

Exploiting brain critical dynamics to inform Brain-Computer Interfaces

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Brain-Computer Interfaces (BCIs) constitute a promising tool for communication and control. However, mastering non-invasive BCI systems remains a learned skill difficult to develop for a non-negligible proportion of users. Even though similarities have been shown between MI-based BCI learning and motor sequence learning our understanding of the dynamical processes, and their reflection on brain signals during BCI performance is still incomplete. In particular, whole-brain functional imaging is dominated by a 'bursty' dynamics, "neuronal avalanches", with fast, fat-tailed distributed, aperiodic perturbations spreading across the whole brain. Neuronal avalanches evolve over a manifold during resting-state, generating a rich functional connectivity dynamics. In this work, we evaluated to which extent neuronal avalanches can be used as a tool to differentiate mental states in the context of BCI experiments.

BCI experiment

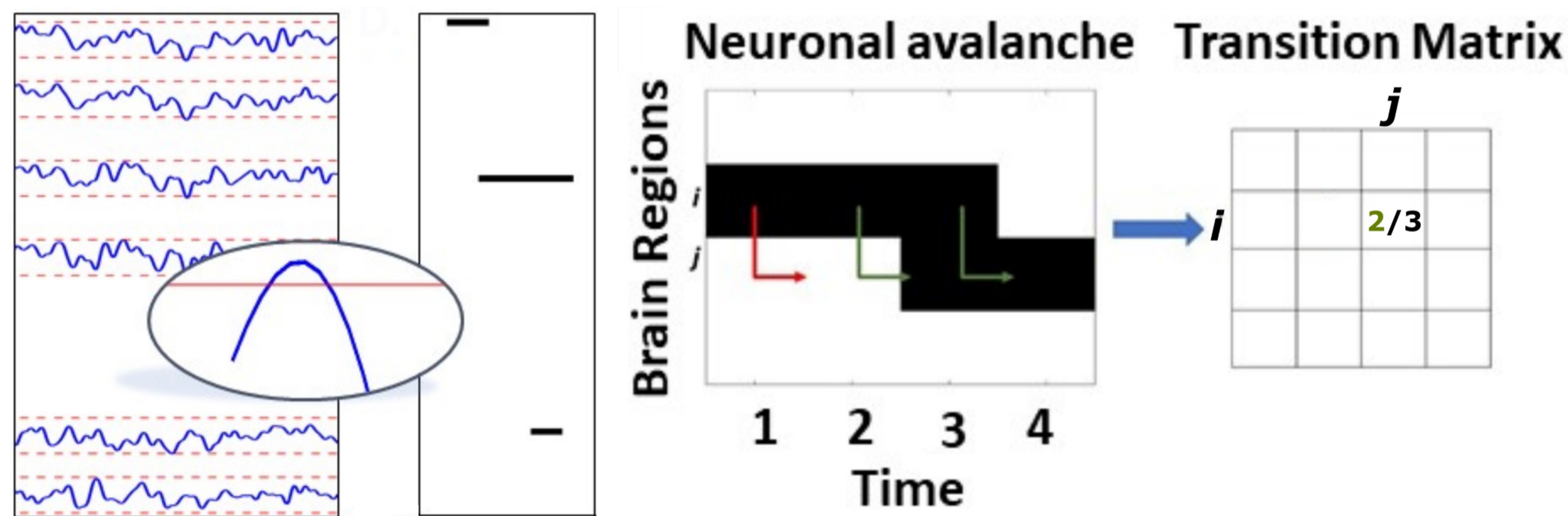
The BCI task consisted of a standard 1D, two-target box task in which the subjects modulated their α and/or β activity. To hit the target-up, the subjects performed a sustained motor imagery of their right-hand grasping and to hit the target-down, they remained at rest. Twenty subjects (aged 27.45 ± 4.01



years, 12 men), all right-handed participated in the study.

Magnetoencephalography (MEG) 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 [1].

Neuronal avalanches computation



The signal was z-scored and thresholded, and set to 1 when above threshold, and to zero otherwise (threshold = |3|). An avalanche was defined as starting when at least one region is above threshold, and as finishing when no region is active. For each avalanche, we have estimated a transition matrix (TM) containing the probability that regions j would be active at time $t+1$, when region i was active at time t [2].

For each subject, we obtained an average transition matrix for the baseline condition (Rest), and an average transition matrix for the motor imagery task (MI).

We set out to test if neuronal avalanches would be suitable to track subject-specific changes induced by a task in the large-scale brain dynamics. Even though we discarded most data, we spotted a number of edges whose dynamics is affected by the execution of a motor imagery task. Our results suggest that avalanches capture functionally-relevant processes of interest for alternative BCI designing.

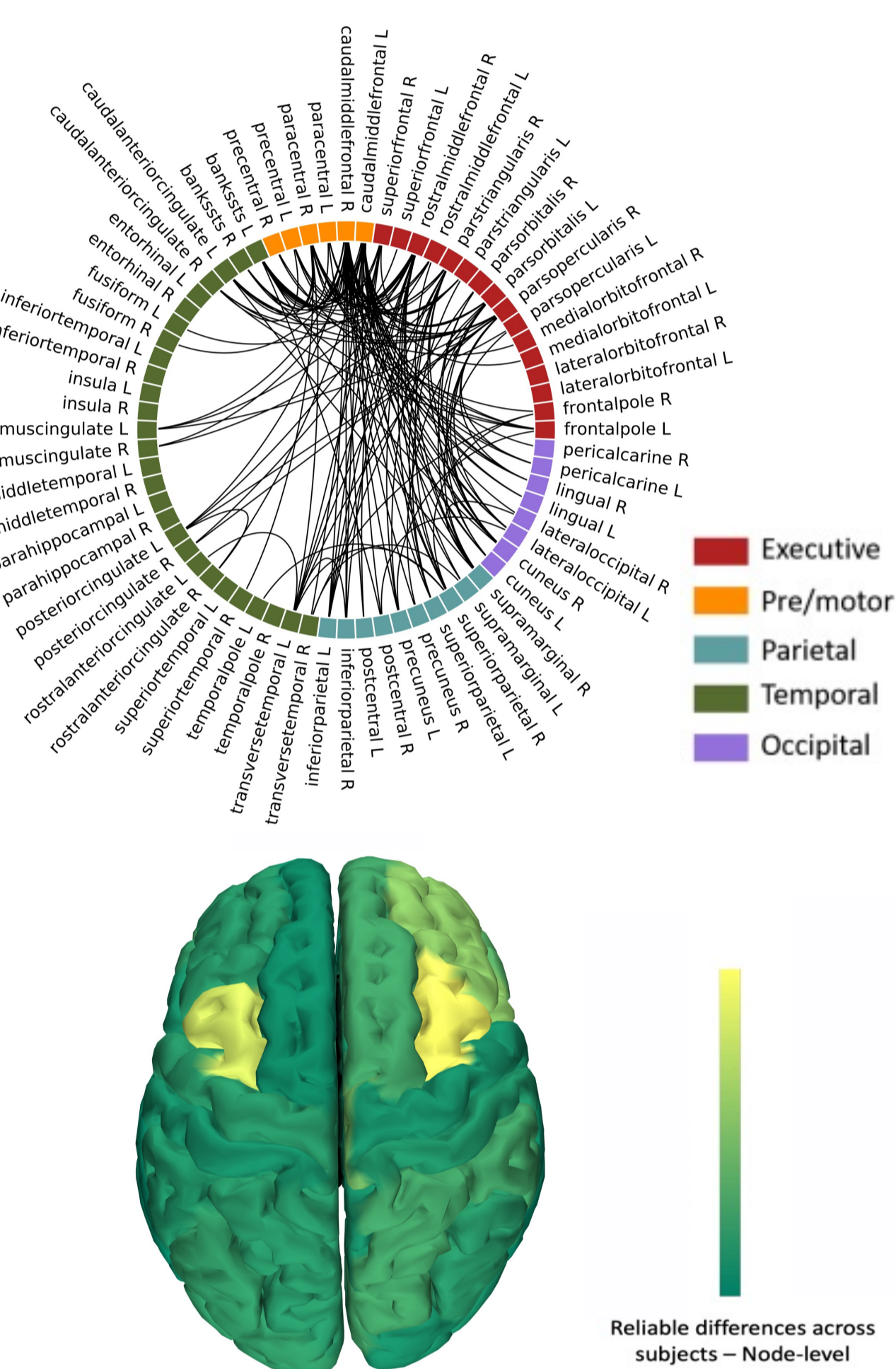
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Neuronal avalanches, a reliable tool to discriminate mental states

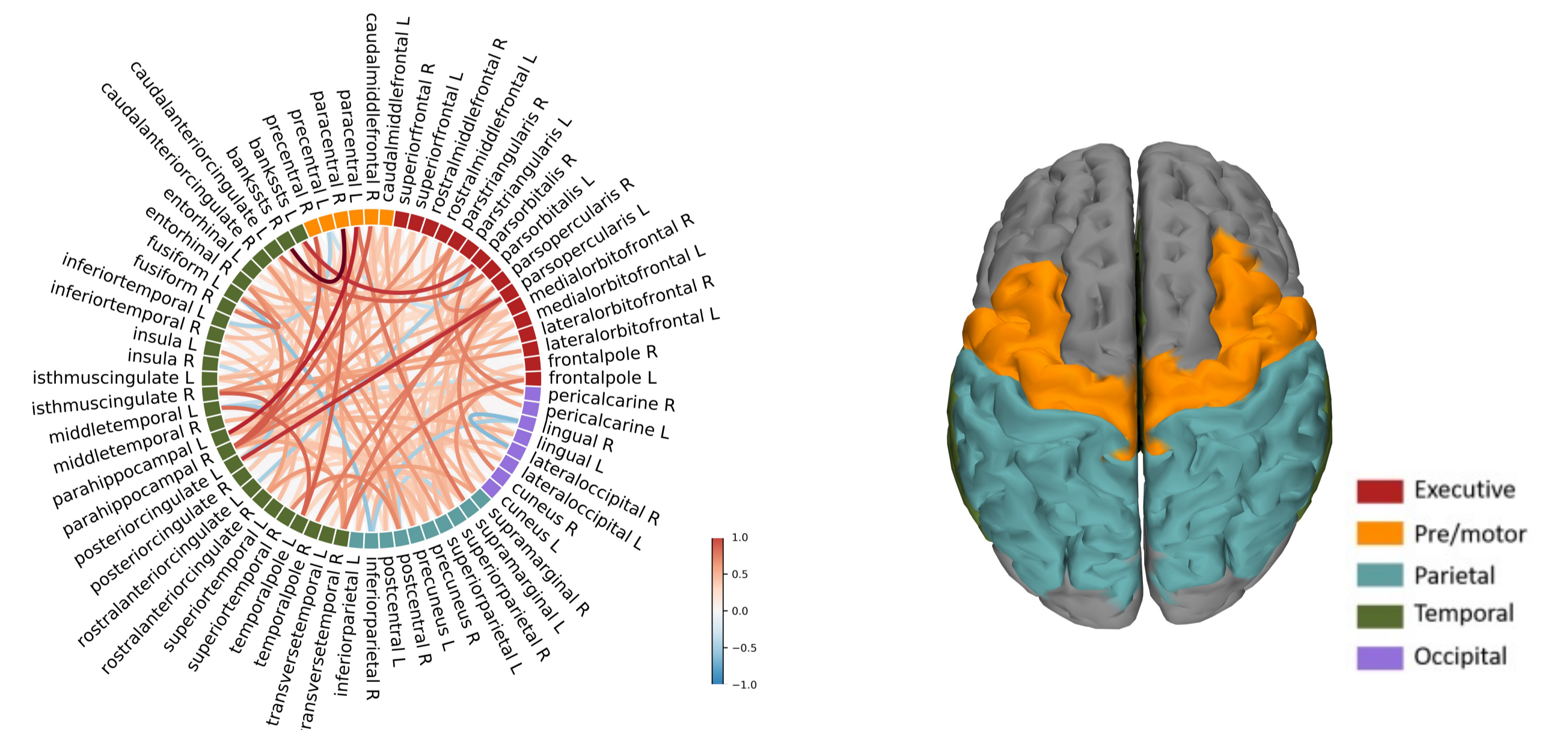
After identifying at the individual level the edges and the nodes, that show a significant condition effect, we went one step further. We looked at the concordance of such differences across subjects. This way, we spotted the edges were engaged differently by perturbations in the two conditions in most subjects.



The reliably different edges cluster on premotor regions bilaterally. Then, we have summed the differences corresponding to all the edges which are incident upon each reliably different region obtaining an overall difference per each such node. In particular, the caudal middle frontal gyri bilaterally are the main regions upon which edges which differ between conditions cluster. These regions are involved in planning of motor actions, imagining of actions, as well as in executive attention [3] and in the selection between competing visual targets [4].

Predictive marker of BCI scores

To assess to which extent neuronal avalanches can predict BCI scores, we focused on the differences in the transition probabilities in the edges which are incident upon the "task-related" regions. For each of these edges, we correlated the difference in probability in each subject with the performance in the MI task, as measured using the BCI score.



Nearly all differences correlate positively with the performance in the task. We then computed the average correlation over all the edges connecting any two functional areas. Our findings suggest that perturbations spread more often between premotor/motor areas and parietal areas when the subject is engaged in the motor-imagery task as compared to resting-state condition.

References

- [1] Corsi, et al (2020). Functional disconnection of associative cortical areas predicts performance during BCI training. *NeuroImage*
- [2] Sorrentino, et al (2021). The structural connectome constrains fast brain dynamics. *Elife*
- [3] Andersson, et al (2009). Correlations between measures of executive attention and cortical thickness of left posterior middle frontal gyrus-A dichotic listening study. *Behavioral and Brain Functions*
- [4] Germann, et al (2020). Area 8A within the Posterior Middle Frontal Gyrus Underlies Cognitive Selection between Competing Visual Targets. *ENeuro*

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