Functional connectivity predicts MI-based BCI learning

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Marie-Constance Corsi [1] Mario Chavez [2] Denis Schwartz [1] Nathalie George [1] Laurent Hugueville [1]
Ari E. Kahn [2] Sophie Dupont [1] Danielle S. Bassett [2] Fabrizio De Vico Fallani [1]

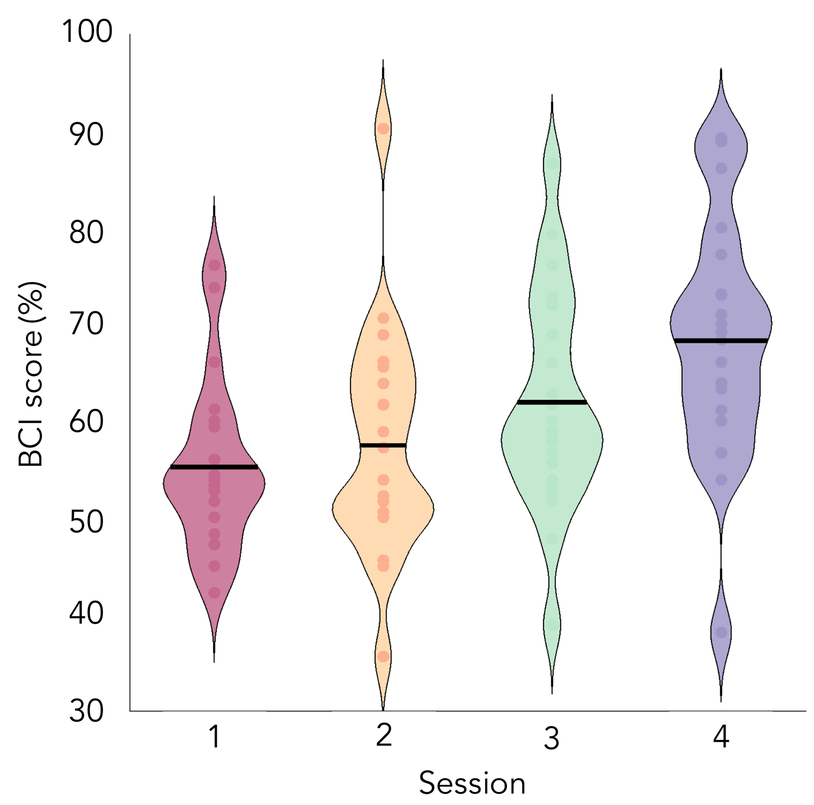
[1] Sorbonne Université, Institut du Cerveau – Paris Brain Institute, ICM, CNRS, Inria, Inserm, AP-HP, Hôpital de la Pitié-Salpêtrière, F-75013, Paris, France
[2] University of Pennsylvania, Philadelphia, USA

marie.constance.corsi@gmail.com @MConstanceCorsi

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 terms of cortical activations and network recruitment. We hypothesized that the associated characteristics would be able to predict the success of learning.

Longitudinal study

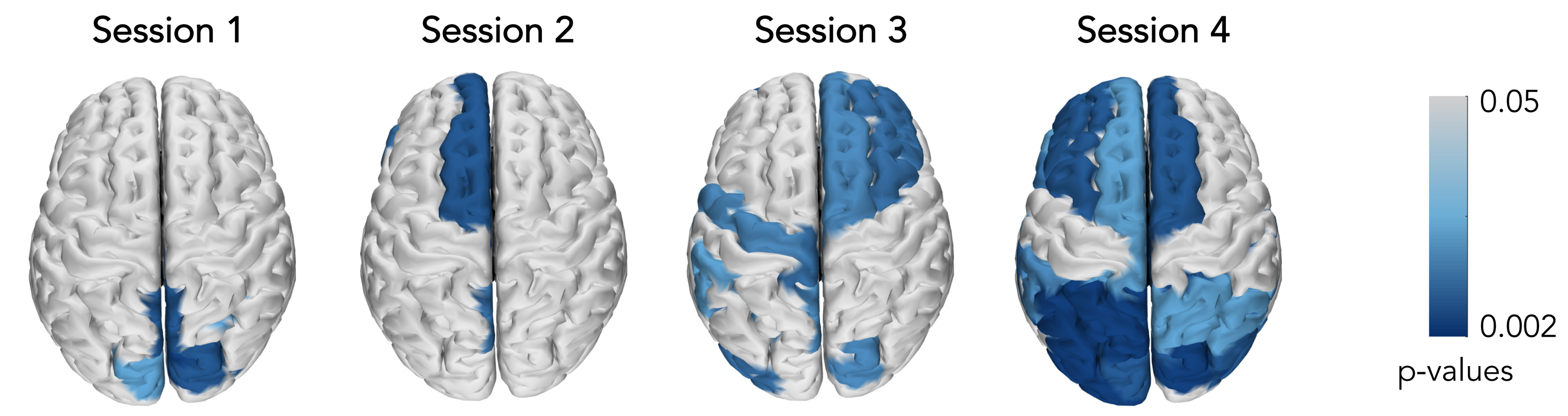
The EEG-based BCI task consisted of a standard 1D, two-target box task in which the subjects modulated their α and/or β activity. To hit the target-up, the subjects performed a sustained motor imagery of their right-hand grasping and to hit the target-down, they remained at rest. 20 healthy subjects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



We found that the ability to control the BCI significantly increased across sessions (days) but not within sessions (hours). The session effect was also present when we averaged the BCI accuracy scores across the runs of each session (one-way ANOVA, $F_{3,57}$=13.9, p=6.56.10^{-7}). Despite the expected high inter-subject variability (> 8.95 %), the group reached on average a reasonable level of control - above the chance level of 57 % by the end of the training.

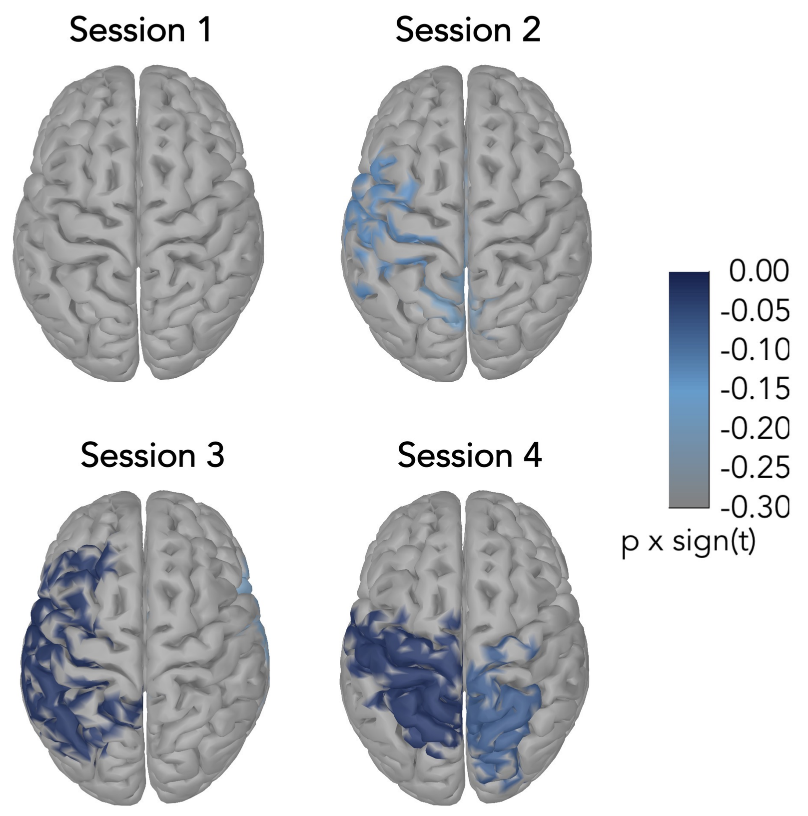
Functional connectivity (FC) patterns

To evaluate the cortical changes at the network level, we considered the imaginary coherence [2] between the source reconstructed signals of each pair of regions of interest (ROI) corresponding to Destrieux atlas.



By statistically comparing the FC values between MI and Rest conditions at the group level, we found a progressive decrease of task-related connectivity in both α and β frequency ranges across sessions. In α_2, the strongest decreases involved parieto-occipital interactions. For each subject, we also computed the relative node strength Δ_N. Middle occipital gyrus, cuneus, superior occipital gyrus, associated with visuo-spatial attentional tasks decreased significantly with the training.

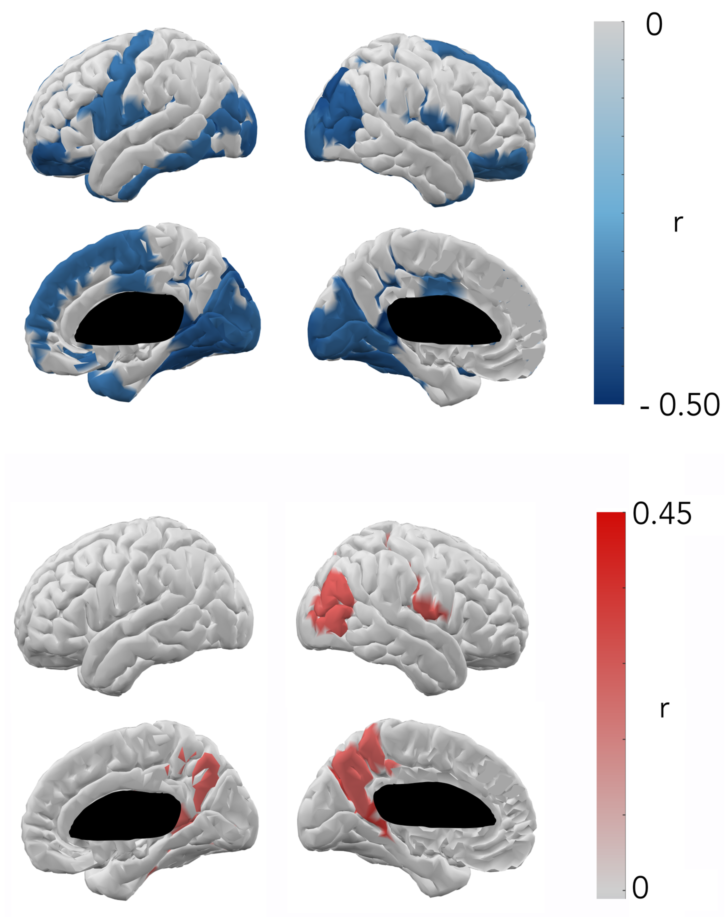
Cortical changes



To evaluate the spatiotemporal cortical changes associated with the BCI training, we computed statistical differences among activations recorded in the MI and the rest conditions via a paired t-test, corrected for multiple comparisons using the cluster approach at the group level.

In session 3, these diffused decrements were particularly significant in the α_2 and β_1 frequency bands, and mainly spanned the primary sensorimotor cortex and in secondary higher-order premotor and somatosensory areas. At the end of training, these decrements were localized to the contralateral paracentral lobule, precentral gyrus, and superior parietal lobule.

Predictive markers of BCI scores



Higher BCI scores were associated with the recruitment of a higher number of task-related cortical sources and with larger decreases of relative power in α_2. Better performance was rather associated with the decrease of Δ_N in associative areas and in premotor and primary visual areas. We observed significant correlations in regions known to be involved in specific cognitive aspects of human learning, such as decision making (fronto-marginal gyrus), in visual attention task (occipital pole), and in both mental rotation and working memory (orbital part of the inferior frontal gyrus). With Δ_N, we found significant predictions for different ROIs involved during visual information processing (middle occipital gyrus), but also during motor imagery and working memory (precuneus).

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The progressive enhancement of motor-related activity, together with the fading of FC in associative areas, are significantly associated with BCI learning. These signatures varied over individuals and, more importantly, are significant predictors of future BCI learning rate in the case of FC. These results offer new insights into the crucial role of neuroplasticity in the prediction of human learning.

References

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Acknowledgements

This work was partially supported by the program ''Investissements d'avenir'' ANR-10-IAIHU-06; ''ANR-NIH CRCNS'' ANR-15-NEUC-0006-02 and by NICHD 1R01HD086888-01.

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