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

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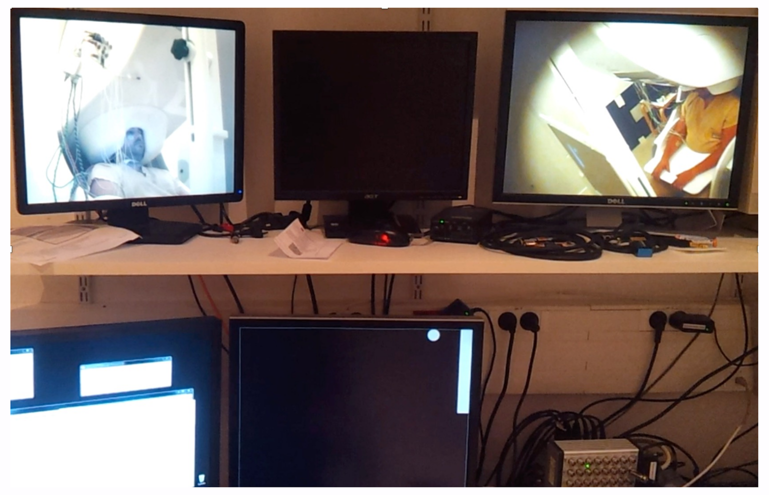
Non-invasive Brain-Computer Interfaces (BCIs) can exploit the ability of subjects to voluntary modulate their brain activity through mental imagery. Despite its clinical applications, controlling a BCI appears to be a learned skill that requires several weeks to reach relatively high-performance in control, 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. Such an enriched description could reveal fresh insights into learning processes that are difficult to observe at the signle layer level and eventually improve the prediction of future BCI performance.

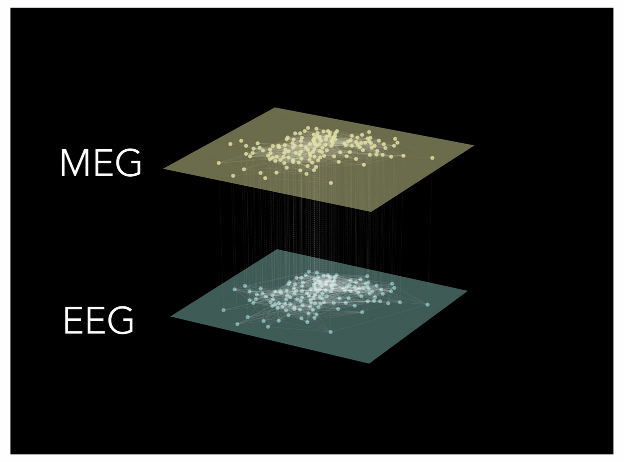
Longitudinal study

The EEG-based BCI task consisted of a standard 1D, two-target box task in which the subjects modulated their α and/or β 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 ± 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

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

Optimization of the contribution c of each layer/modality to maximise the contrast between conditions:

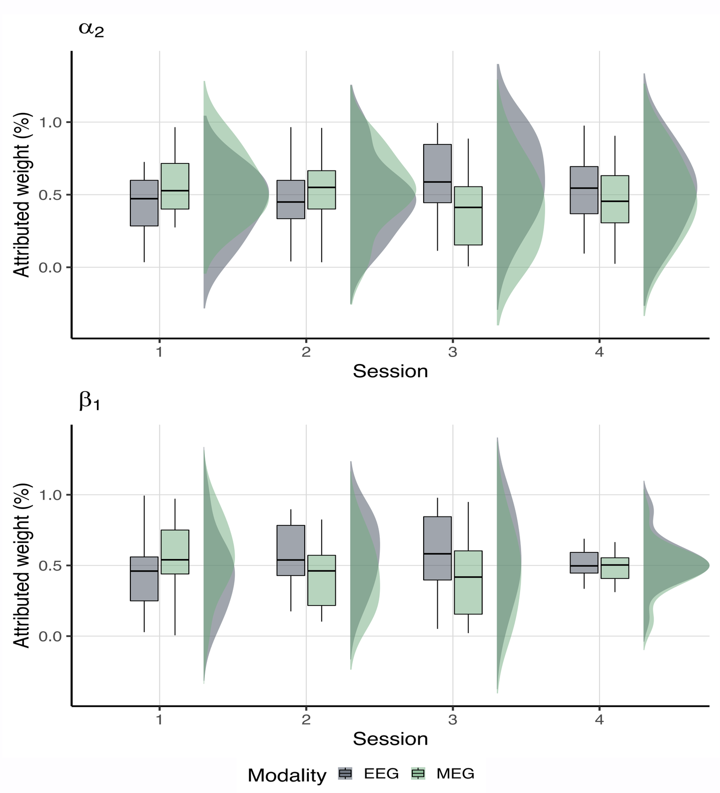
$$F(c) = \frac{(\langle C^{MI}(c)\rangle - \langle C^{Rest}(c)\rangle)^2}{(s^{MI})^2 + (s^{Rest})^2}$$

Where:

$$(s^{cond})^2 = \sum_{i\in\{1...N\}} (\langle C_i^{cond}(c)\rangle - \langle C^{cond}(c)\rangle)^2$$

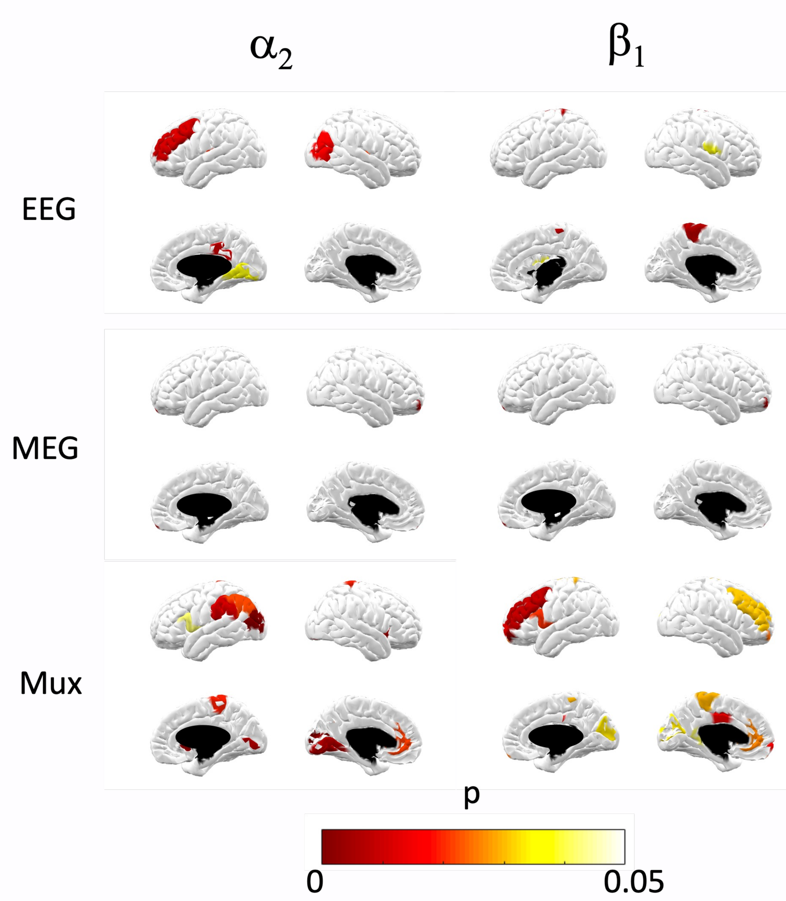
$\langle C^{cond}(c)\rangle$, averaged coreness over the nodes i

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



Relative coreness ΔC 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.



ΔC presented a significant session effect involving different brain areas. Within the **α**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 (orbital part of the inferior frontal gyrus and subcallosal gyrus) and in learning complex motor skills (middle-posterior part of the cingulate gyrus). In each case, we obtained an increase of ΔC with training. Within the **β**1 range, a significant session effect was observed in EEG within the inferior temporal gyrus (dual working memory task processing) and in the multiplex in areas associated with visual processing (superior temporal gyrus), working memory (middle frontal gyrus), and motor planning (short insular gyri).

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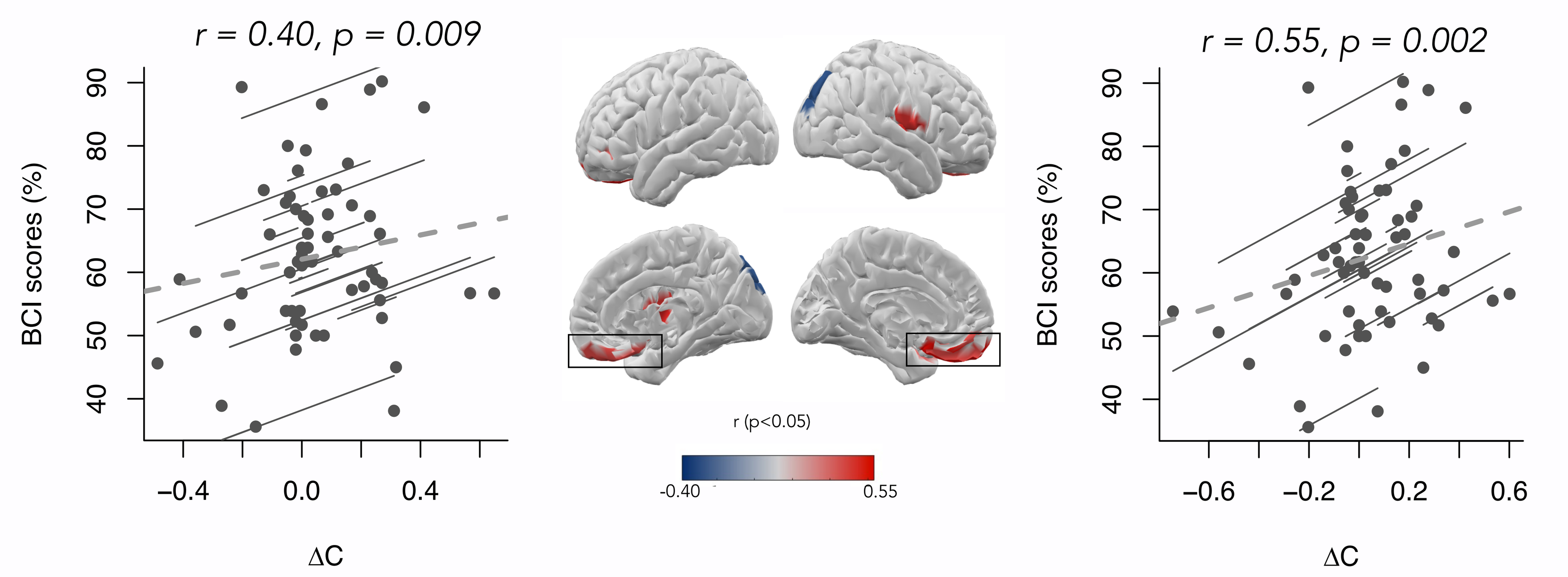
Multiplex relative coreness correlated with future BCI performance

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



We observed significant correlations only with multiplex within the **α**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.

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 **α** band was paralleled by a decrease of the integration of visual processing and working memory areas in the **β** band. Such changes were more visible in multiplex in which brain network properties correlated with future BCI scores in the **α**2 band.

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

References

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