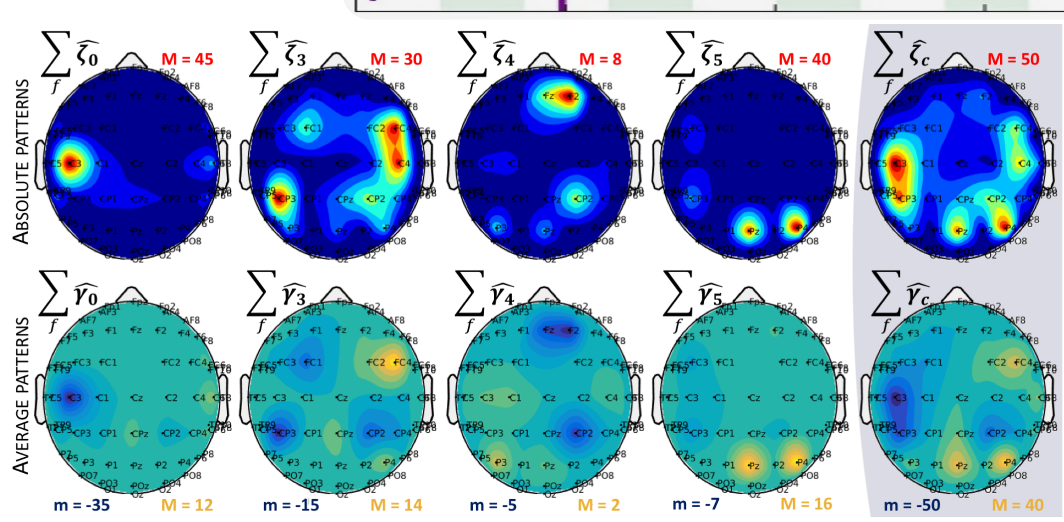
- Method tested on 17 subjects with 3 bimodal neuro-feedbak sessions of motor imagery tasks.
- We tested 5 NF-predictors:

1. $\widetilde{y_{\alpha_c}}(t) = \langle \boldsymbol{X}, \widehat{\boldsymbol{\alpha}_c}\rangle$, learned from $\boldsymbol{X}$ and $NF_c$ =NF-EEG + NF-fMRI
2. $\widetilde{y_{\alpha_e}}(t) = \langle \boldsymbol{X}, \widehat{\boldsymbol{\alpha}_e}\rangle$, learned from $\boldsymbol{X_0}$ and NF-EEG
3. $\widetilde{y_{\alpha_f}}(t) = \langle \boldsymbol{X}, \widehat{\boldsymbol{\alpha}_c}\rangle$, learned from $\boldsymbol{X_d}$ and NF-fMRI
4. $\widetilde{y_{\alpha_e}}(t) + \widetilde{y_{\alpha_f}}(t)$
5. $y_e(t) + \widetilde{y_{\alpha_f}}(t)$, with $y_e(t)$ = NF-EEG(t)




Example of prediction




Average and absolute activation patterns over all subjects and frequency bands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