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# M/EEG networks integration to elicit patterns of motor imagery-based Brain-Computer Interface (BCI) training

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Non-invasive Brain-Computer Interfaces (BCIs) can exploit the ability of subjects to voluntarily modulate their brain activity through mental imagery. Despite its clinical applications, controlling a BCI appears to be a learned skill that requires several weeks to reach relatively high-performance in control, without being sufficient for 15 to 30 % of the users [1]. This gap has motivated a deeper understanding of mechanisms associated with motor imagery (MI) tasks. Here, we investigated dynamical changes in multimodal network recruitment. We hypothesized that integrating information from EEG and MEG data, show a better description of the core-periphery changes occurring during a motor imagery-based BCI training.

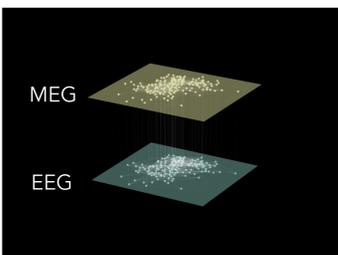
## Longitudinal study

The EEG-based BCI task consisted of a standard 1D, two-target box task in which the subjects modulated their  $\alpha$  and/or  $\beta$  activity. To hit the target-up, the subjects performed a sustained motor imagery of their right-hand grasping and to hit the target-down, they remained at rest. 20 healthy subjects (aged  $27.45 \pm 4.01$  years, 12 men), all right-handed, participated in the study.

Magnetoencephalography (MEG) and electroencephalography (EEG) signals were simultaneously recorded. M/EEG data were preprocessed using the Independent Component Analysis method, followed by the source reconstruction on the epoched data [2].



## Multiplex core-periphery computation



To study the core-periphery properties of the brain networks, we used the probability for a given node to belong to the core, defined as the coreness [3].

Multiplex coreness of node  $i$  –  $C_i$

$$C_i = \frac{1}{N-1} \sum_{k=1}^{N-1} \delta_i^k; \quad \delta_i^k = 1, \text{ if nodes } i \text{ in the core, } 0 \text{ otherwise}$$

Optimization of the contribution  $c$  of each layer/modality:

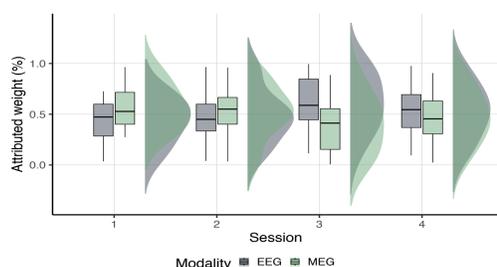
$$F(c) = \frac{((c^{MI}(c)) - (c^{Rest}(c)))^2}{(s^{MI})^2 + (s^{Rest})^2}$$

Where:

$$(s^{cond})^2 = \sum_{i \in \{1 \dots N\}} ((c_i^{cond}(c)) - (c^{cond}(c)))^2$$

$(c^{cond}(c))$ , averaged coreness over the nodes  $i$

$c_i^{cond}$ , coreness computed in node  $i$ , condition  $cond$



Studying the network integration changes at the single and multilayer levels provides additional information to characterize dynamic brain reorganization during BCI training. A progressive increase of the integration of somatosensory areas in the  $\alpha$  band was paralleled by a decrease of the integration of visual processing and working memory areas in the  $\beta$  band. Such changes were more visible in multiplex in which brain network properties correlated with future BCI scores in the  $\alpha 2$  band.

Taken together, our results cast new light on brain network reorganization occurring during BCI training and more generally during human learning.

### References

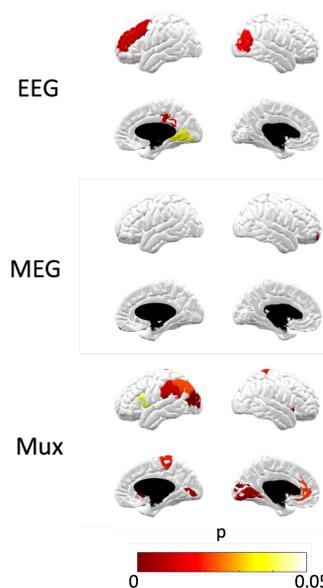
- [1] Allison and C. Neuper, "Could Anyone Use a BCI?," in Brain-Computer Interfaces, Eds. Springer London, 2010,
- [2] Corsi, et al (2020). Functional disconnection of associative cortical areas predicts performance during BCI training. NeuroImage
- [3] Battiston et al. (2018) Multiplex core-periphery organization of the human connectome. Journal of The Royal Society Interface

### Acknowledgements

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## Relative coreness $\Delta C$ during training

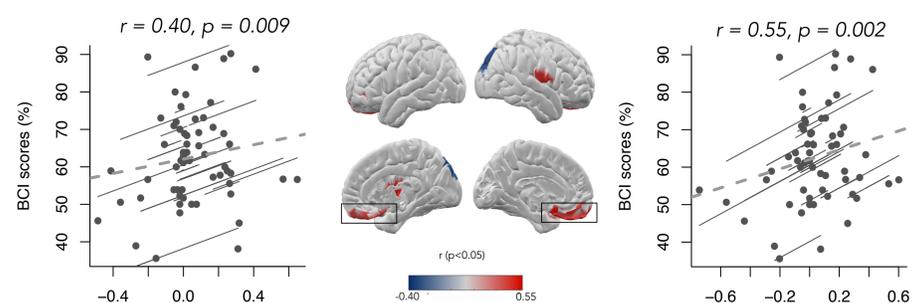
To provide a more detailed description of the evolution of the relative coreness over training, we performed a one-way ANOVA for each layer separately.



$\Delta C$  presented a significant session effect involving different brain areas. Within the  $\alpha 2$  range, a significant session effect was observed in EEG mostly within the long insular gyrus and the gyrus rectus; a significant session effect was observed in MEG in the supramarginal gyrus (working memory and motor planning); and in the multiplex a significant session effect was observed in areas involved during motor planning and working memory and in learning complex motor skills. In each case, we obtained an increase of  $\Delta C$  with training.

## Multiplex relative coreness correlated with future BCI performance

To assess whether relative coreness could be associated with future BCI performance, we estimated the correlation between  $\Delta C$  in session  $i$  and the BCI score obtained in session  $i + 1$ .



We observed significant correlations only with multiplex within the  $\alpha 2$  band. More precisely, a positive correlation ( $p < 0.01$ ) was observed in the gyrus rectus, the subcentral gyrus, but also the long insular gyrus (involved during somatosensory tasks). A negative correlation was obtained in the superior occipital gyrus associated with visual processing.

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