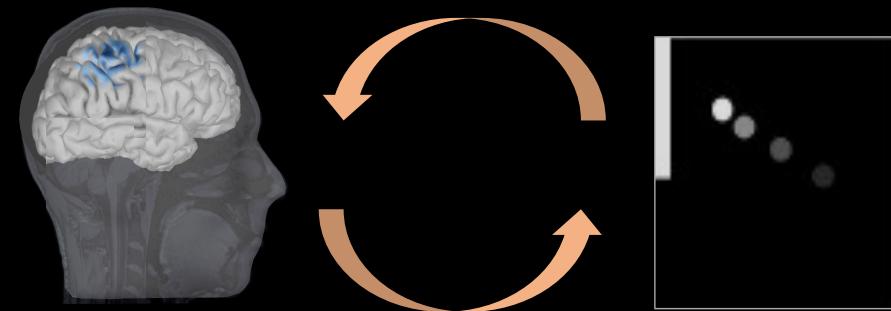


# A theory-driven approach to data analysis: practical applications



Marie-Constance Corsi,

Inria research scientist

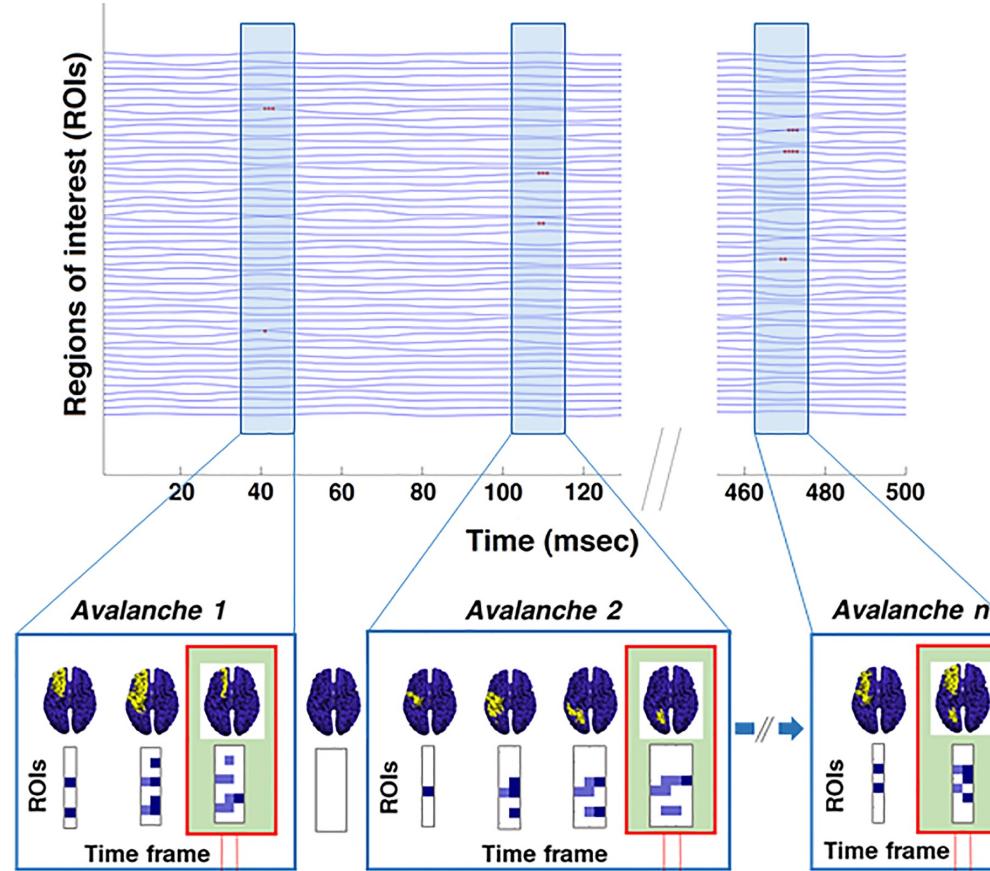
NERV team, Paris Brain Institute



# Capturing fast, non-linear brain dynamics

2

Neuronal avalanches: bursts of enhanced activity observed across neuroimaging modalities

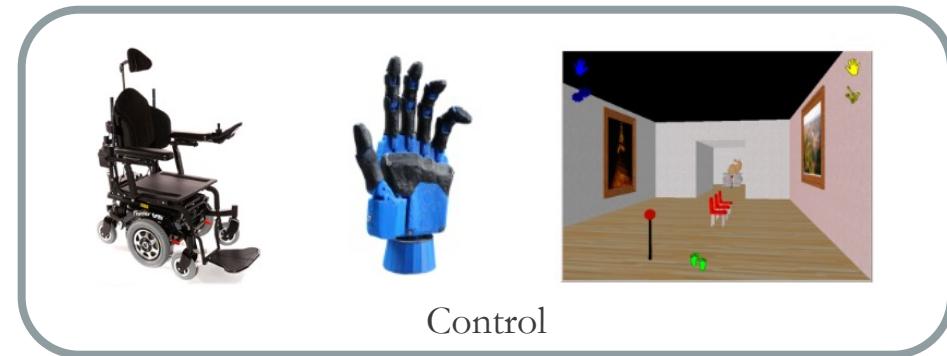
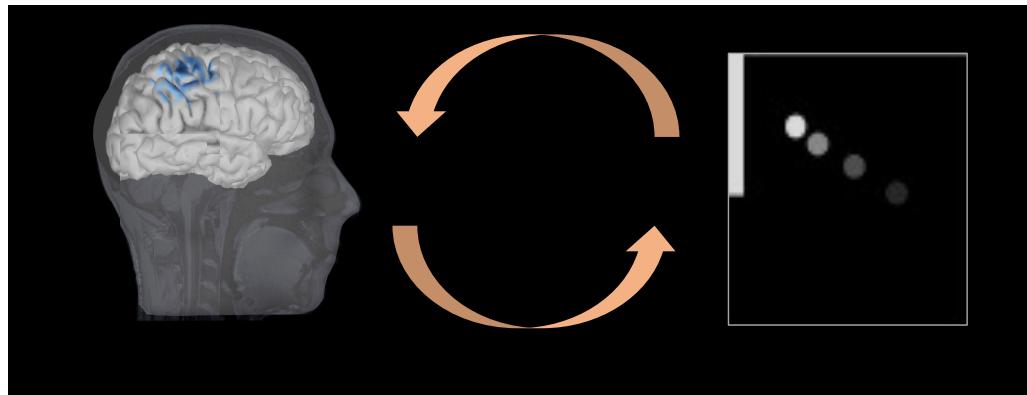


Adapted from [Polverino et al, Neurology, 2022]

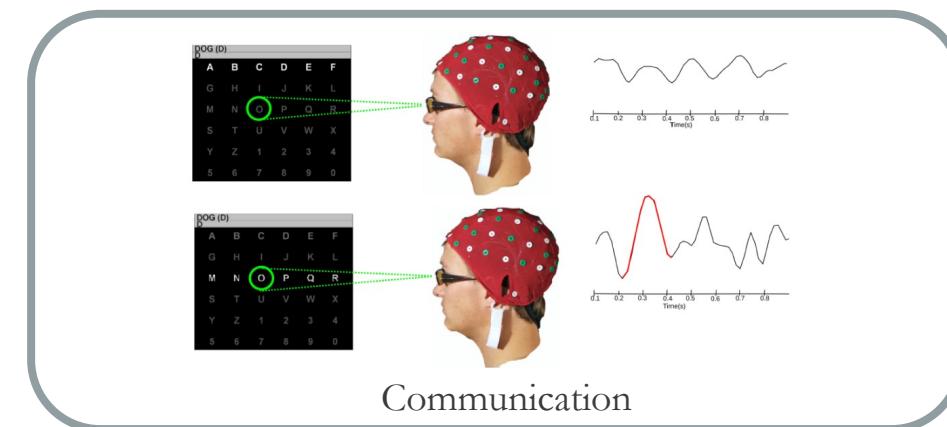
## Hypothesis:

The neuronal avalanches could spread differently according to the task/populations & provide original features

# What is a Brain-Computer Interface (BCI)?



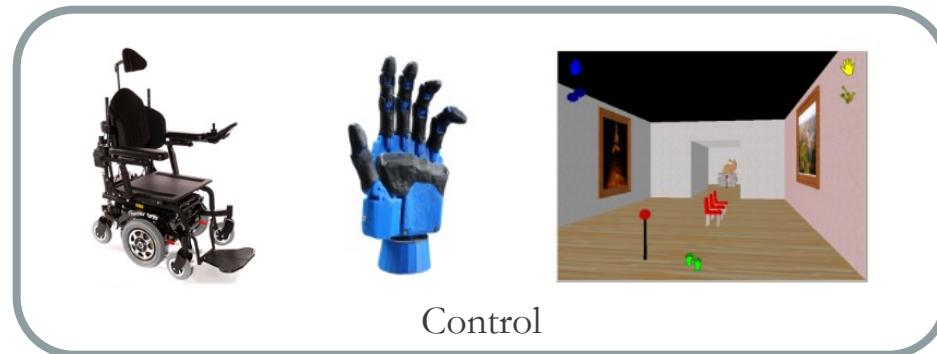
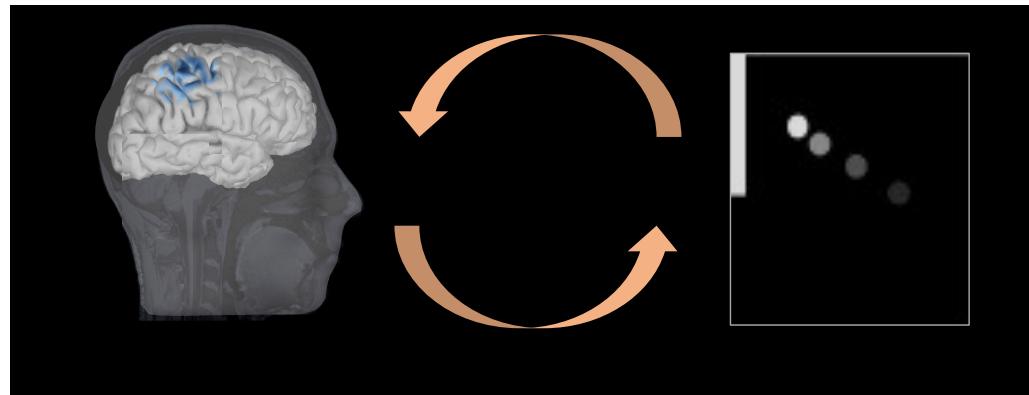
Control



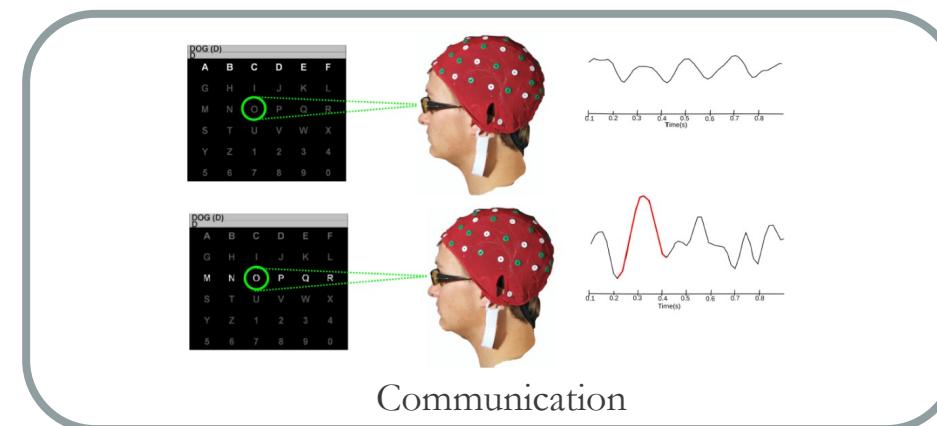
Communication

Adapted from (Lotte et al, 2015)

# What is a Brain-Computer Interface (BCI)?



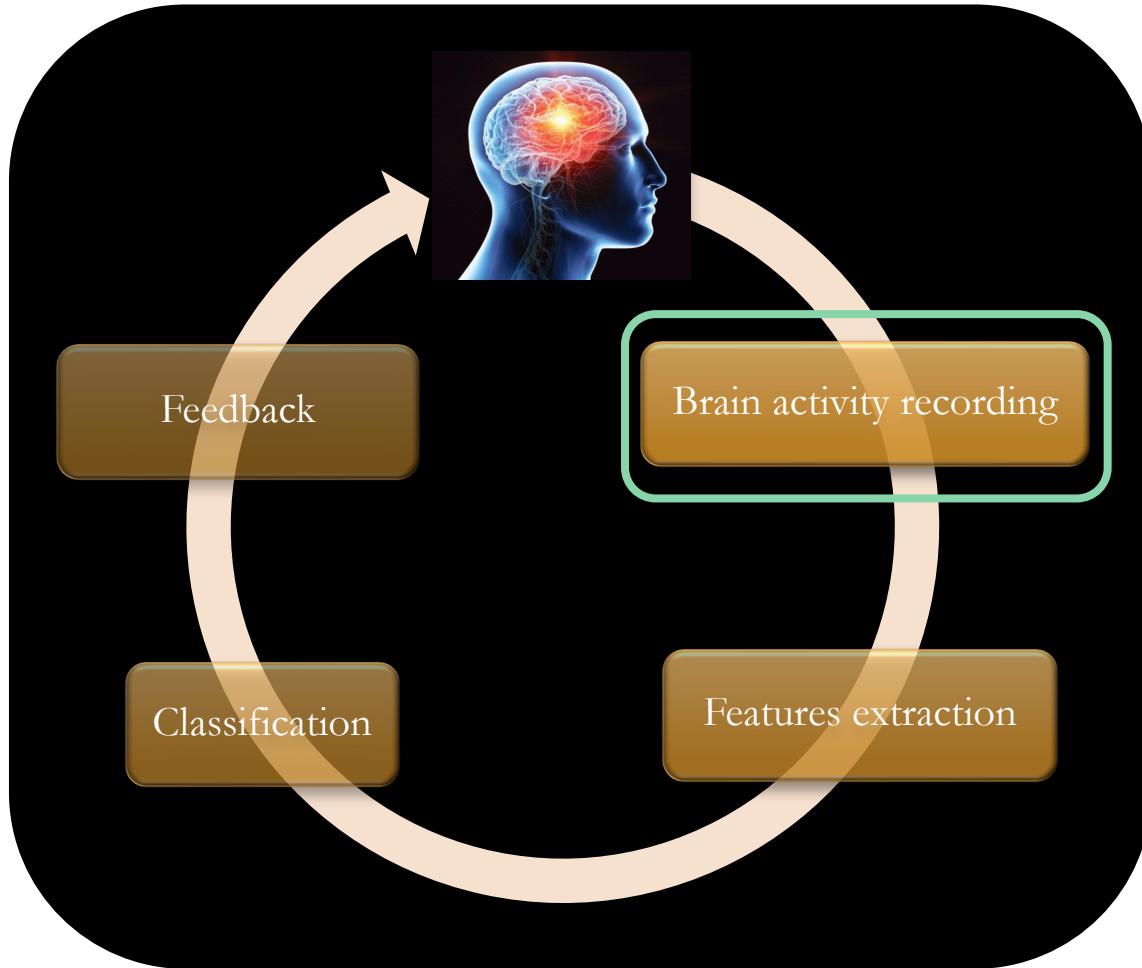
Control



Communication

Adapted from (Lotte et al, 2015)

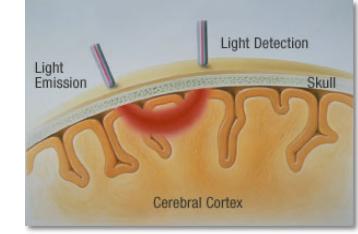
# Behind the magic...



## Non-invasive tools



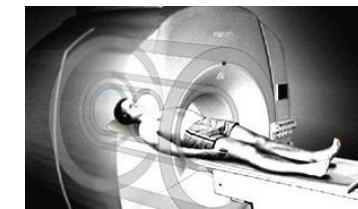
EEG



NIRS

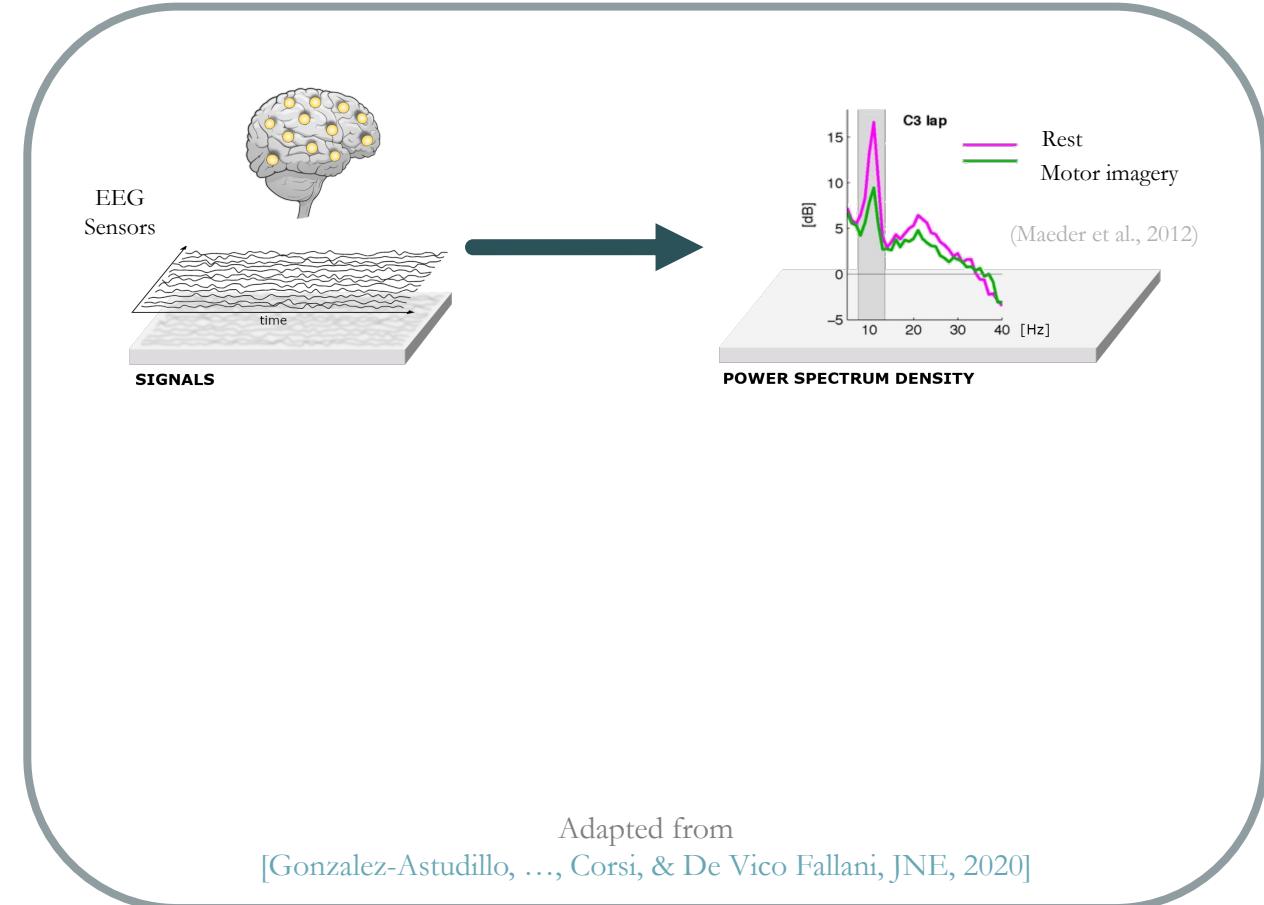
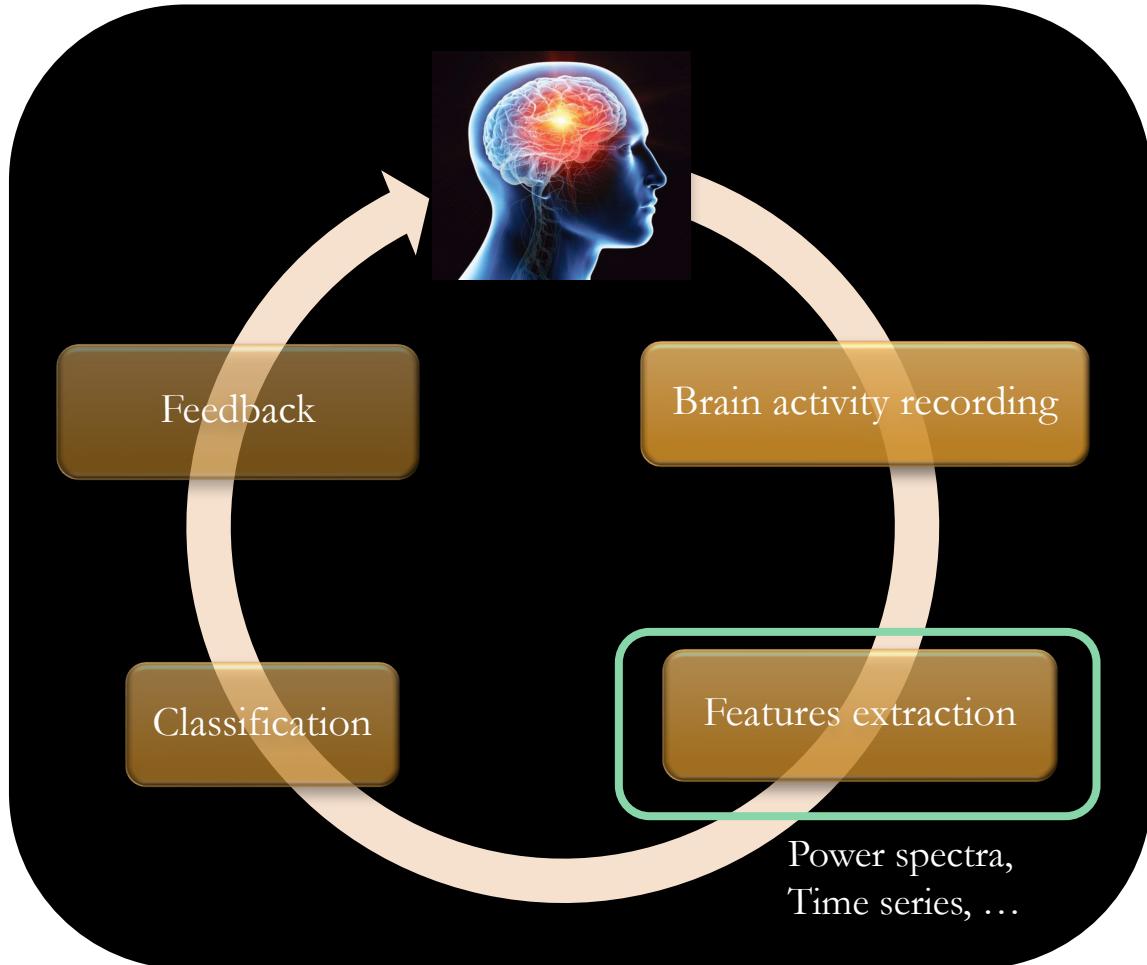


MEG

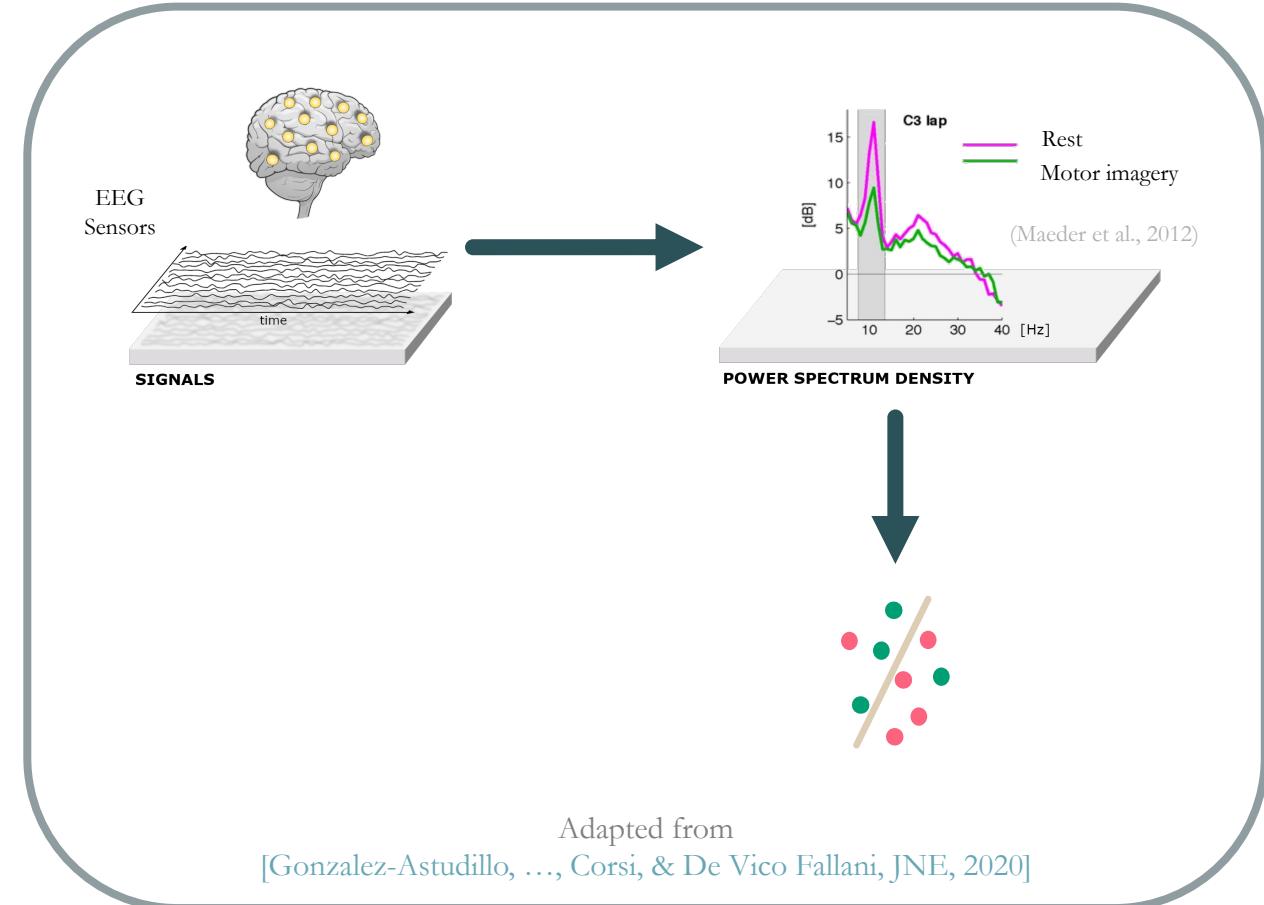
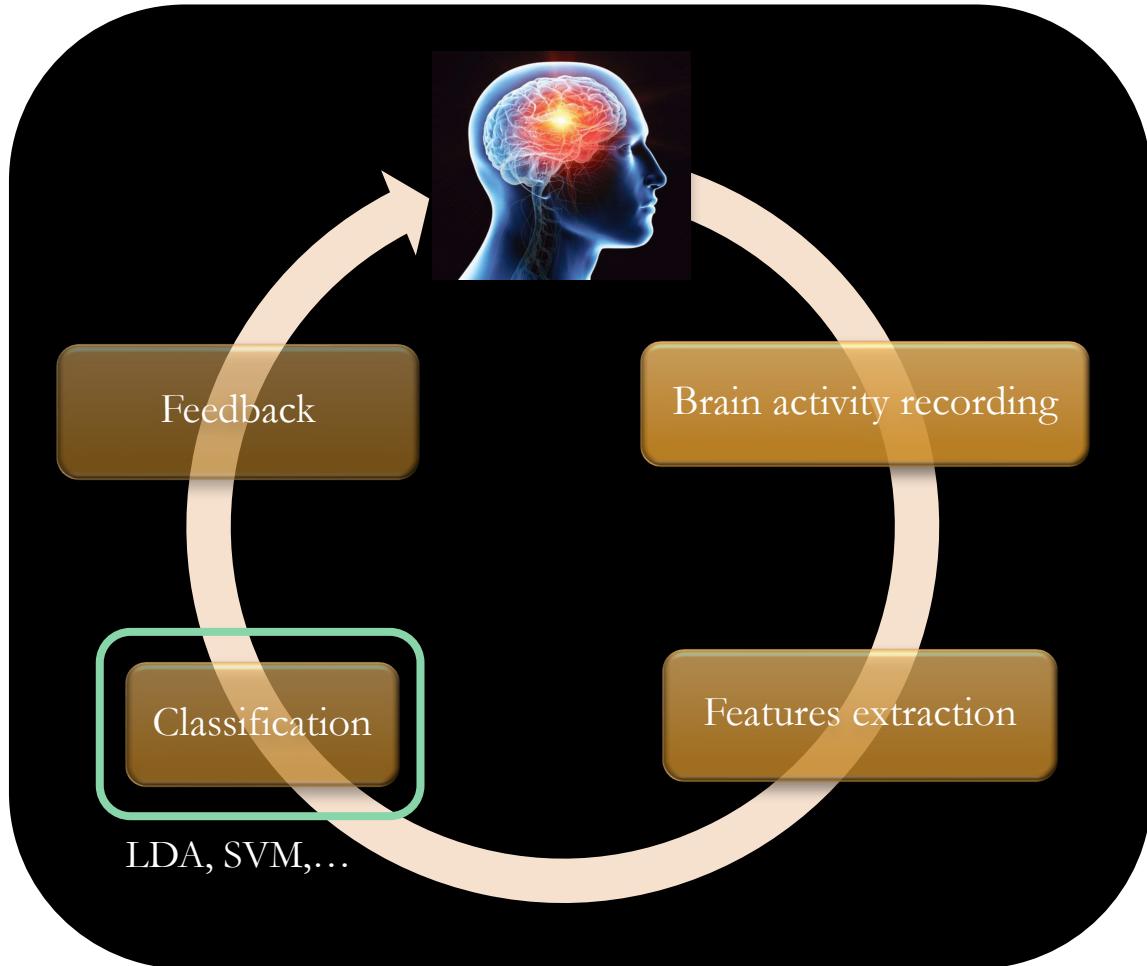


fMRI

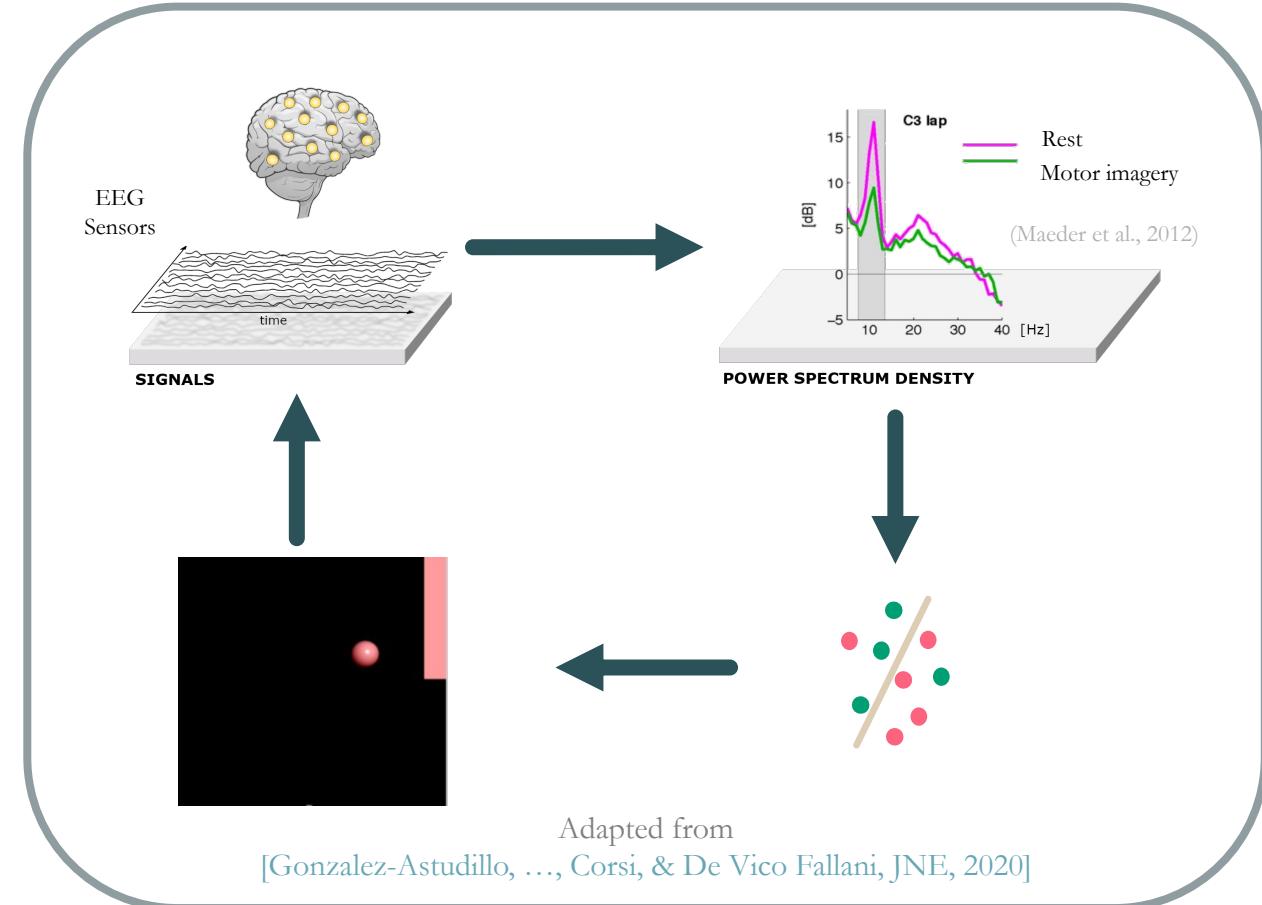
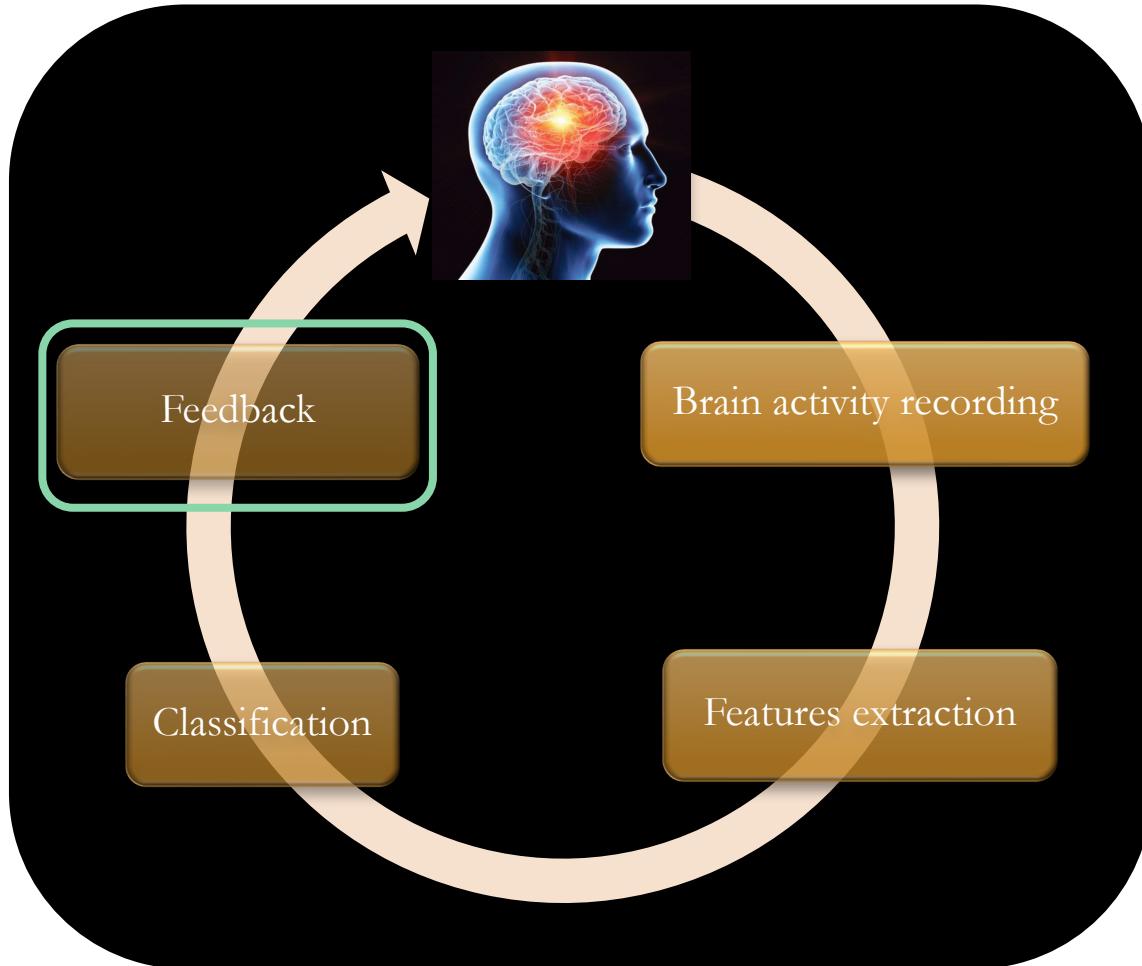
# Behind the magic...



# Behind the magic...

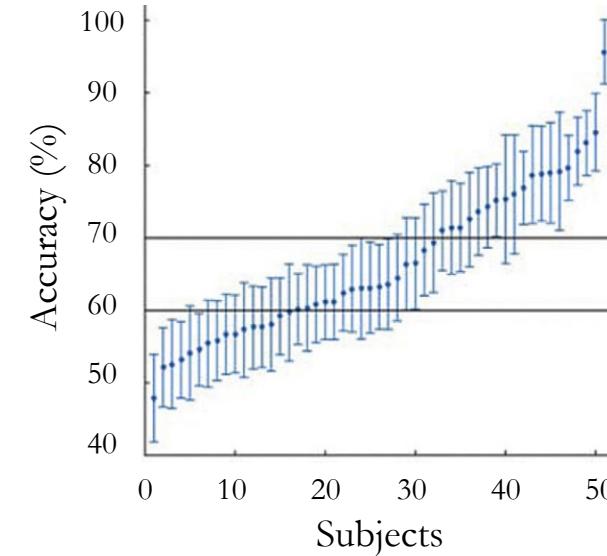
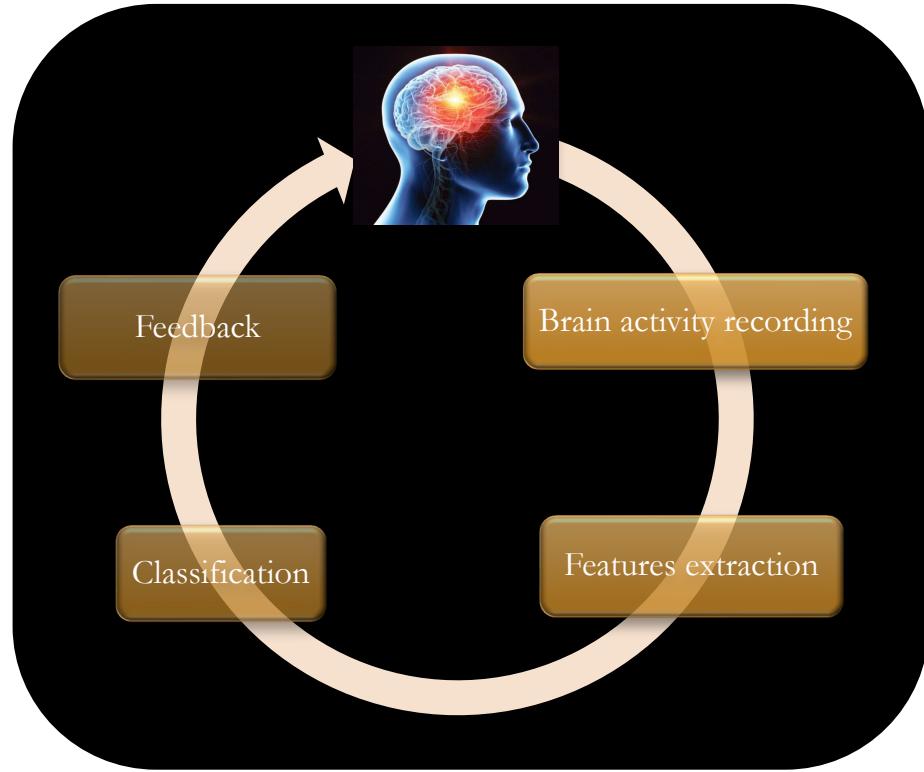


# Behind the magic...



# Brain-Computer Interface (BCI) – current challenges

9



Adapted from (Ahn & Jun, 2015)

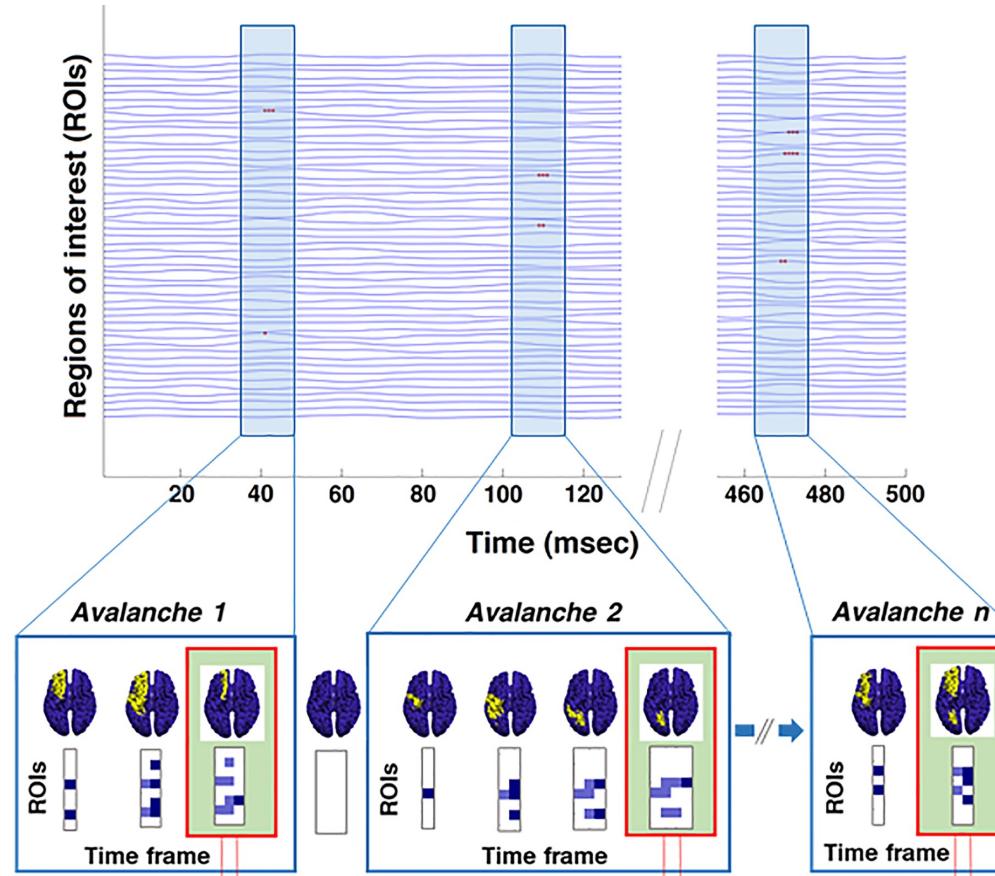
## Problem:

Current BCIs fail to detect the mental intentions in ~30% of users – **BCI inefficiency** (Thompson, 2018)  
⇒ Rely on local measurements of the brain activity

# Capturing fast, non-linear brain dynamics

10

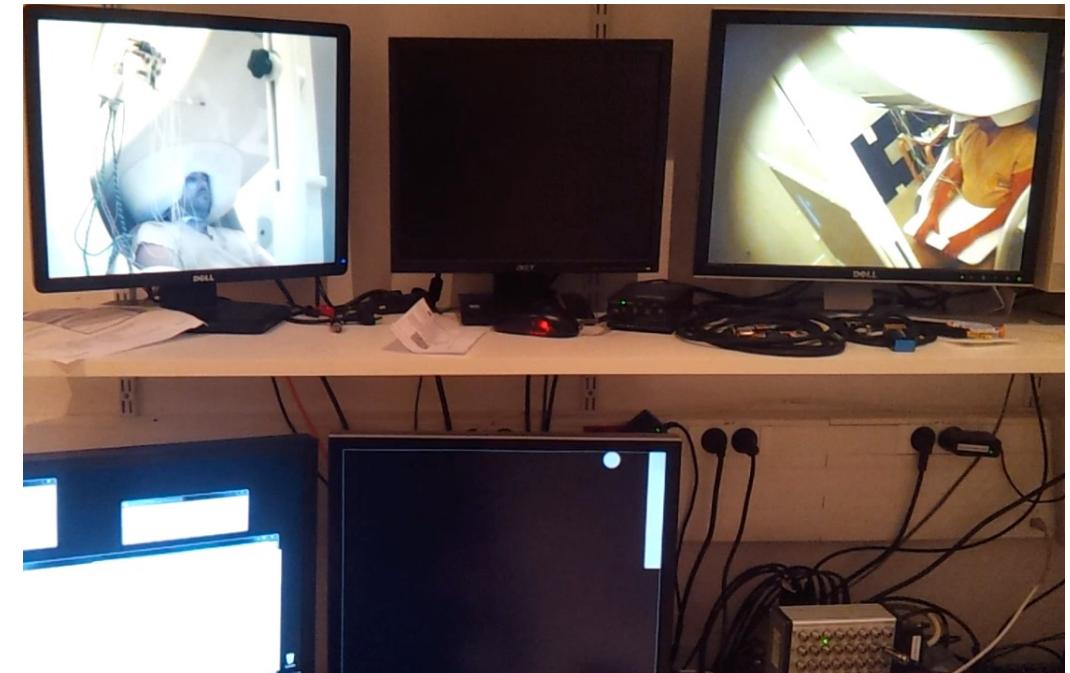
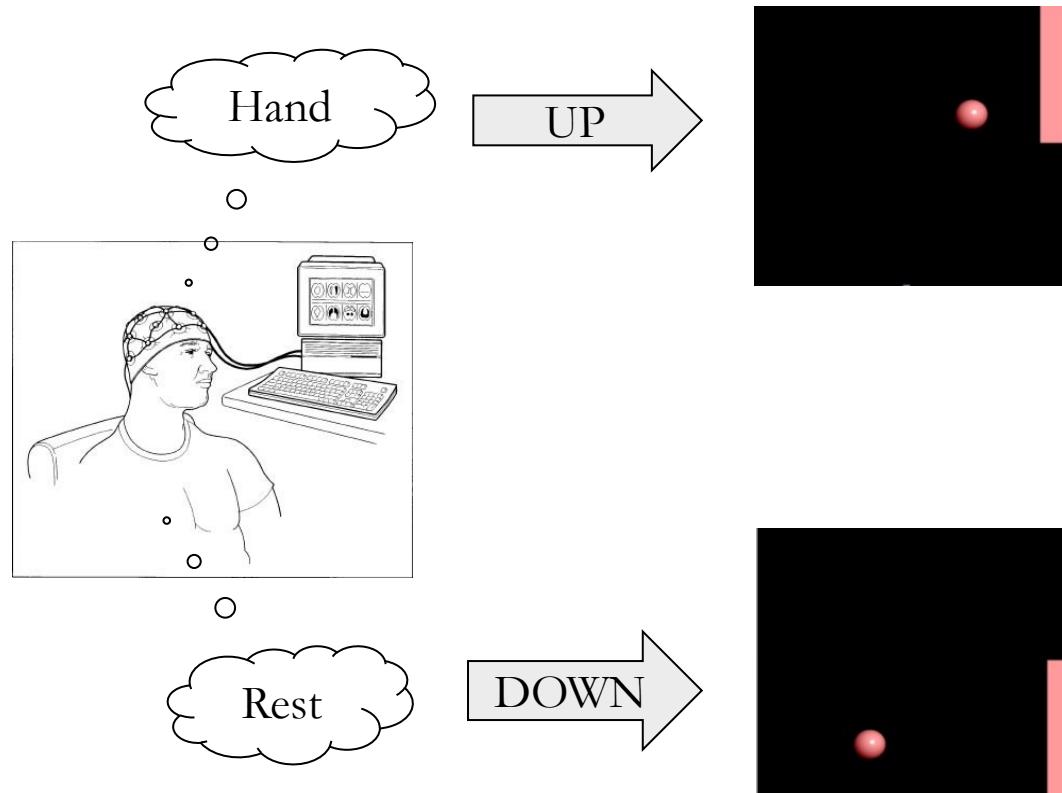
Neuronal avalanches: bursts of enhanced activity observed across neuroimaging modalities



Adapted from [Polverino et al, Neurology, 2022]

## Hypothesis:

The neuronal avalanches could spread differently according to the task & provide original markers of BCI performance.



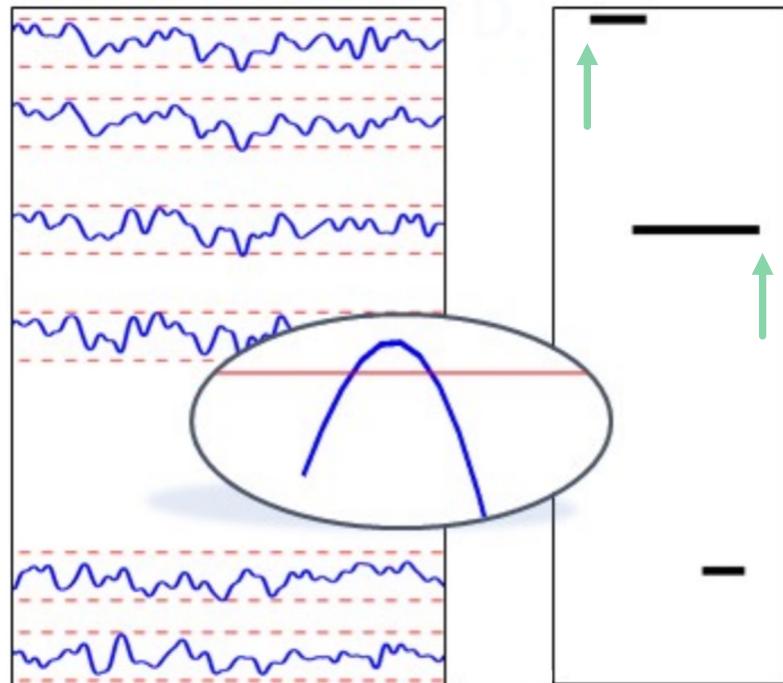
For a complete description of the protocol and the dataset, please refer to [Corsi et al, NeuroImage, 2020]

## Objective:

Tracking the dynamical features related to motor imagery as compared to rest

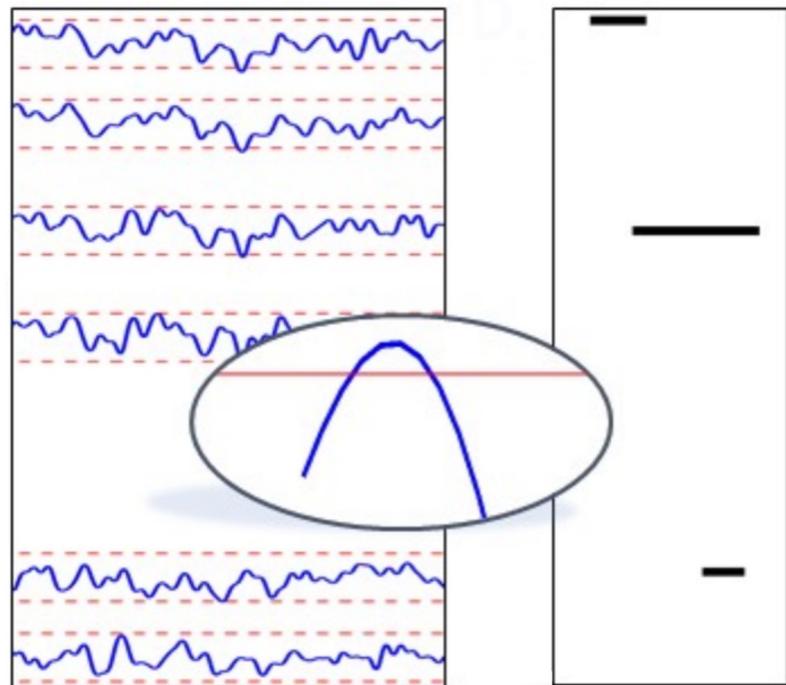
# Differences in transition probabilities discriminate mental states

12

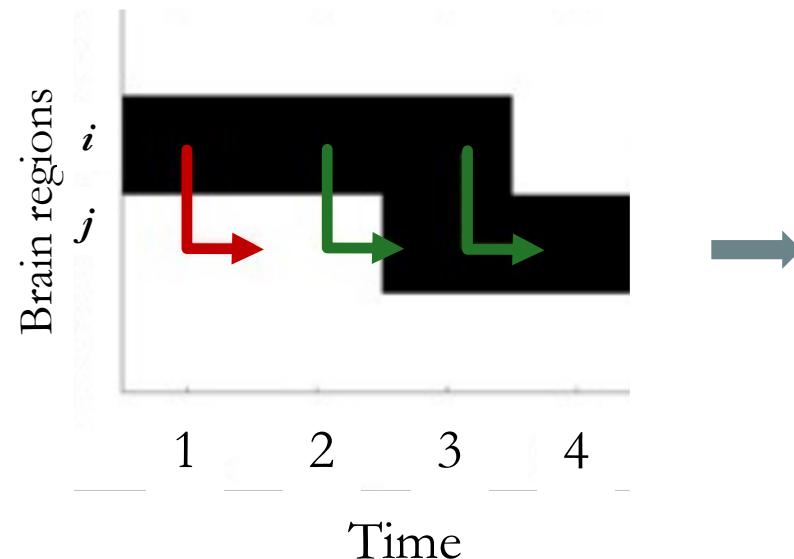


Adapted from [Sorrentino et al, eLife, 2021]





## Neuronal avalanche



## Avalanche Transition Matrix

(ATM)

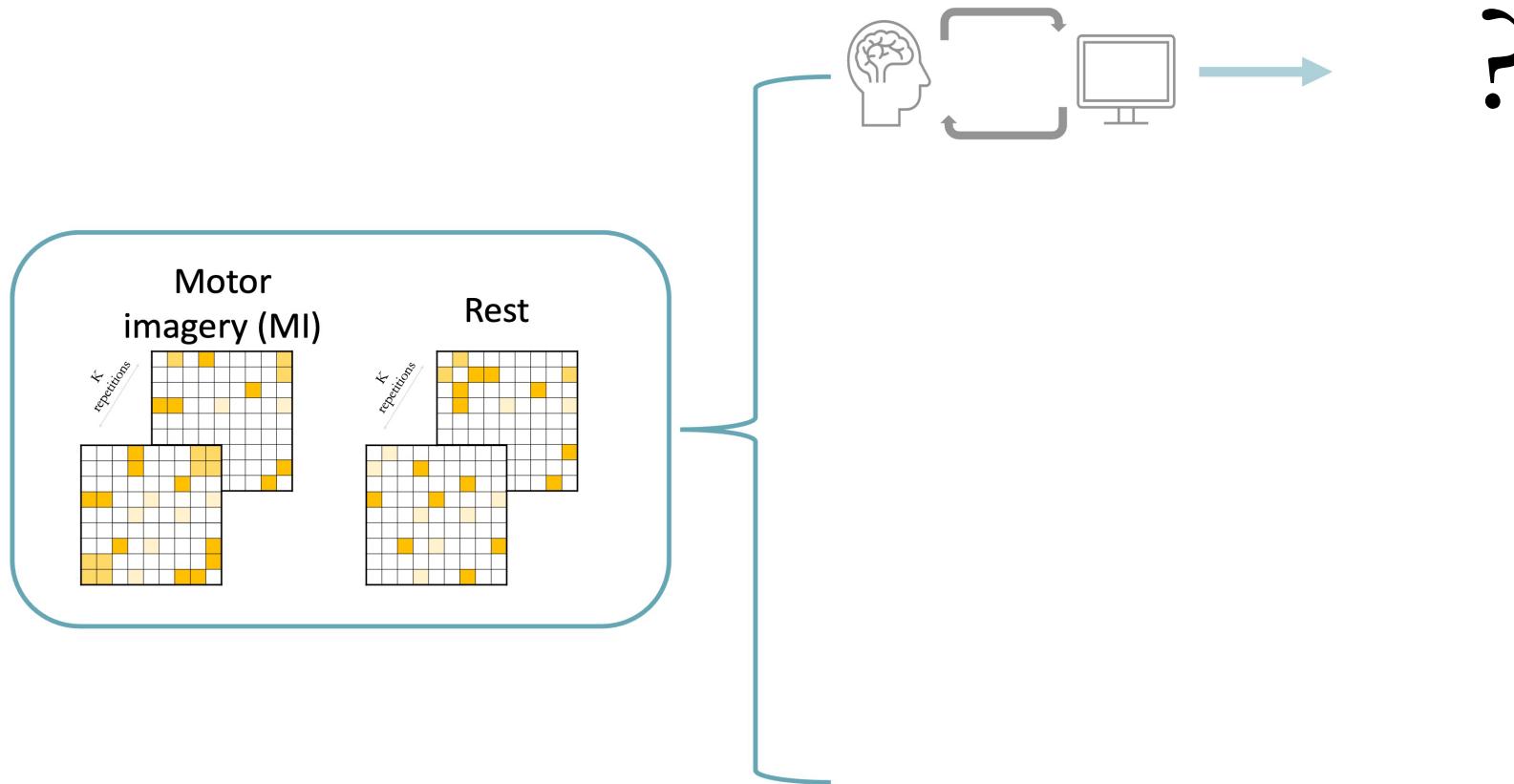
A 10x10 grid illustrating a 2D vector field. The color of each cell represents the value of the vector at that position. A legend on the right indicates the color mapping for values ranging from -1 (dark blue) to 1 (dark red). The grid shows a central region with high values (red/orange) transitioning to lower values (yellow/green) towards the edges.

Adapted from [Sorrentino et al, eLife, 2021]



# Differences in transition probabilities discriminate mental states

14



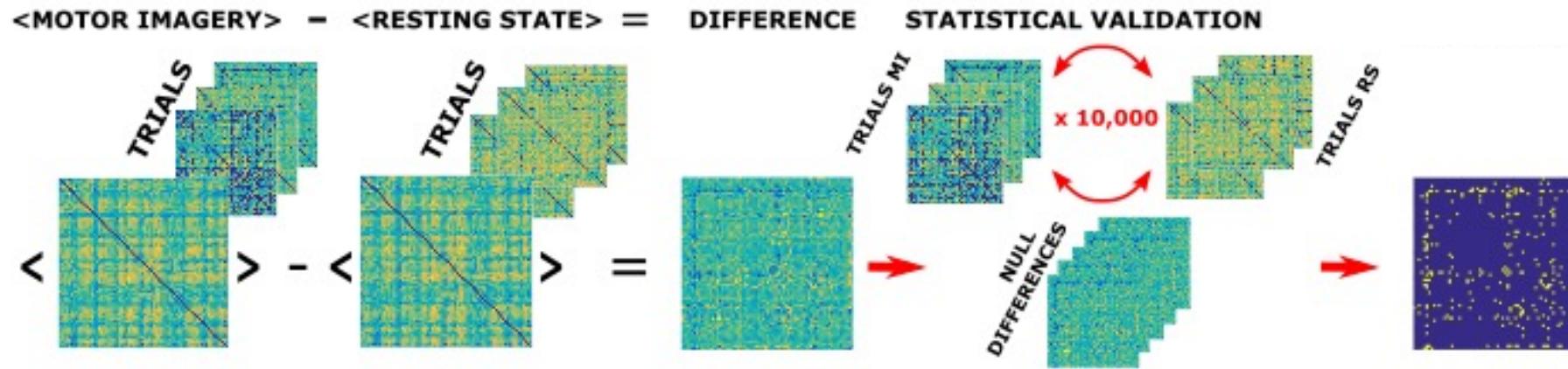
[Corsi\*, Sorrentino\* et al, iScience, 2024]



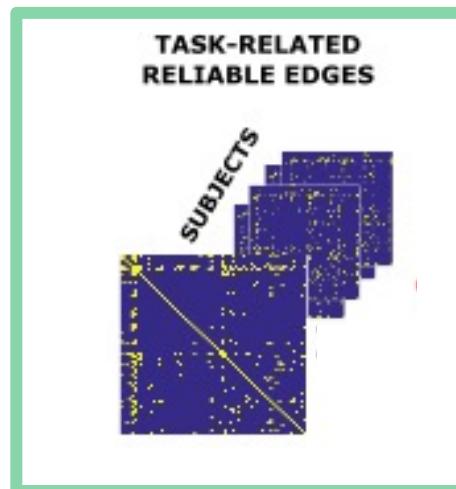
## Differences in transition probabilities discriminate mental states

15

## Subject-level



# Group-level

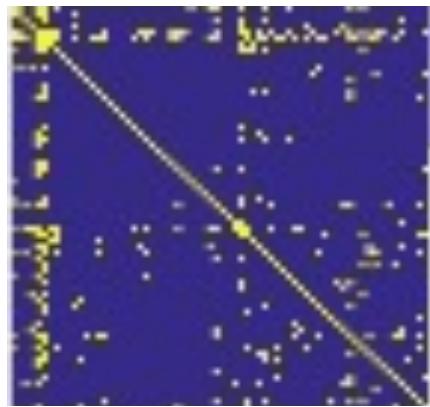


[Corsi\*, Sorrentino\* et al, iScience, 2024]

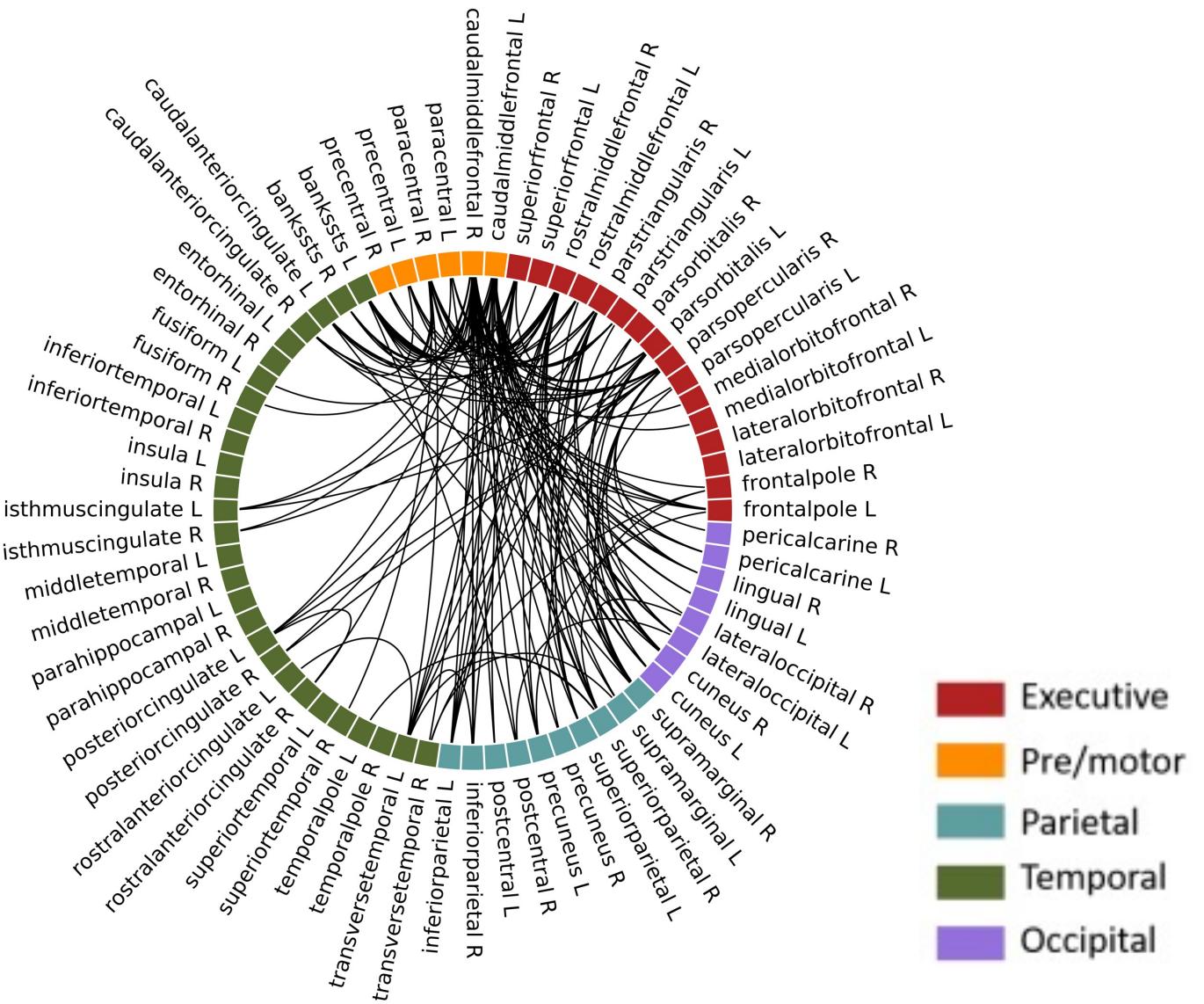


# Differences in transition probabilities discriminate mental states

16



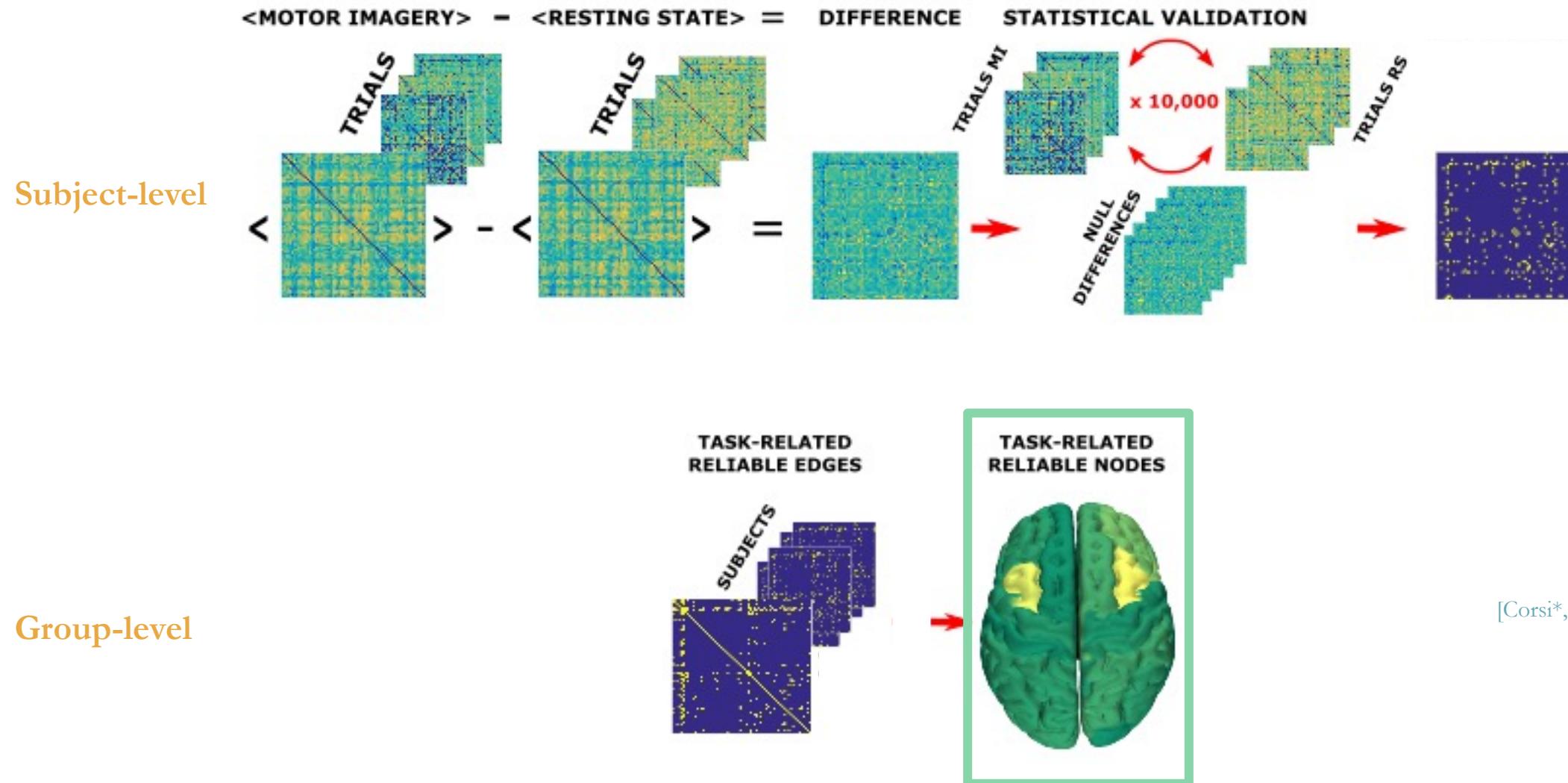
=



Task-related differences are in edges hinging on pre/motor areas (in most subjects)

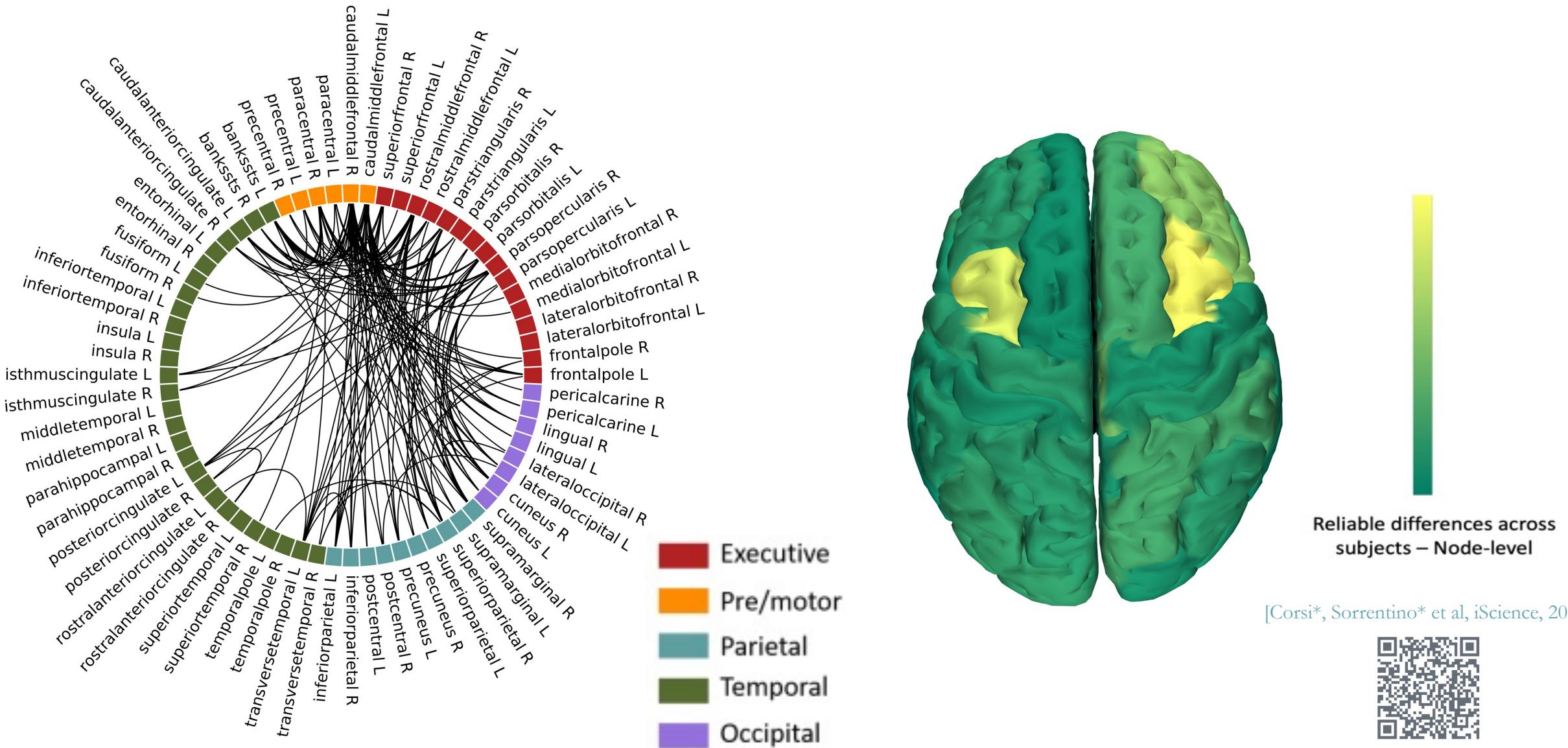
## Differences in transition probabilities discriminate mental states

17



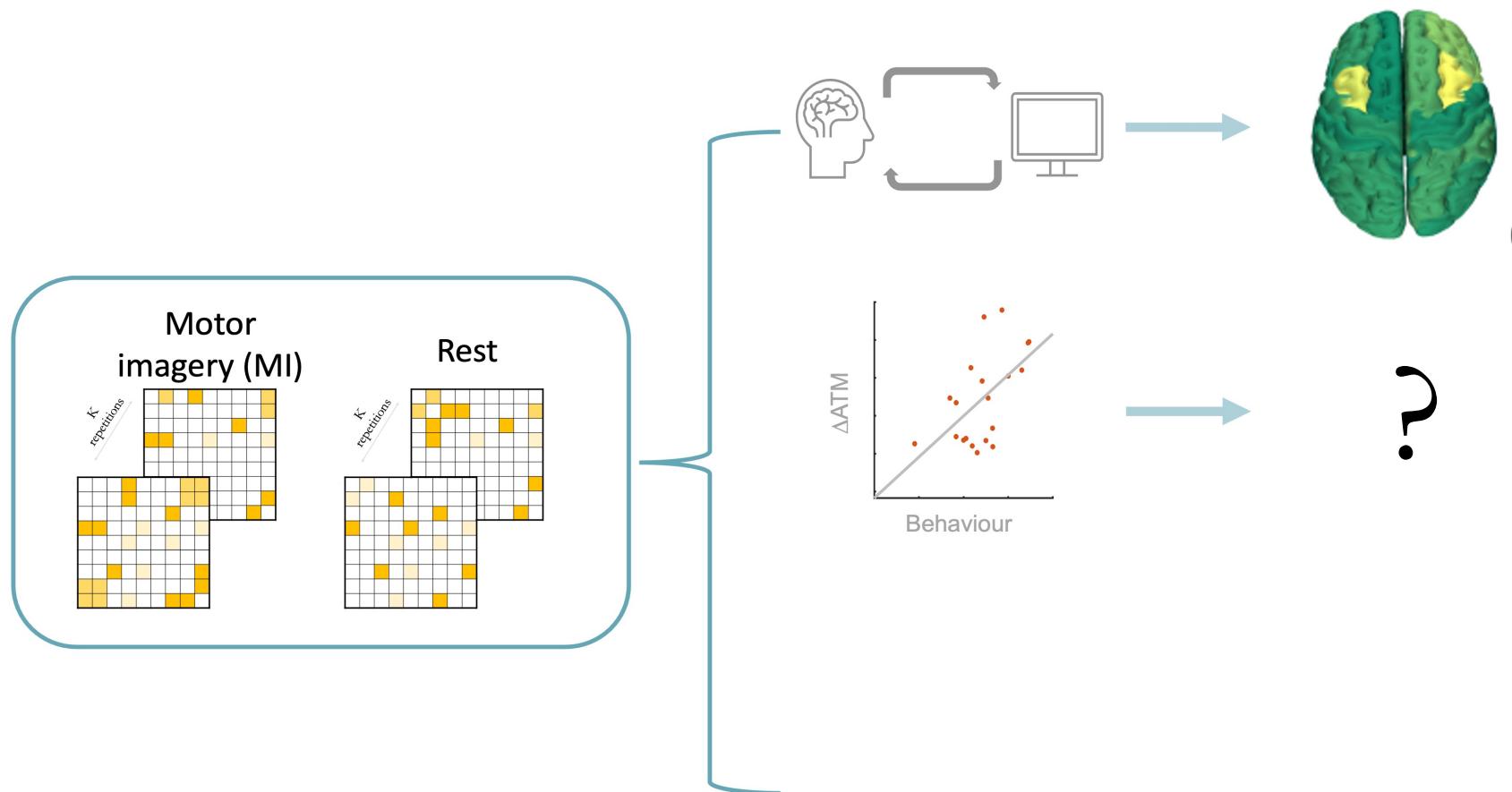
# Differences in transition probabilities discriminate mental states

18



# Differences in transition probabilities relate to BCI scores

19

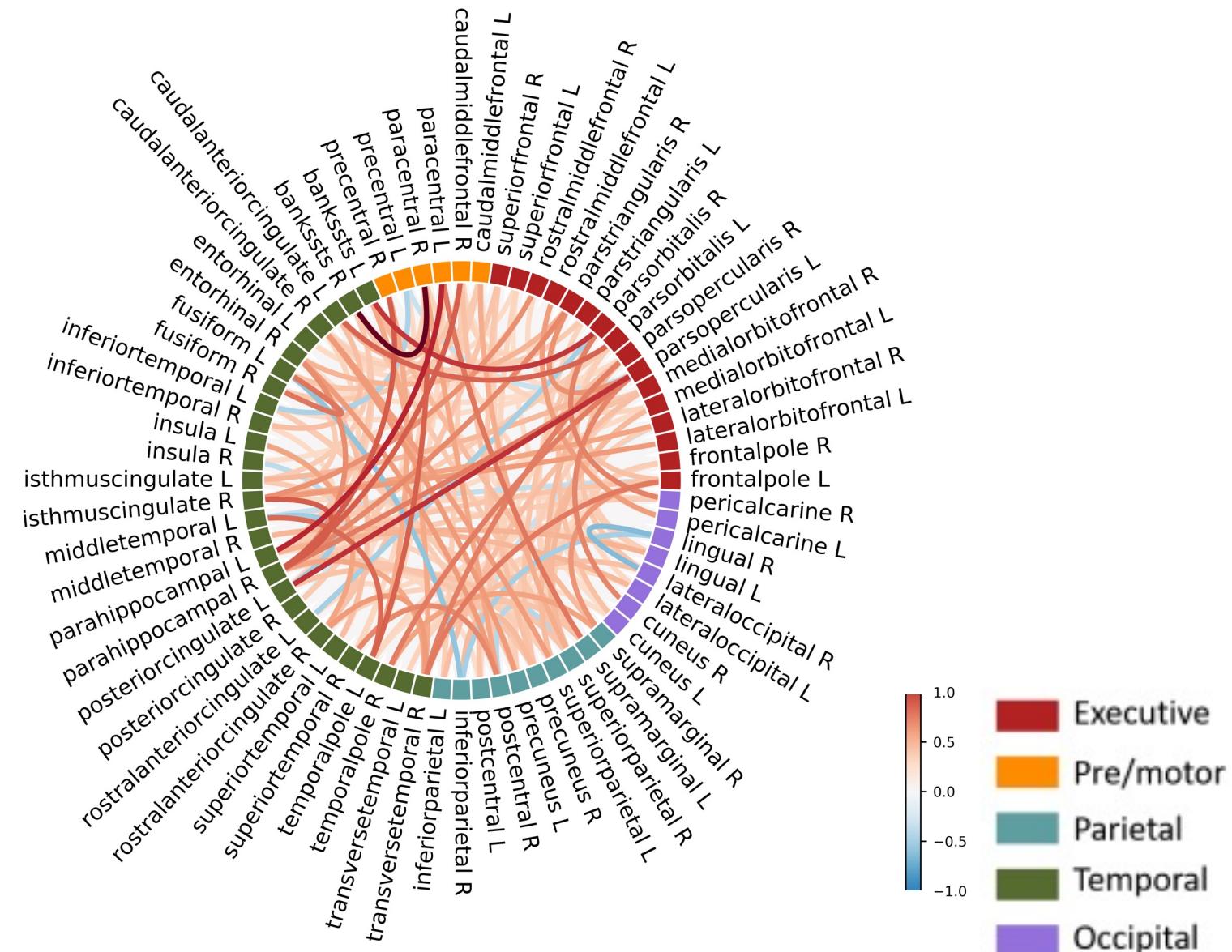
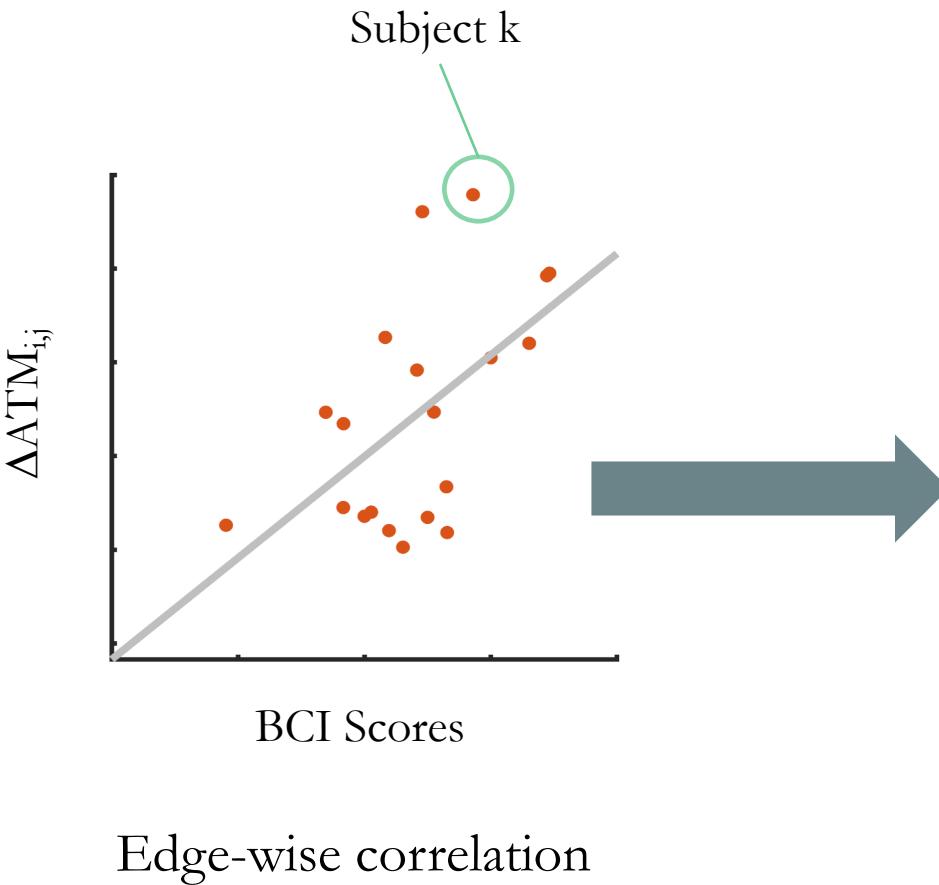


[Corsi\*, Sorrentino\* et al, iScience, 2024]



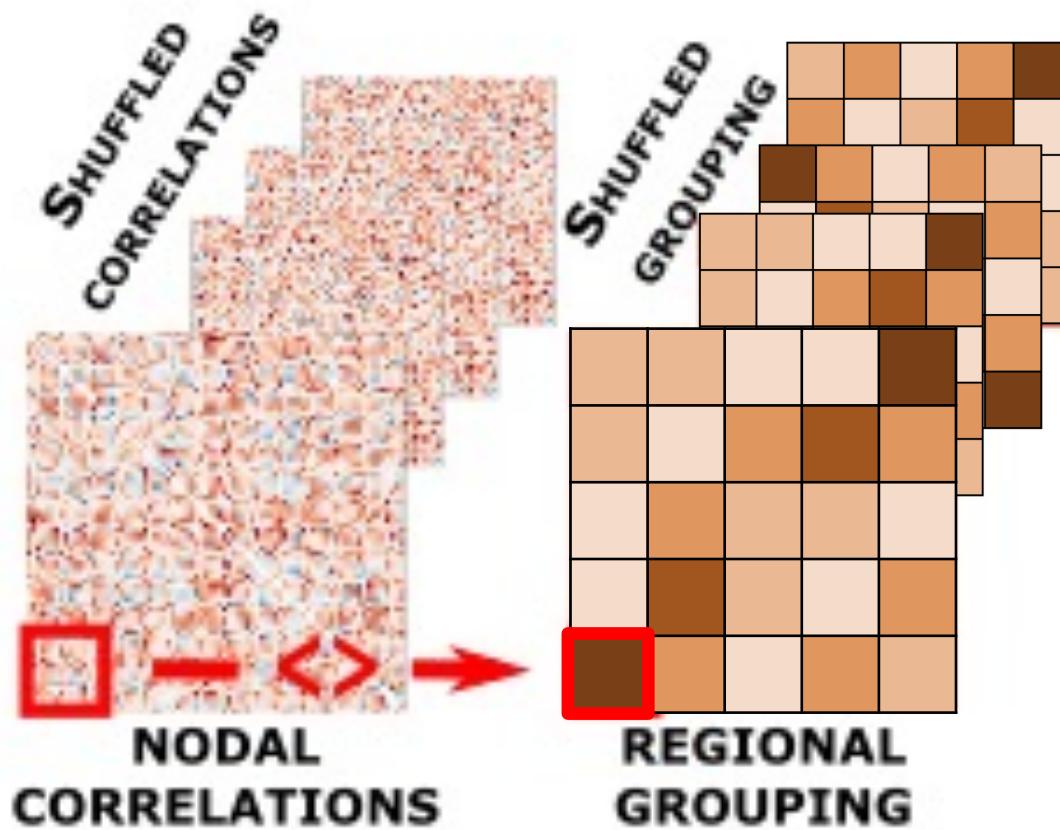
# Differences in transition probabilities relate to BCI scores

20



## Differences in transition probabilities relate to BCI scores

21



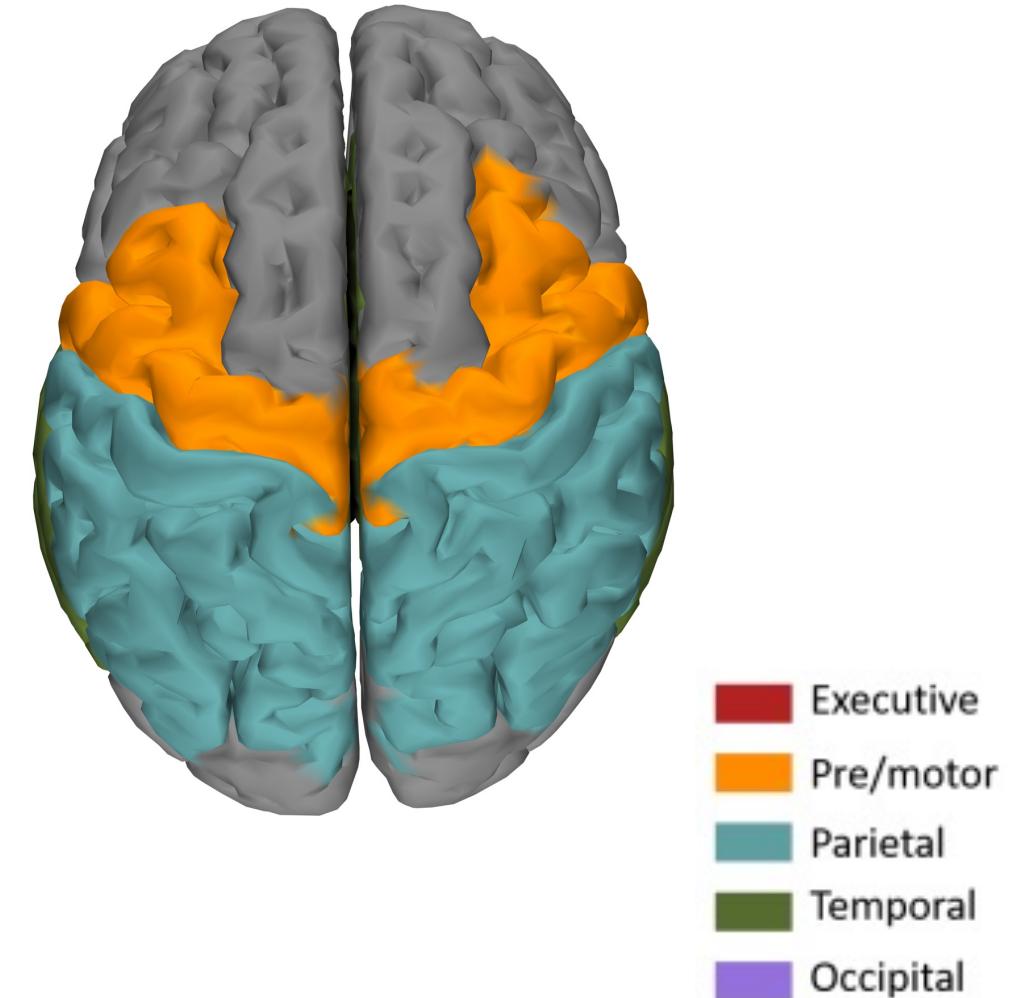
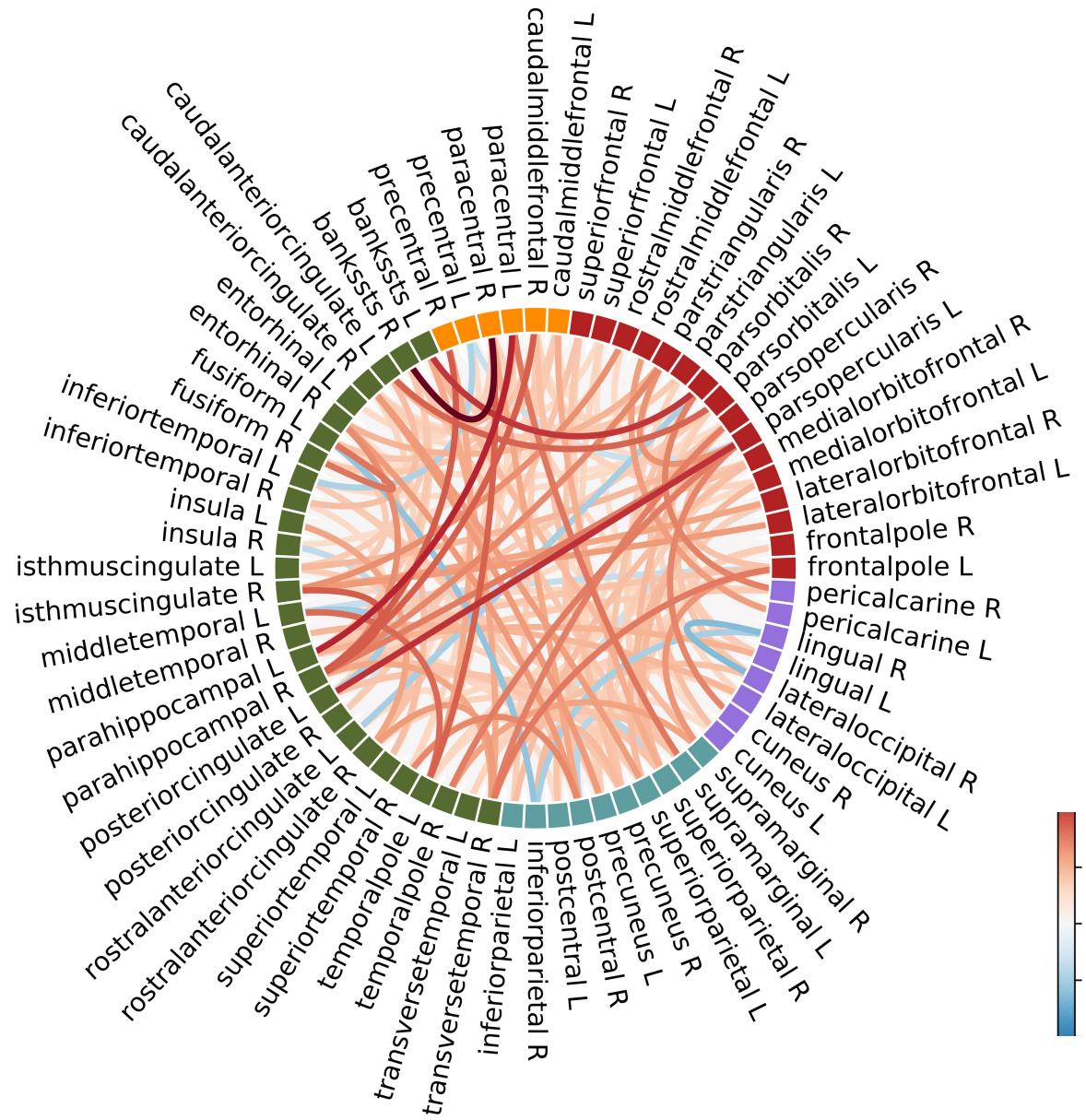
### CORRELATED FUNCTIONAL GROUPS



- Executive (dark red)
- Pre/motor (orange)
- Parietal (teal)
- Temporal (green)
- Occipital (purple)

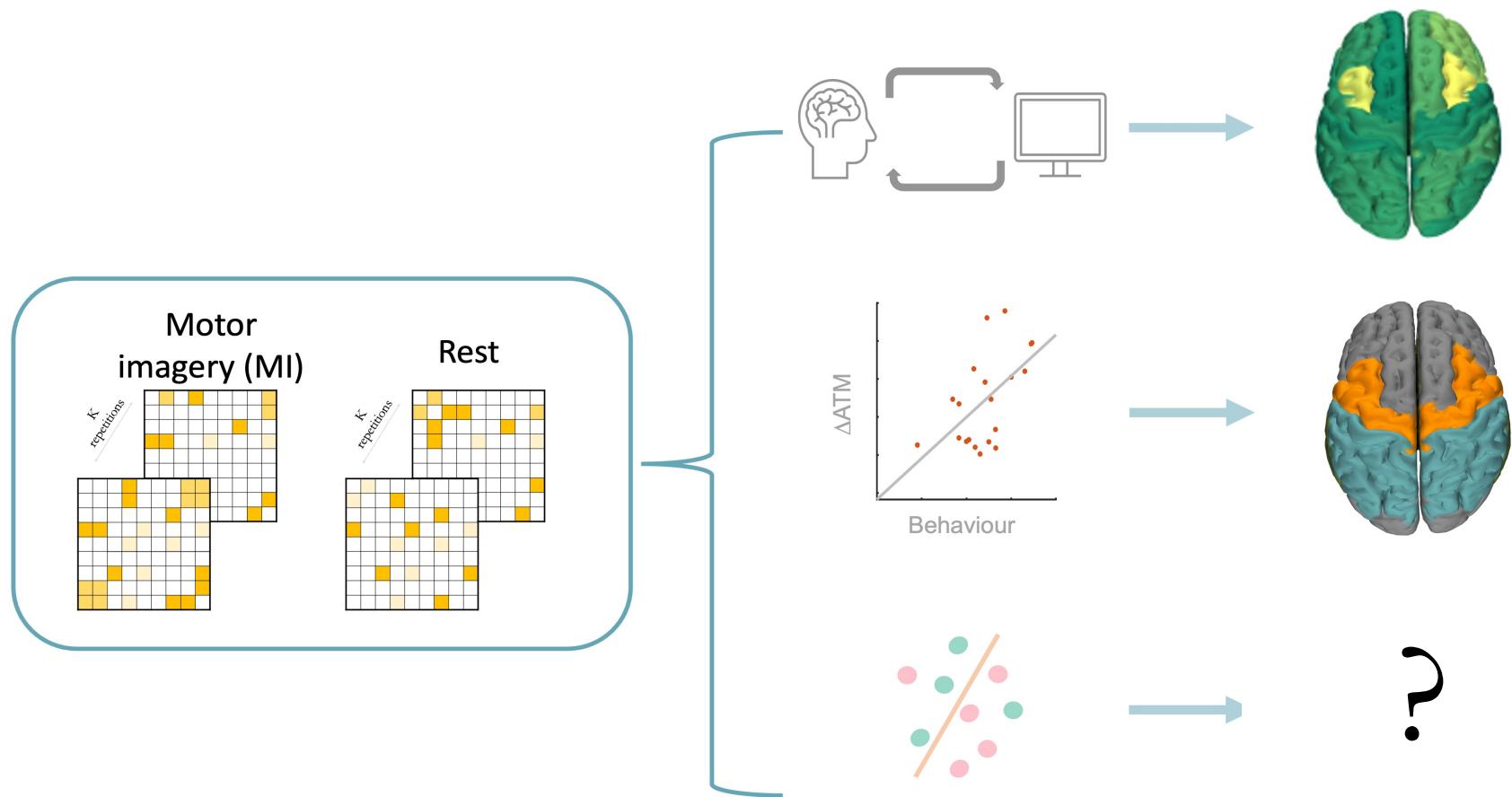
# Differences in transition probabilities relate to BCI scores

22



# Transition probabilities as alternative features for BCI

23



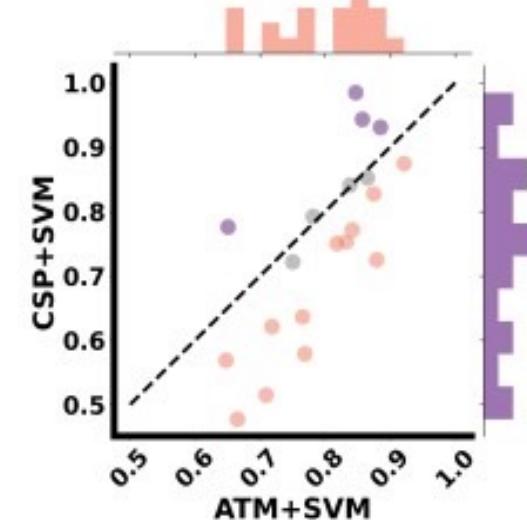
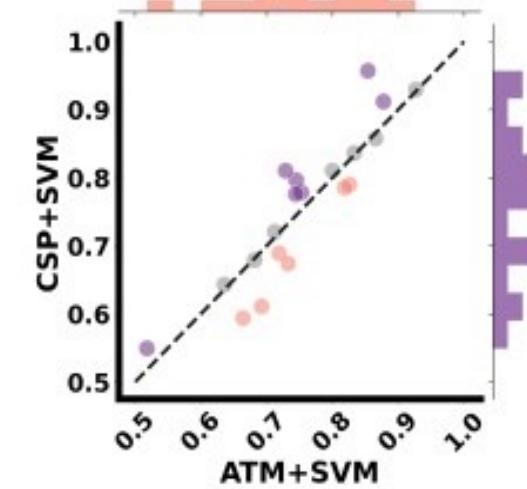
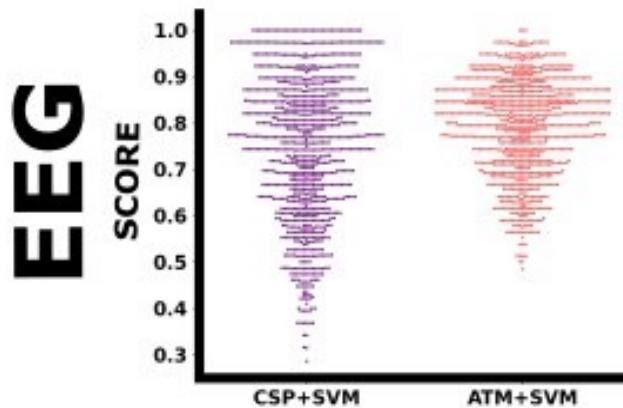
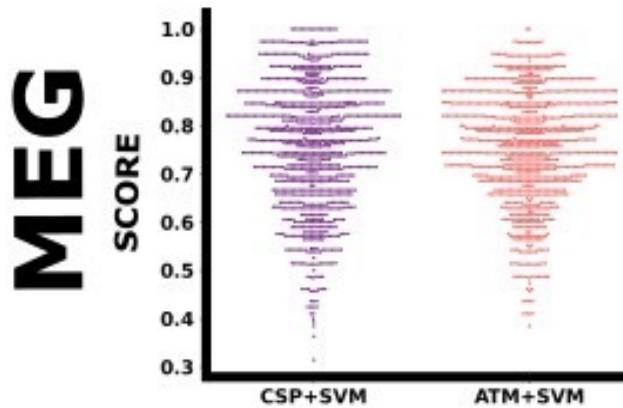
[Corsi\*, Sorrentino\* et al, iScience, 2024]



# Transition probabilities as alternative features for BCI

MEG

EEG



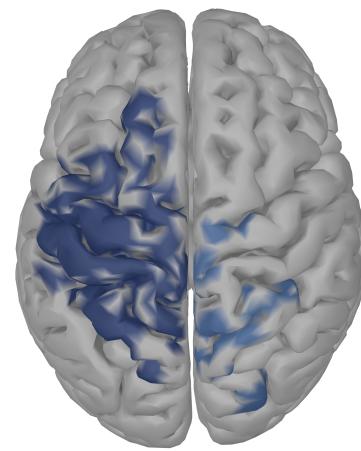
- signif
- equals
- ATM+SVM better
- CSP+SVM better

[Corsi\*, Sorrentino\* et al, iScience, 2024]

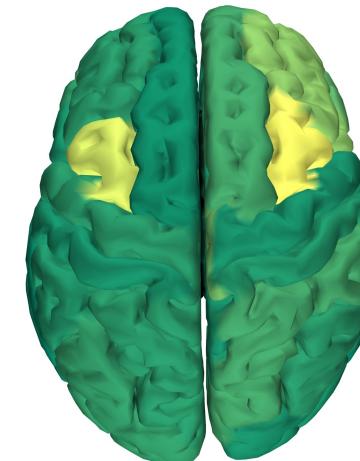


Reliable functional information of task performance retrieval

- Meaningful information communication among regions on the large-scale & aperiodic and scale-free perturbation



Power spectra  
significant at **group** level



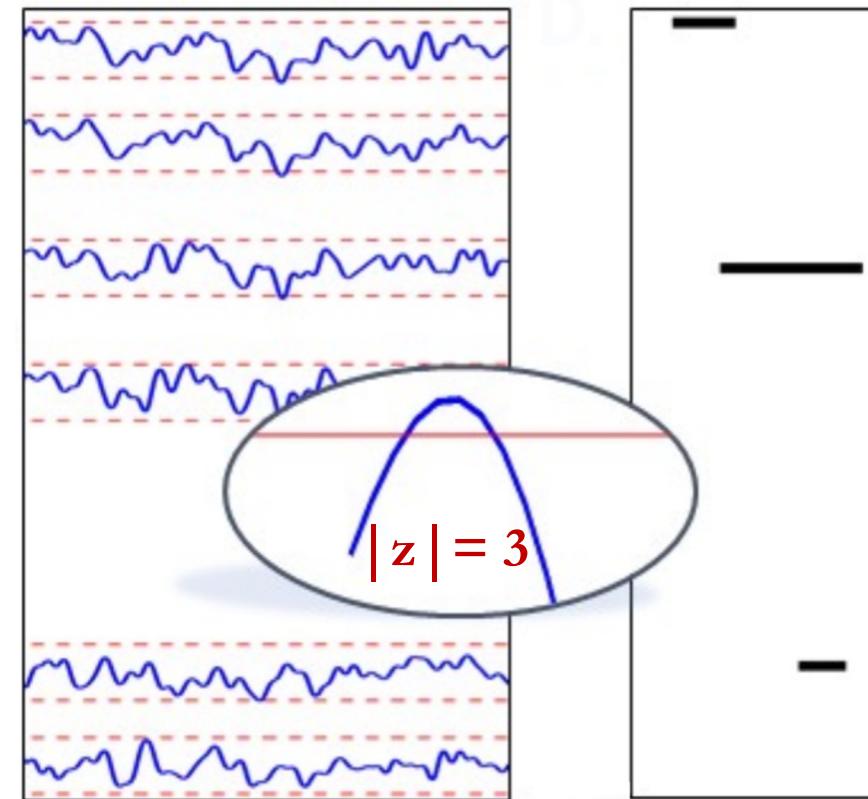
Neuronal avalanches  
significant at **individual** level



⇒ Tracking changes in perturbation spreading while performing different tasks via the avalanches transition matrices

Reliable functional information of task performance retrieval

- Meaningful information communication among regions on the large-scale & aperiodic and scale-free perturbation

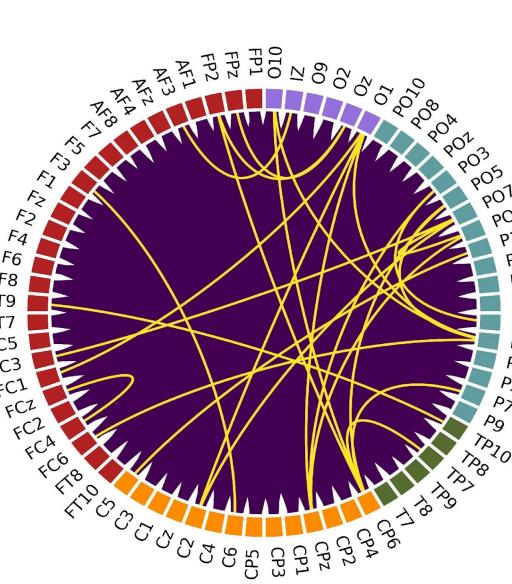
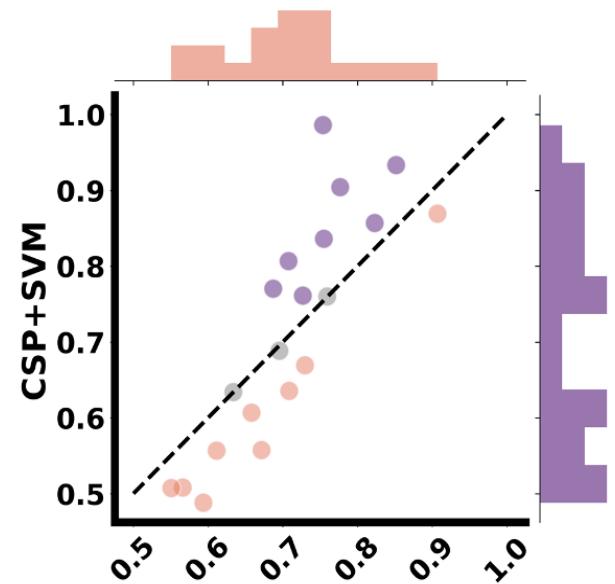


⇒ Focusing on higher-order perturbations to capture functionally-relevant processes & reliable information

# Reliable functional information of task performance retrieval

# Building innovative BCI protocols based on ATMs

- Outperforms the benchmark in EEG – gold standard in BCI → one step closer to the implementation
  - Need to further investigate more suited classification methods



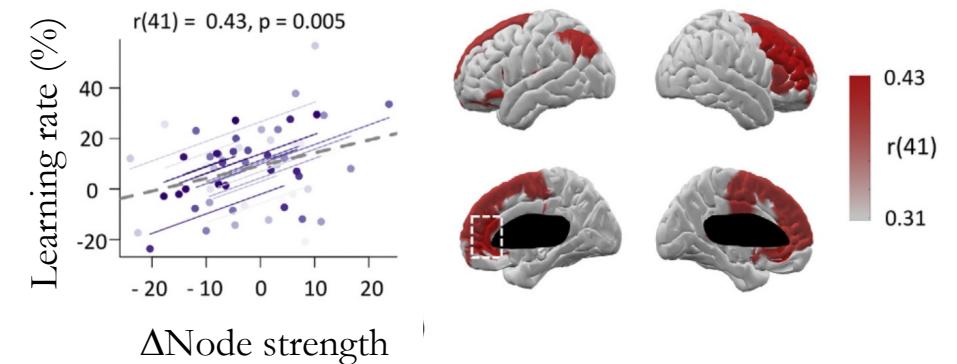
C. Mannino

## Reliable functional information of task performance retrieval

- Meaningful information communication among regions on the large-scale & aperiodic and scale-free perturbation
- Building innovative BCI protocols
  - Tracking changes in perturbation spreading while performing different tasks
  - Focusing on higher-order perturbations to capture functionally-relevant processes & reliable information

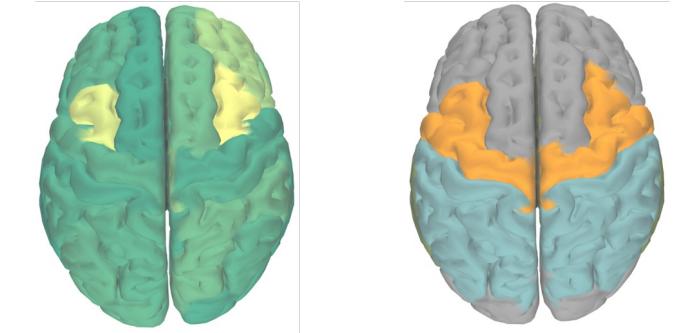
## Markers of BCI performance

- Current predictors of BCI
  - Local measurements – power spectra (Ahn et al, 2015) → replicability issues
  - Time-averaged brain interactions (Sugata et al, 2014) & Brain networks metrics [Gonzalez-Astudillo et al, JNE, 2020] → online implementation?
    - node strength & learning process [Corsi et al, NeuroImage 2020]
    - core-periphery properties & multimodal integration [Corsi et al, JNE 2021]
- Spreading of neuronal avalanches
  - Patterns behaviorally meaningful (Chialvo et al, 2010)
  - Computational fast marker



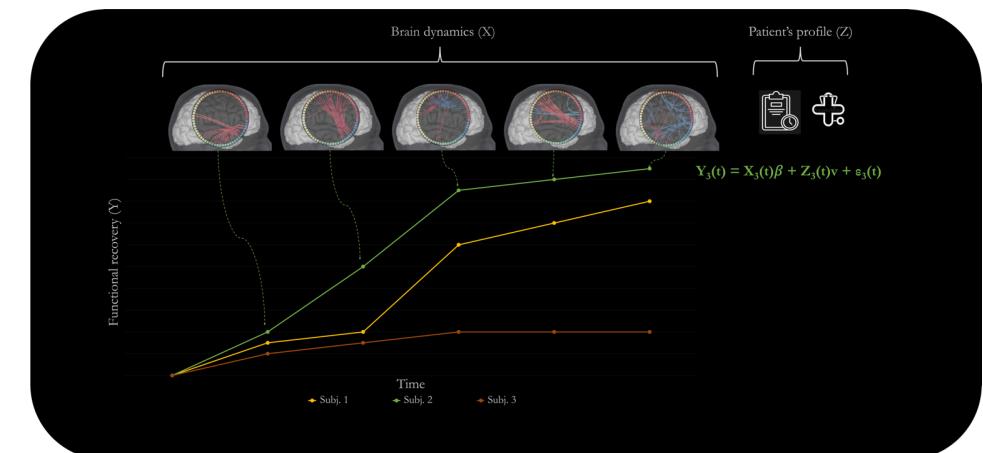
## Implication of the results

- New task performance & changes in paths of propagation of the neuronal avalanches
- Robust topography of the edges involved during BCI performance
- Positive correlations between individual differences related & BCI scores
- Analysis replicated – robustness of our framework



## Perspectives

- Innovative BCI protocols relying on ATMs
- Brain dynamics as potential predictors of BCI performance
- Additional tool to predict the BCI training outcome



## Paris Brain Institute

Camilla Mannino,  
Tristan Venot  
Mario Chavez,  
Denis Schwartz,  
Nathalie George,  
Laurent Hugueville,  
Christophe Gitton  
Sophie Dupont,  
Juliana Gonzalez-Astudillo,  
Fabrizio De Vico Fallani



## Penn University

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Ankit Khambhati,  
Jennifer Stiso,  
Arnold Campbell,  
Danielle S. Bassett (PI)



## Institut de Neuroscience des Systèmes

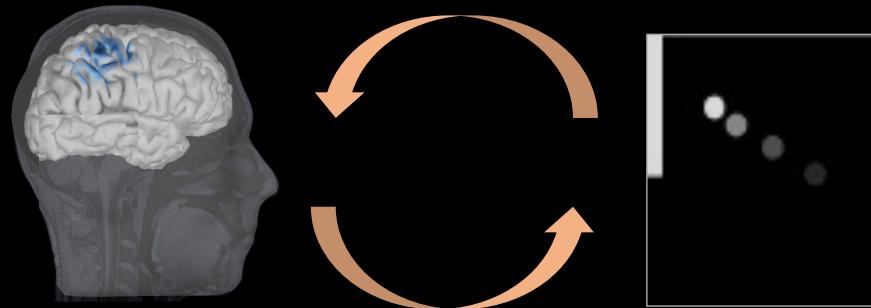
Pierpaolo Sorrentino,

Viktor Jirsa



Institut de  
Neurosciences des  
Systèmes

Thank you for your attention!



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MConstanceCorsi



[mccorsi](https://github.com/mccorsi)