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# EEG-fMRI neurofeedback of a motor imagery task

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## Introduction

EEG-fMRI-neurofeedback(NF) has been introduced for the first time by Zotev et al [1]. The authors hypothesized that bimodal EEG-fMRI-NF could be more efficient than unimodal EEG-NF or fMRI-NF performed alone. A recent study identified the fMRI signature of motor imagery during EEG-NF [3]. However to our knowledge EEG-fMRI-NF, EEG-NF and fMRI-NF have never been compared before. In the present work, we propose an EEG-fMRI-NF protocol of a motor imagery (MI) task and compare the cross-modal effects of EEG-NF, fMRI-NF and EEG-fMRI-NF. We hypothesized that:

• **EEG activations** :  $EEG-NF \geq EEG-fMRI-NF > fMRI-NF$

(">" meaning stronger activations)

• **fMRI activations** :  $fMRI-NF \geq EEG-fMRI-NF > EEG-NF$

As compared to [1] in which EEG and fMRI were represented with two separate gauges, our feedback metaphor integrates both EEG and fMRI signal in a single bi-dimensional feedback (a ball moving in 2D) in order for the subject to more easily perceive the NF training as one regulation task instead of two.

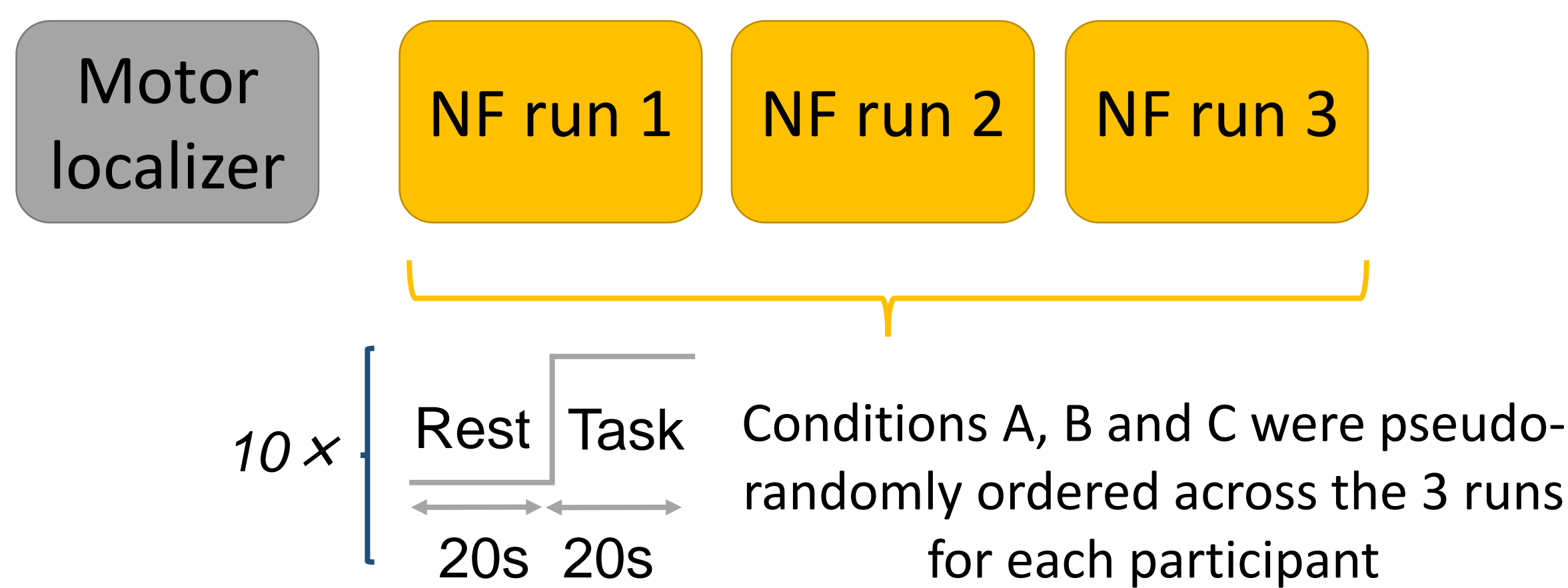
## Methods

10 right-handed NF-naïve healthy volunteers with no prior MI experience (mean age: 28 years +/- 5.7 years, 2 females) were included in the study with approval from the Institutional Review Board.

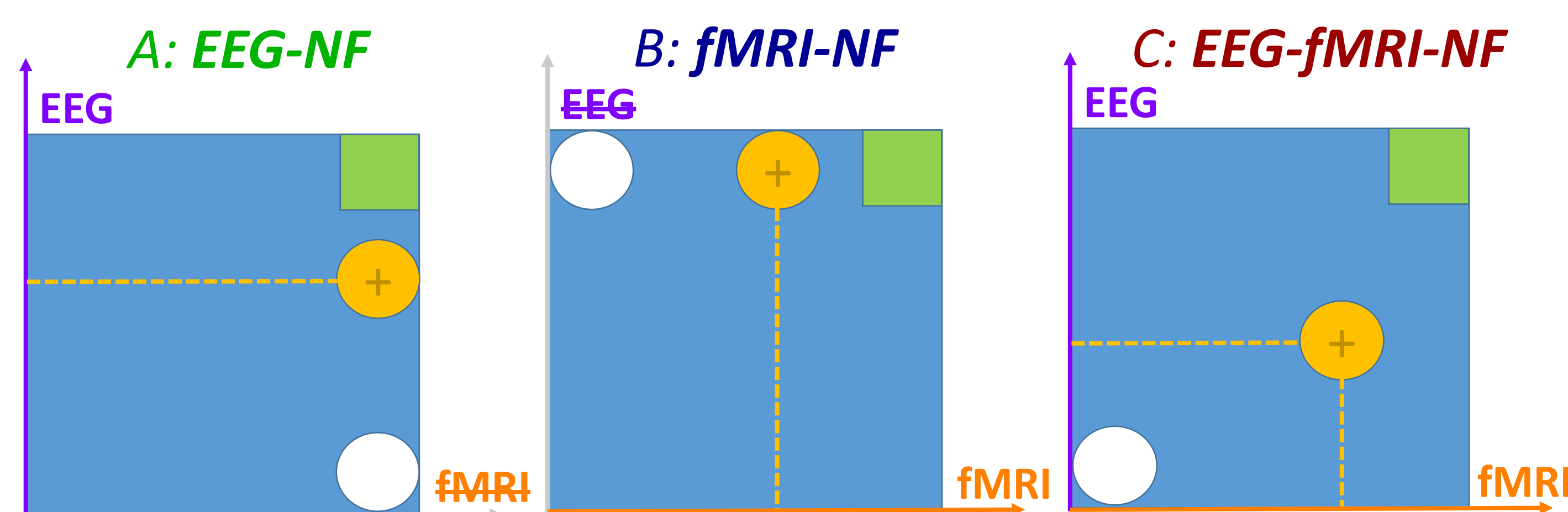
At the beginning of the session, the subject performed a motor localizer task to identify two regions-of-interest (ROI) over his/her left and right primary motor cortex (M1) that would be used later for computing the fMRI feedback component. The subject then underwent 3 NF runs corresponding to 3 different feedback modality conditions :

- **A: EEG-NF**
- **B: fMRI-NF**
- **C: EEG-fMRI-NF**

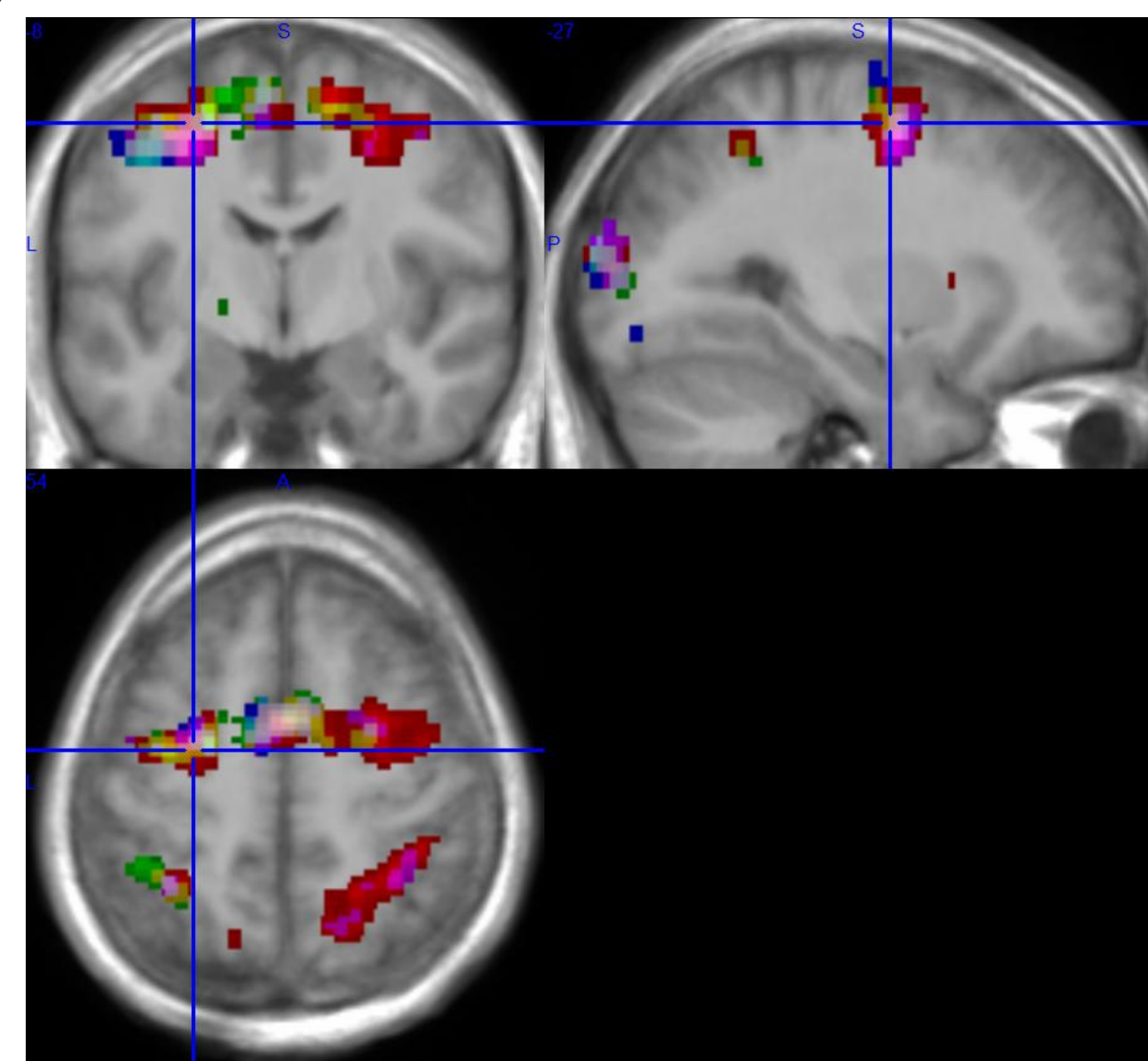
pseudo-randomly ordered. Each NF run consisted of 20s blocks of rest alternating with 20s blocks of self-regulation with NF, repeated 10 times. During rest the screen displayed a white cross while during NF blocks the screen displayed a white ball moving in two dimensions (one for EEG, and one for fMRI) and a green square representing the NF goal. In unimodal feedback conditions, the ball was only moving in the corresponding dimension. During NF blocks, the subject was instructed to bring the ball closer to the green square by performing kinesthetic motor imagery of their right hand.



The ball abscissa depicted a BOLD laterality index (signal difference) between the left and right M1 ROI [3] and was updated every TR (2s). In a similar fashion, the ball ordinate depicted the laterality index between C1 and C2 in the  $\mu$  band and was updated every 125 ms.



## Results



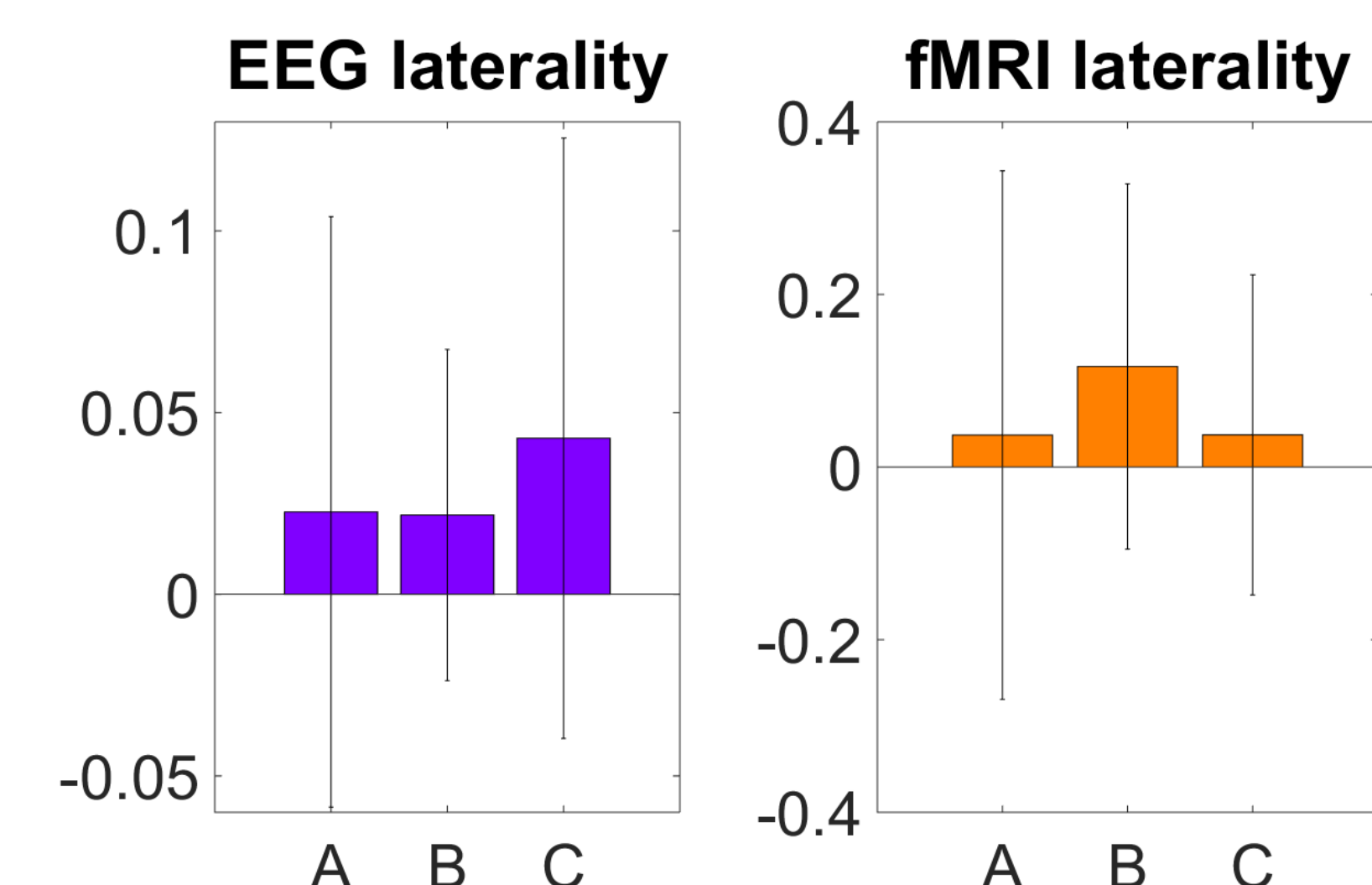
BOLD activation maps at group level (TASK > REST;  $p < 0.001$ )

- **Green** : A
- **Blue** : B
- **Red** : C
- **Light blue** : A+B
- **Yellow** : A+C
- **Magenta** : B+C
- **White** : A+B+C

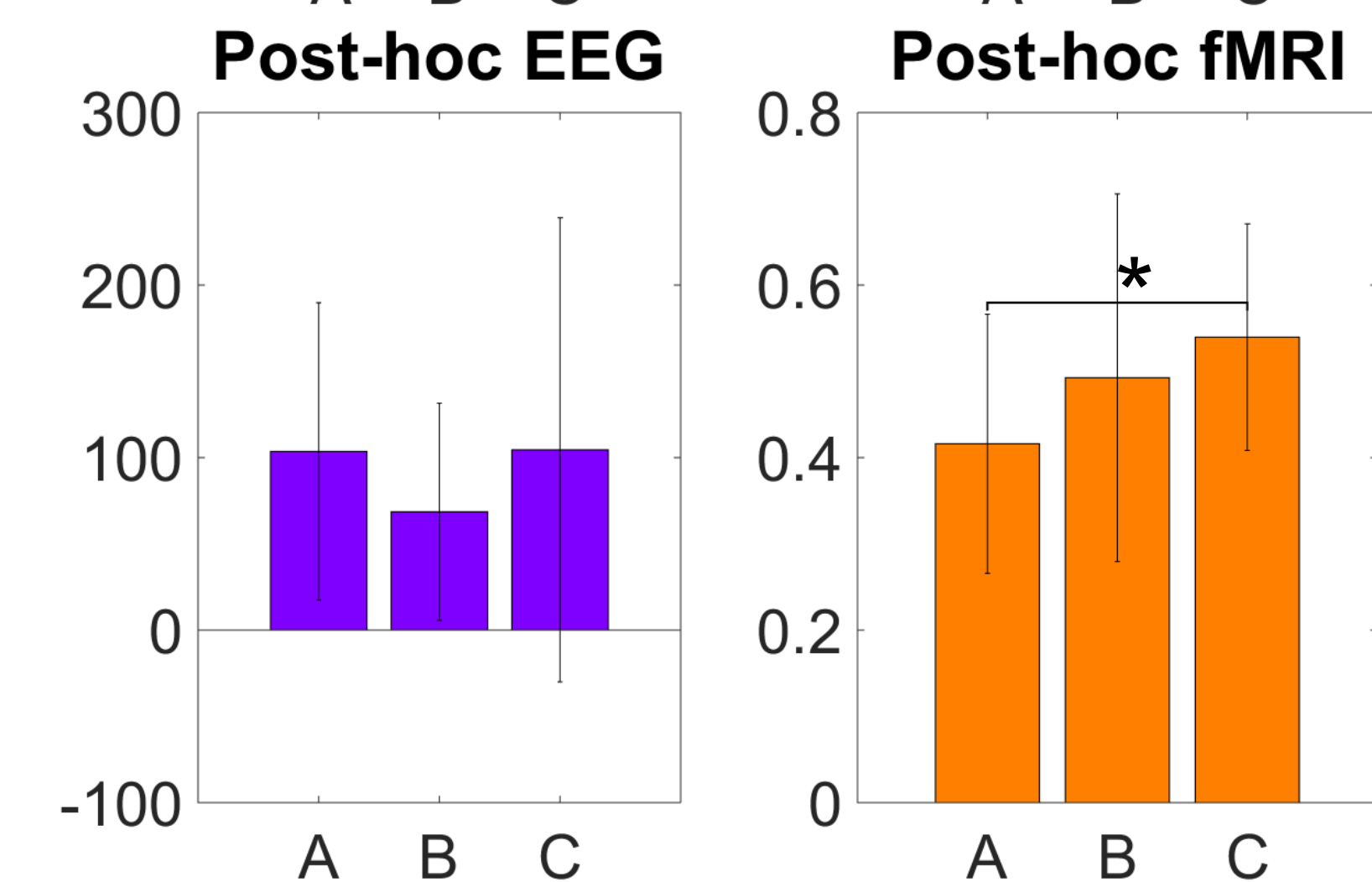
Activations in premotor cortex (left and right), supplementary motor area, inferior parietal lobule, and visual cortex.

Group means during NF blocks

Top: EEG and fMRI laterality (NF features) in percent signal change (psc) with respect to baseline show a very high subject variability.



Bottom: post-hoc EEG activations (TASK-REST) in absolute power in the  $\mu$  band after CSP filtering, and post-hoc fMRI activations in strongest motor cluster after GLM. fMRI activations were significantly stronger during EEG-fMRI-NF as compared to EEG-NF.



Questionnaire results

- All participants reported that they did not feel like they had to perform two tasks during the EEG-fMRI-NF condition.
- 6 participants found that fMRI was easier to control than EEG ; 3 found that EEG was easier to control than fMRI; 1 found no difference.
- 8 participants reported to have paid the same attention to both dimensions during the EEG-fMRI-NF condition, the 2 others reported that they looked more at the dimension that was harder for them to control (in one case EEG, in the other fMRI).
- Subjects found that the fMRI update rate (0.5 Hz) was too slow.

## Conclusion

EEG-fMRI-NF triggered stronger fMRI activations than EEG-NF on a single session. We would expect to observe significant symmetrical results on EEG activations with more subjects and more NF training. Our study gives preliminary insights about how EEG and fMRI complement each other and thus about how to design a bimodal EEG-fMRI-NF training goal. In this perspective, the choice of the EEG and fMRI features and the choice of the feedback metaphor seems of higher importance.

## References

- [1] V. Zotev, R. Phillips et al, "Self-regulation of human brain activity using simultaneous real-time fMRI and EEG neurofeedback" *NeuroImage*, vol. 85, pp. 985-995, 2014.
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