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

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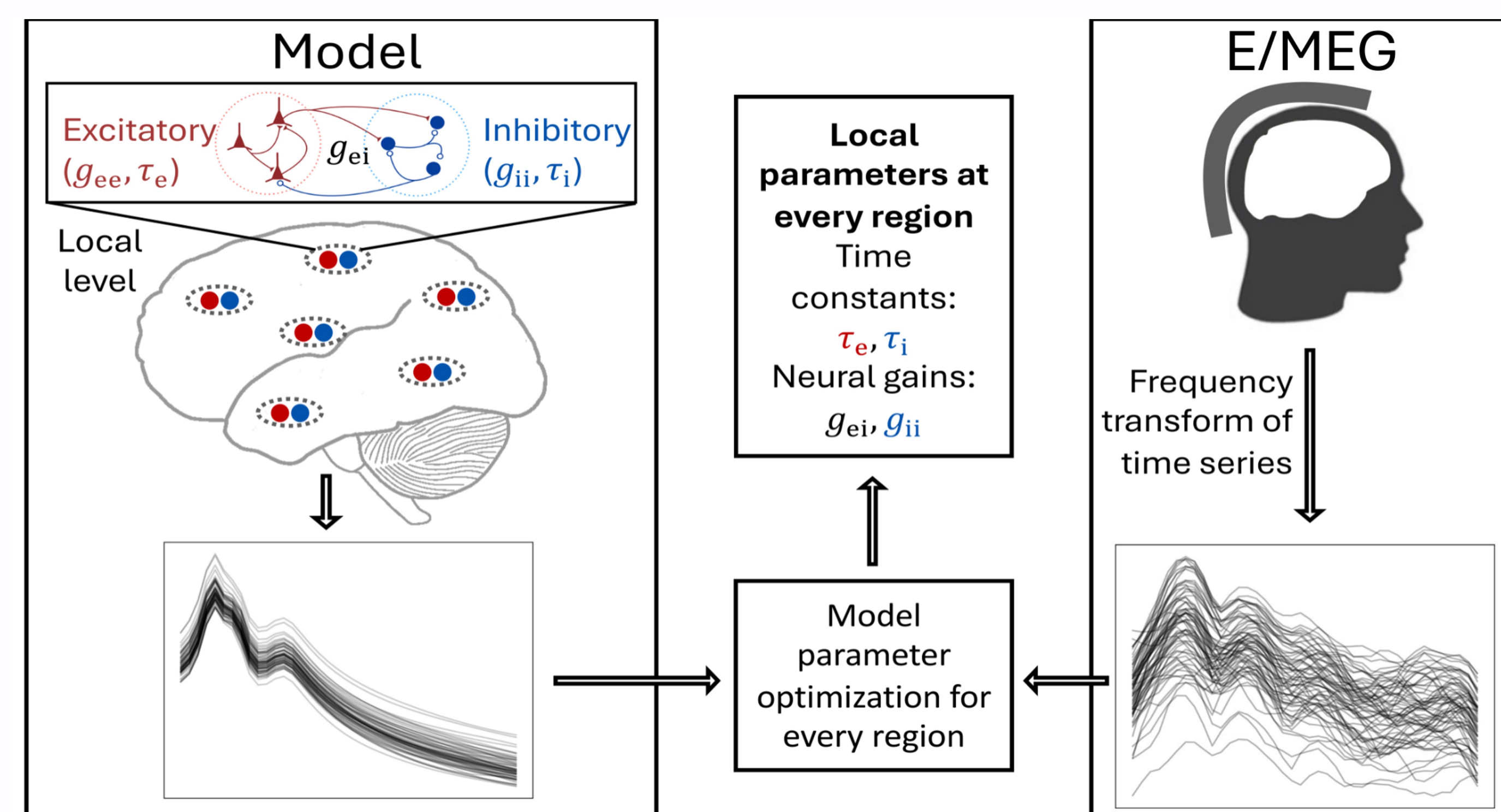
Brain-computer Interfaces (BCI) experiments



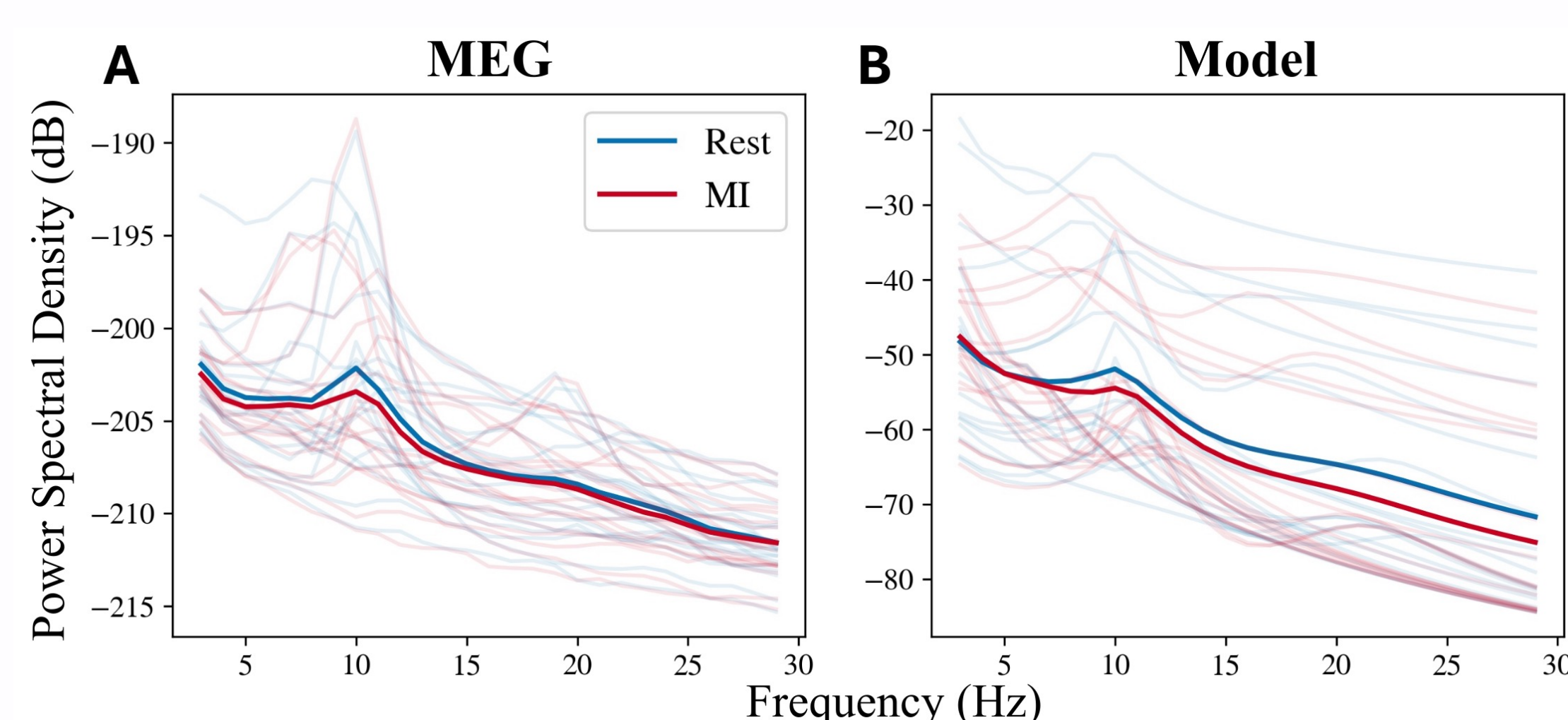
The BCI task consisted of a standard 1D, two-target box task in which the subjects modulated their α and/or β activity. To hit the target-up, the subjects performed a sustained motor imagery (MI) of

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. Magnetoencephalography (MEG) data were preprocessed using the Independent Component Analysis method, followed by the source reconstruction on the epoched data [1].

Biophysical Model of Brain Oscillations



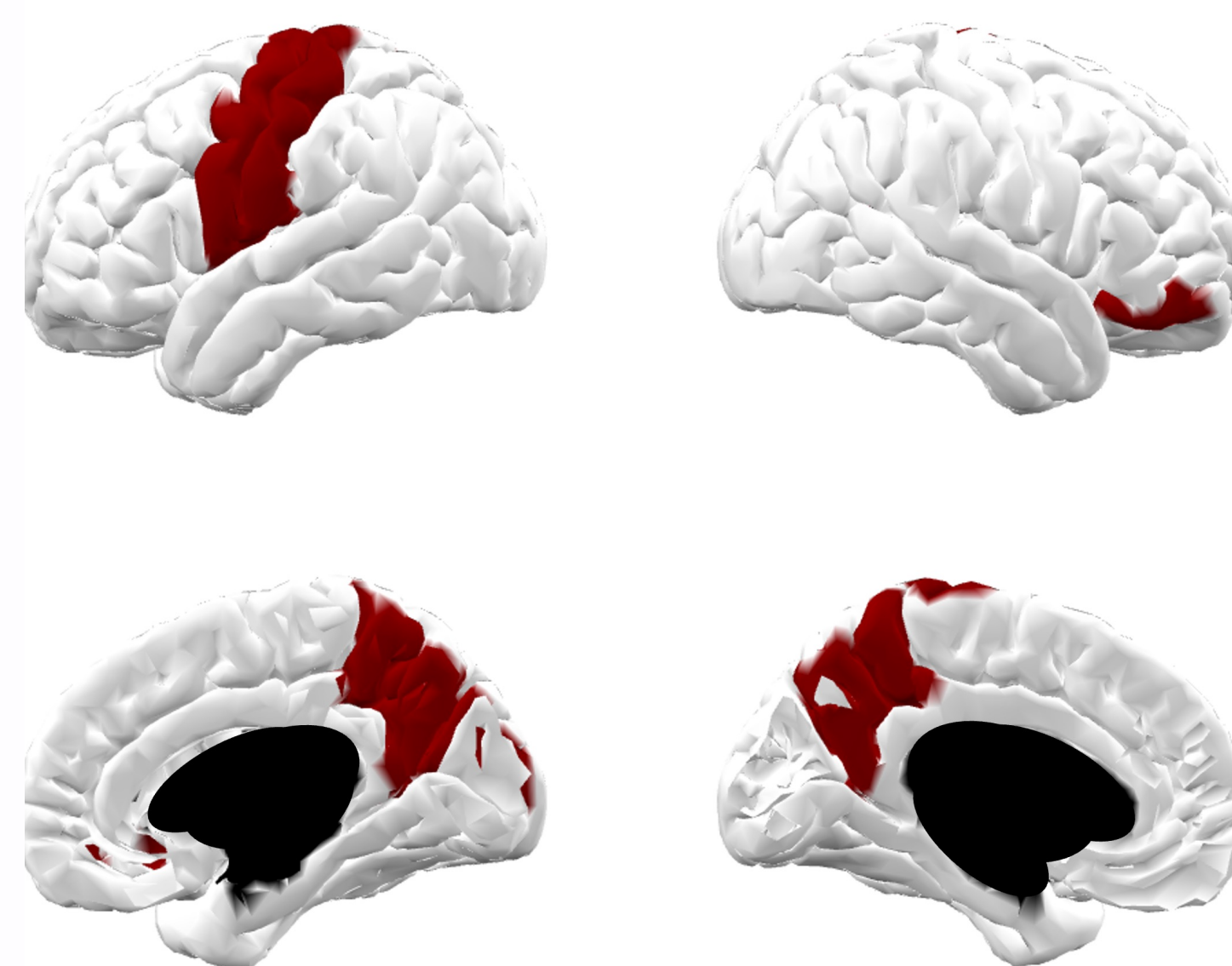
Power spectral density at rest and while performing motor imagery



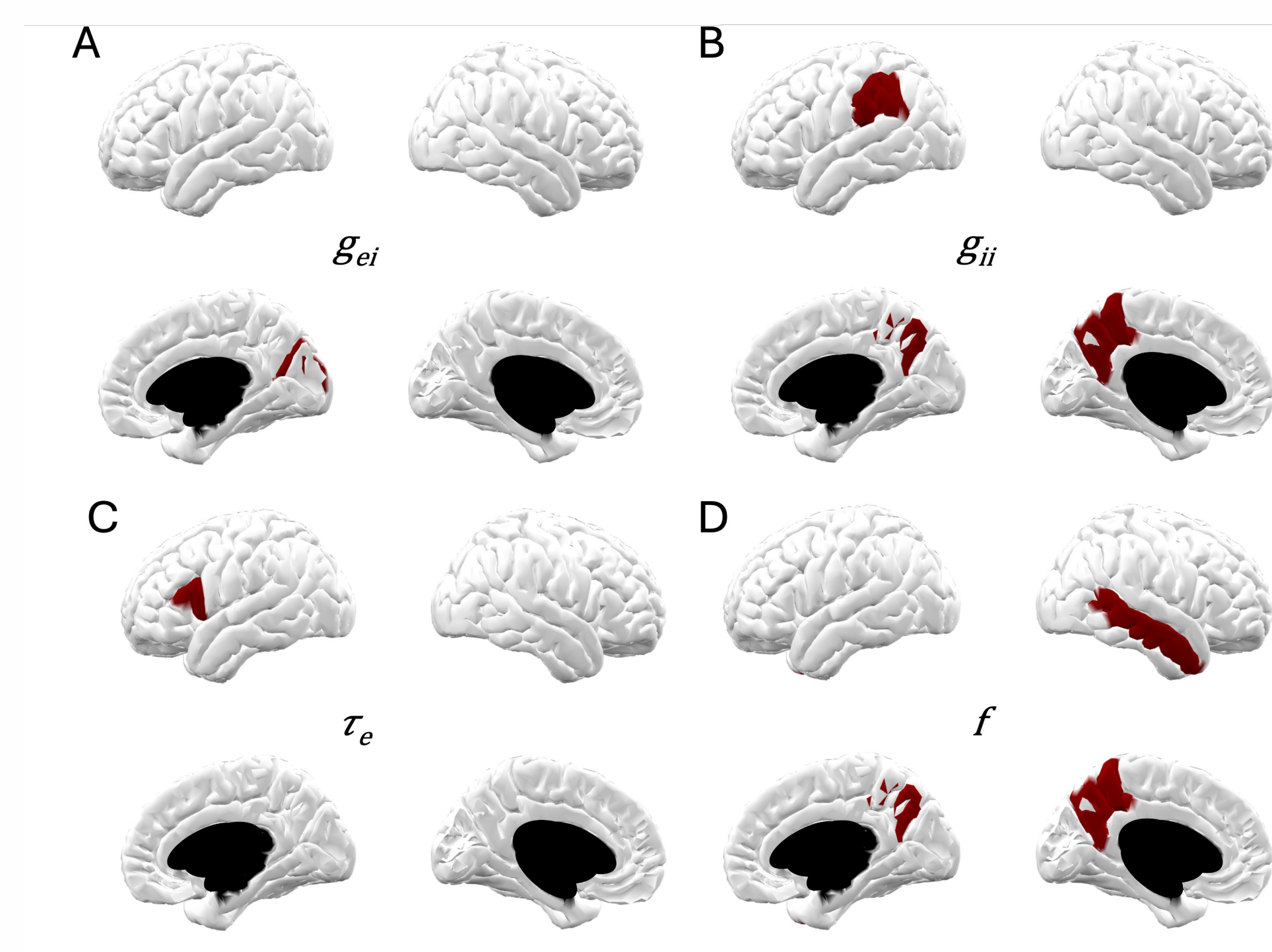
Power spectral density (PSD) of all the subjects and their average (in bold) in the left superior parietal gyrus as an example. Blue: rest; red: motor imagery (MI). A: MEG PSD. B: PSD from model fitting. We see a decrease in the beta band in MI with both MEG and model.

Changes in β frequency band spectral power while controlling a BCI

Together with the left precentral, the left postcentral, and the bilateral precuneus are the main regions where the beta power differs the most between conditions ($p < 0.05$). These regions are involved respectively in motor imagery, mental imagery planning and memory.



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 gain g_{ii} shows a condition effect in regions involved in mental imagery planning and mental imagery (resp. in precuneus and supramarginal gyrus [3]). The time constant τ_e presents a condition effect in pars opercularis involved in decision making. The noise parameter f shows a condition effect in areas involved in mental strategies and visual perception (resp. precuneus and middle temporal gyrus).

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Conclusions

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

Acknowledgements

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