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Biophysical modeling to inform performance in motor imagery-based Brain-Computer Interfaces

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► **To cite this version:**

Parul Verma, Marie-Constance Corsi. Biophysical modeling to inform performance in motor imagery-based Brain-Computer Interfaces. CNS 2024 - 33rd Annual Computational Neuroscience Meeting, Jul 2024, Natal, Brazil. hal-04701021

HAL Id: hal-04701021

<https://inria.hal.science/hal-04701021v1>

Submitted on 18 Sep 2024

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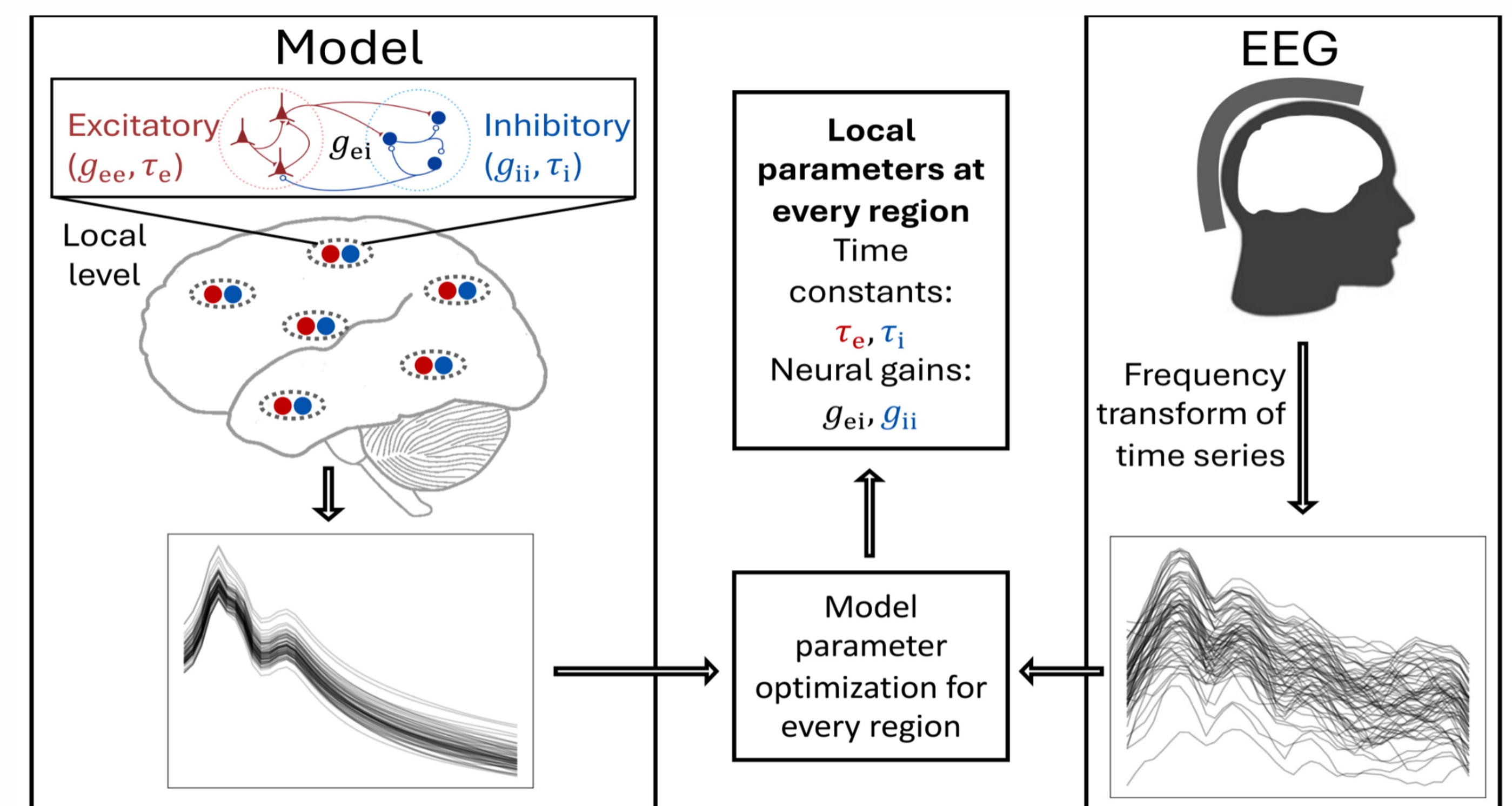
Brain-computer Interfaces (BCI) experiments



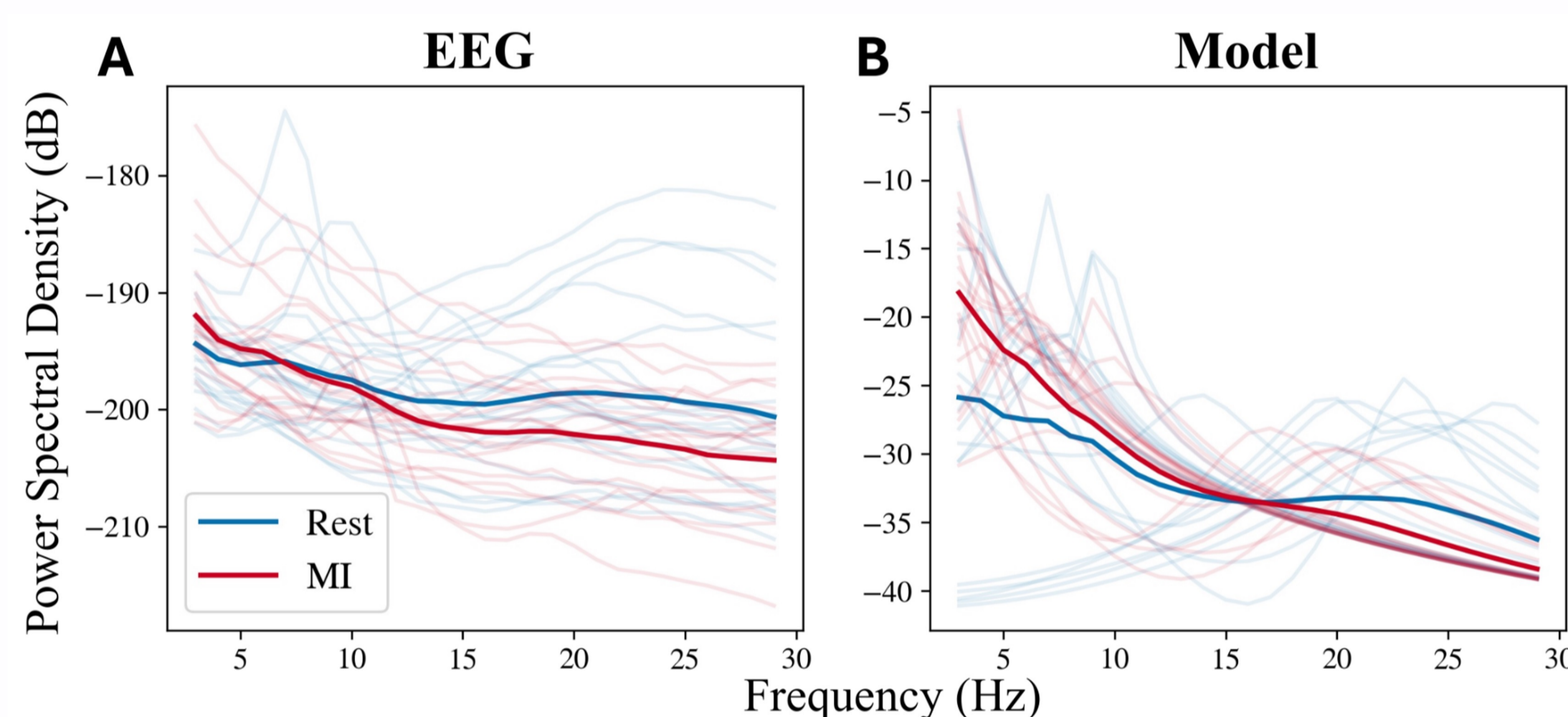
The BCI task consisted of a standard 1D, two-target box task in which the subjects modulated their α and/or β activity. To hit the target-up, the subjects performed a sustained motor imagery (MI) of

their right-hand grasping and to hit the target-down, they remained at rest. Twenty subjects (aged 27.45 ± 4.01 years, 12 men), all right-handed participated in the study. Electroencephalography (EEG) data were preprocessed using the Independent Component Analysis method, followed by the source reconstruction on the epoched data [1].

Biophysical Model of Brain Oscillations



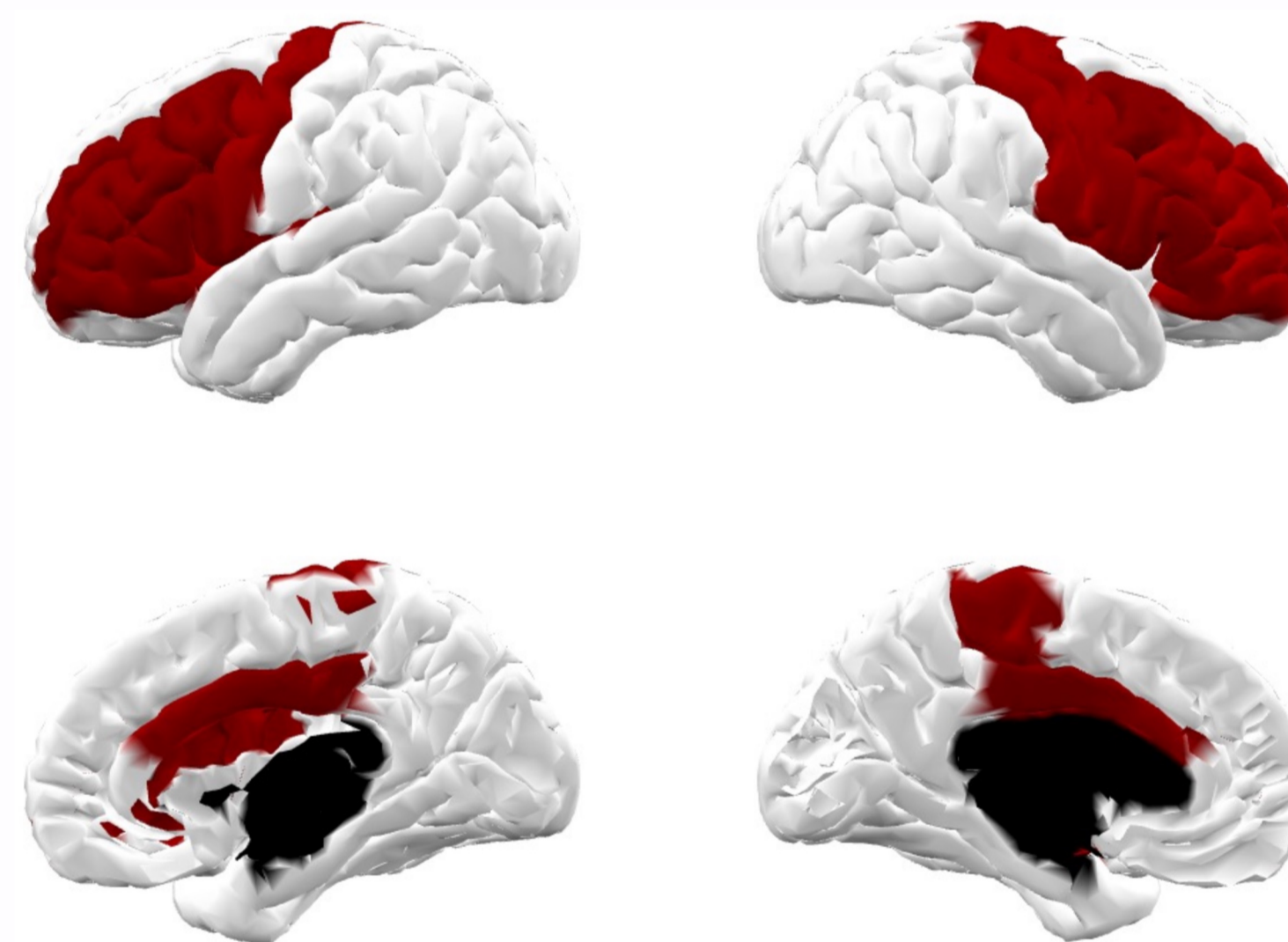
Power spectral density at rest and while performing motor imagery



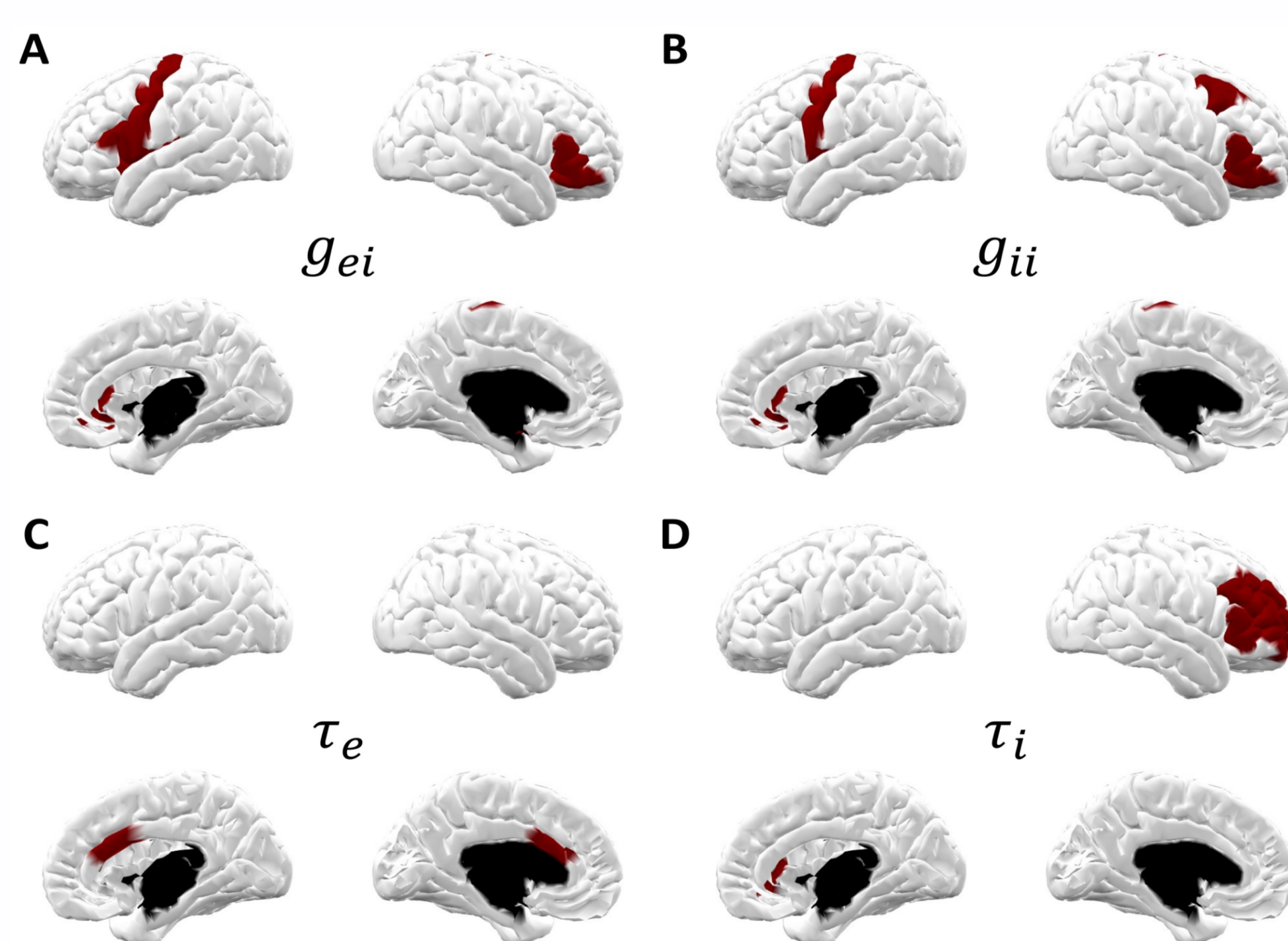
Power spectral density (PSD) of all the subjects and their average (in bold) in the left precentral area as an example. Blue: rest; red: motor imagery (MI). A: EEG PSD. B: PSD from model fitting. We see a decrease in the beta band in MI with both EEG and model.

Changes in β frequency band spectral power while controlling a BCI

Together with the posterior cingulate gyri, the caudal middle frontal gyri bilaterally are the main regions where the beta power differs the most between conditions ($pFDR < 5 \cdot 10^{-3}$). These regions are involved respectively in working memory and in planning of motor actions, imagining of actions, as well as in executive attention and in the selection between competing visual targets.



Changes in biophysical model parameters while controlling a BCI



Model was fit to frequency spectra from rest and MI task for every subject and every region. Model parameters were compared between rest and MI only for the regions where beta spectral power was different. The neural gains g_{ei} and g_{ii} show a condition effect in regions involved in motor imagery (in premotor cortex and in precentral gyrus) [3]. The time constant τ_i presents a condition effect in premotor cortex whereas an effect was observed in the anterior cingulate cortex, involved in decision-making, in τ_e .

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Conclusions

- An overall reduction in the spectral power in the beta band is observed with EEG while performing MI as compared to rest in regions located over (pre)motor areas, in line with previous studies [4]

Within these regions, model parameters also differ between MI & rest conditions

Both the neural gains and time constants differ in regions involved in motor imagery, motor planning, and decision making.

Future directions

- Identify markers of BCI performance
- Track differences in model parameters with training progression
- Model motor imagery-based BCI training explicitly

References

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- [4] Corsi, M-C, Sorrentino, P et al, Measuring Neuronal Avalanches to inform Brain-Computer Interfaces. *iScience* (2024).

Acknowledgements

The authors acknowledge support from Transatlantic Research Partnership from the FACE Foundation.