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► To cite this version:

Marie-Constance Corsi, Pierpaolo Sorrentino, Denis P Schwartz, Nathalie George, Laurent Hugueville, et al.. Neuronal avalanches differentiate resting-state and task conditions in Brain-Computer Interfaces. OHBM 2022 - Organization of Human Brain Mapping, Jun 2022, Glasgow, United Kingdom. hal-03695403

HAL Id: hal-03695403

<https://inria.hal.science/hal-03695403v1>

Submitted on 14 Jun 2022

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Neuronal avalanches differentiate resting-state and task conditions in Brain-Computer Interfaces

Poster No:

2757

Submission Type:

Abstract Submission

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Introduction:

Brain-Computer Interfaces (BCIs) constitute a promising tool for communication and control. However, mastering non-invasive BCI remains a learned skill difficult to develop for a non-negligible proportion of users (Allison et al., 2010). Even though similarities have been shown between MI-based BCI learning and motor sequence learning (McDougle et al., 2016), 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, with fast, fat-tailed distributed, aperiodic perturbations (i.e. "Neuronal Avalanches") spreading across the whole brain (Tagliazucchi et al., 2012). Neuronal avalanches spread preferentially across the white-matter bundles (Sorrentino et al., 2021), are affected by neurodegenerative diseases (Sorrentino, et al., 2021), and evolve over a manifold during resting-state, generating a rich functional connectivity dynamics (Rabuffo et al., 2021). Here we hypothesize that they could be used to differentiate different behaviors. To test our hypothesis, we used source-reconstructed MEG signals in a BCI framework, where 19 subjects were compared in resting-state and while performing a motor imagery task. We obtained the probabilities of each pair of regions being recruited sequentially in an avalanche (Sorrentino et al., 2021), and compared, edge- and subject-wise, such probabilities in the two conditions.

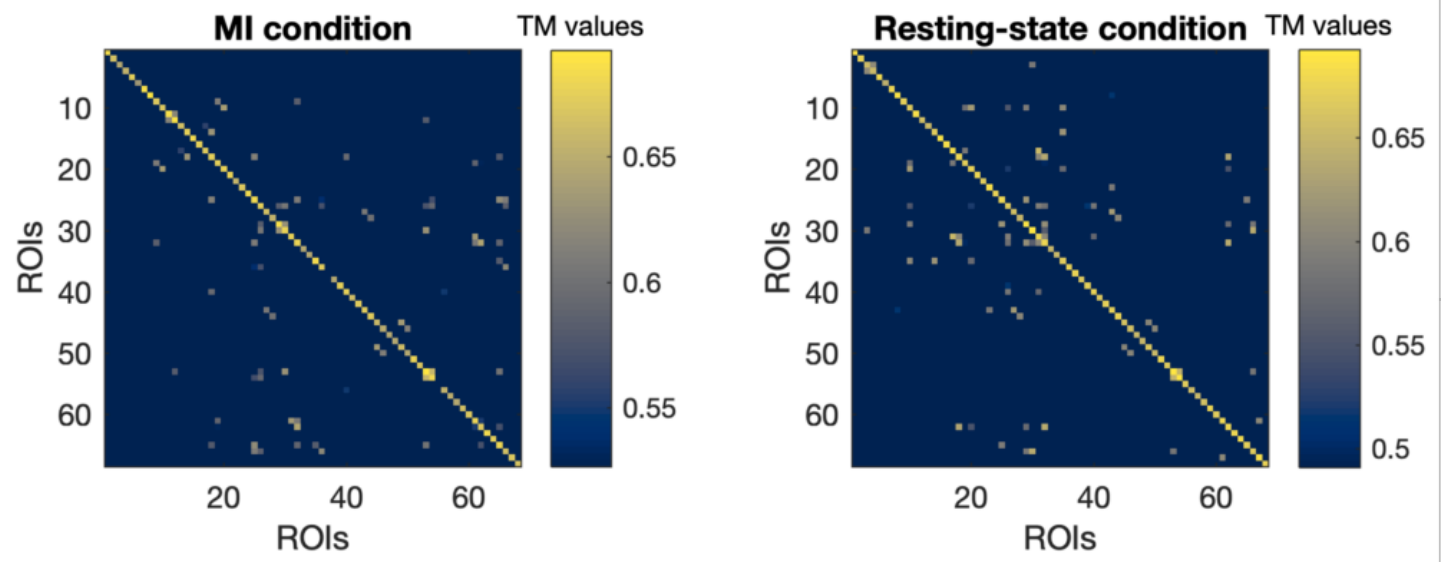
Methods:

Here, we applied the neuronal avalanches approach to MEG data recorded during a BCI training session performed by a group of 19 healthy subjects (aged 28.1 ± 3.6 years, 11 men). They were instructed to control the vertical position of a moving cursor by modulating their neural activity via a motor imagery task. For a complete description of the preprocessing steps, one can refer to (Corsi et al., 2020). The signal was then z-scored (over time) and thresholded, and set to 1 when above threshold, and to zero otherwise (threshold = $|3|$). We binned the data every 3 samples, since in this condition we measured a branching ratio of 1, which is typical of a critical branching process. 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 . Then, for each subject, we obtained one TM per experimental condition (Fig. 1), and then computed the difference between the two. We used a permutation approach followed by FDR correction to statistically validate the differences. We then considered only those edges that were significant in at least 60% of the subjects (Fig. 2A). Finally, we located the nodes where significant edges clustered (Fig. 2B).

Results:

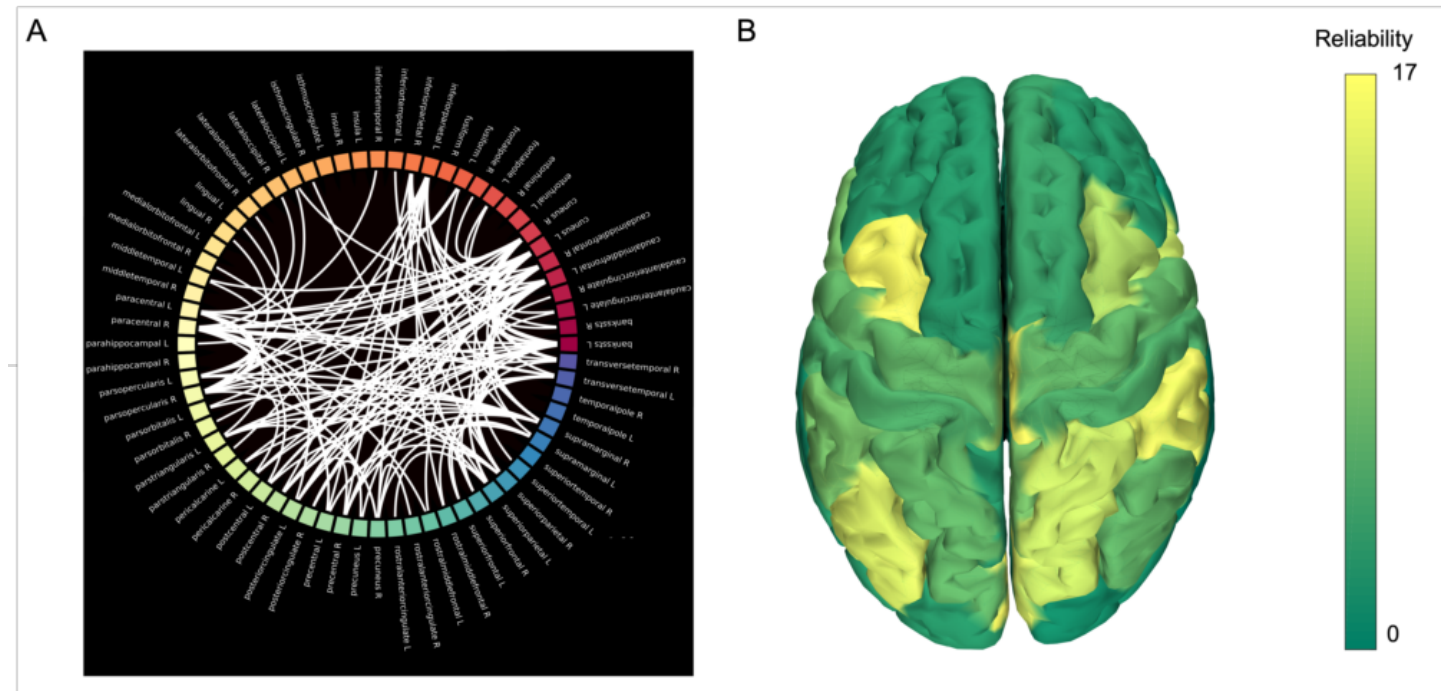
Our results show that all the significantly different edges cluster upon a limited number of brain regions. In particular, the premotor areas appear to differ, bilaterally, between the conditions. The caudal middle frontal gyrus belongs to the premotor areas, who are involved in planning of motor actions, imagining of actions, as well as in executive attention (Andersson et al., 2009) and in the selection between competing visual targets

(Germann et al., 2020). The involvement is prominent to the left. Furthermore, the cuneuli bilaterally are also shown to differ between the two conditions, which might be related to the role these regions play in visual processing.



(https://files.aievolution.com/prd/hbm2201/abstracts/abs_2575/Fig1.png)

·Fig 1. Transition matrices (TM) averaged over the trials and the subjects respectively obtained in the MI (on the left) and the Baseline condition (on the right).



(https://files.aievolution.com/prd/hbm2201/abstracts/abs_2575/Fig2.png)

·Fig 2. Reliability analysis. (A) Edges showing a significant condition effect in more than 60% of the cohort (N=9 subjects). (B) Nodes involved in the most reliable edges.

Conclusions:

In this work, 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. Despite the fact that we discarded most data (via a high threshold), 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.

Higher Cognitive Functions:

Executive Function, Cognitive Control and Decision Making
Imagery

Modeling and Analysis Methods:

Connectivity (eg. functional, effective, structural) ¹
EEG/MEG Modeling and Analysis

Motor Behavior:

Brain Machine Interface ²

Keywords:

MEG
Other - Neuronal avalanches

¹²Indicates the priority used for review

My abstract is being submitted as a Software Demonstration.

No

Please indicate below if your study was a "resting state" or "task-activation" study.

Resting state
Task-activation

Healthy subjects only or patients (note that patient studies may also involve healthy subjects):

Healthy subjects

Was any human subjects research approved by the relevant Institutional Review Board or ethics panel? NOTE: Any human subjects studies without IRB approval will be automatically rejected.

Yes

Was any animal research approved by the relevant IACUC or other animal research panel? NOTE: Any animal studies without IACUC approval will be automatically rejected.

Not applicable

Please indicate which methods were used in your research:

MEG
Structural MRI

For human MRI, what field strength scanner do you use?

3.0T

Which processing packages did you use for your study?

Free Surfer

Provide references using author date format

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