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► To cite this version:

Camilla Mannino, Mario Chavez, Pierpaolo Sorrentino, Marie-Constance Corsi. Neuronal avalanches for EEG-based motor imagery BCI: robustness of classification performance & validity of feature selection. Journées CORTICO 2024, May 2024, Nancy, France. <hal-04621936>

HAL Id: hal-04621936

<https://hal.science/hal-04621936v1>

Submitted on 24 Jun 2024

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Neuronal avalanches for EEG-based motor imagery BCI: robustness of classification performance & validity of feature selection

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INTRODUCTION

Multiple studies reported that 15%–30% of the subjects fail in controlling a BCI device. This is a phenomenon referred to as the “BCI inefficiency”

Among the potential causes of this phenomenon are the features used. Indeed, by relying mostly on local measurements they might not fully capture the brain functioning that also consists in interactions between areas.

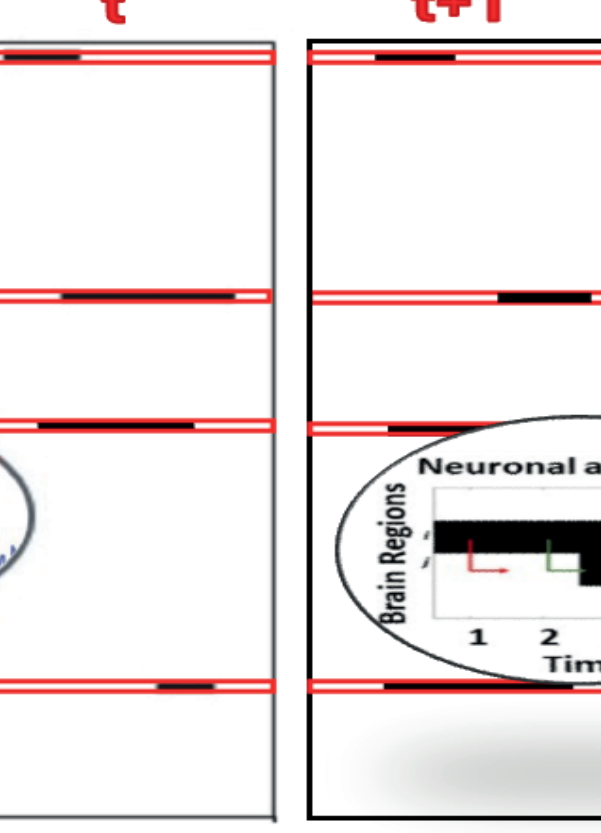
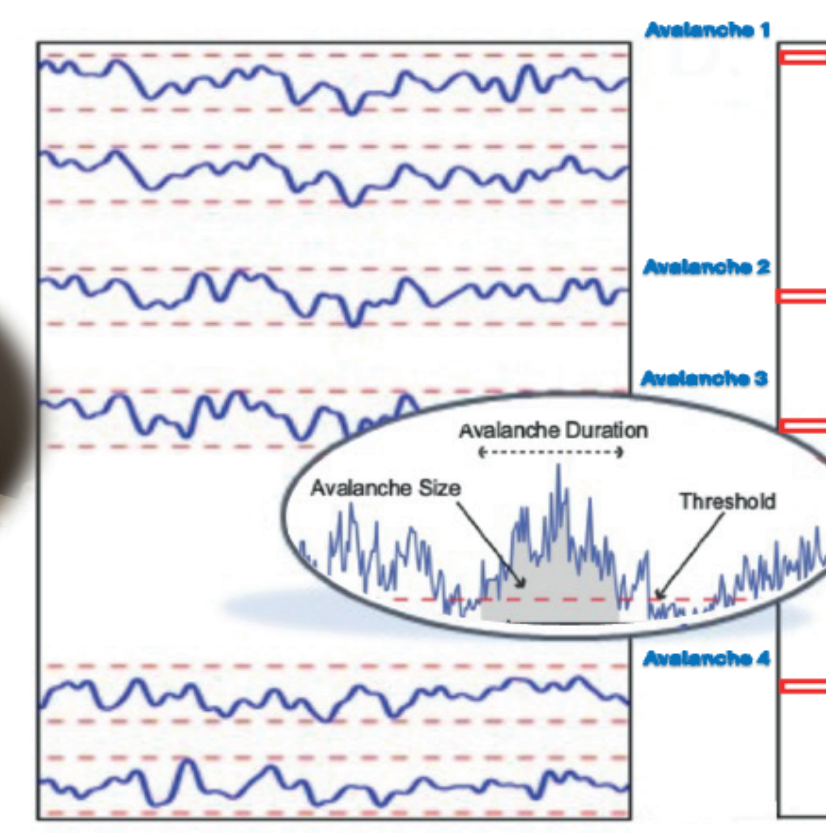
To overcome these limitations in recent researchs we proposed to use a metric that captures the dynamic nature of the brain activity: **the neuronal avalanches**.

METHOD

Motor Imagery BCI Re-grasp protocol

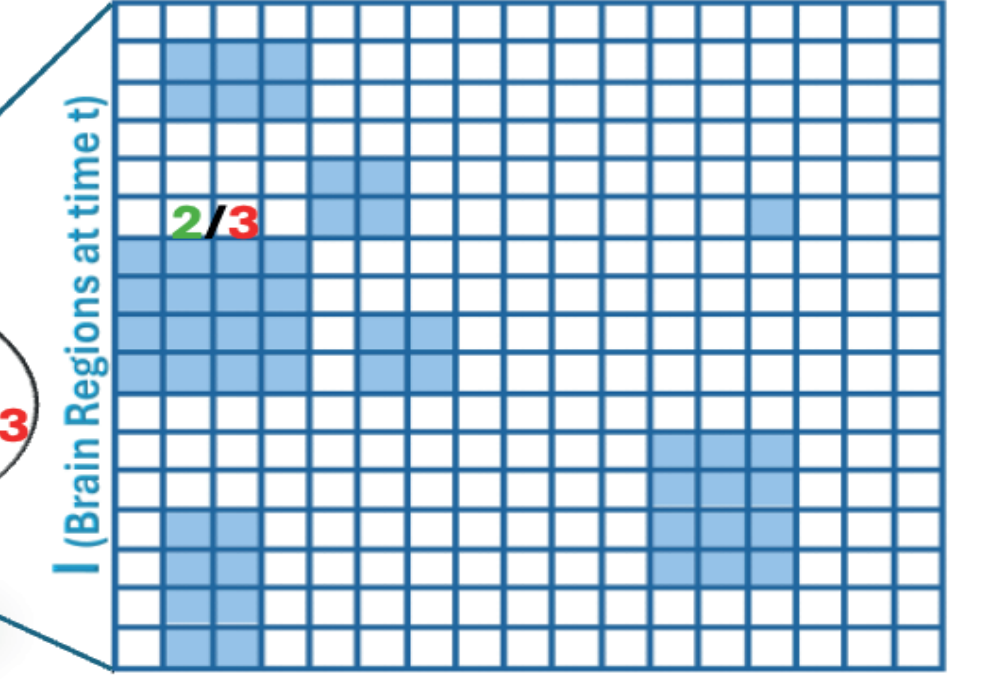


20 Subjects EEG data



Avalanche Transition Matrix (ATM)

J (Brain Regions at time t+1)



RESULTS

CLASSIFICATION PERFORMANCE

AT GROUP LEVEL:

In **sensor-space**: larger inter-subject variability with **CSP+SVM (71%+/-15%)** VS **ATM+SVM (71% +/- 9%)**.

In the **source-space**: **ATM+SVM (80%+/-8%)** VS **CSP+SVM (75%+/-14%)** (t-test, pval<0.05) statistical improvement and a reduced inter-subject variability.

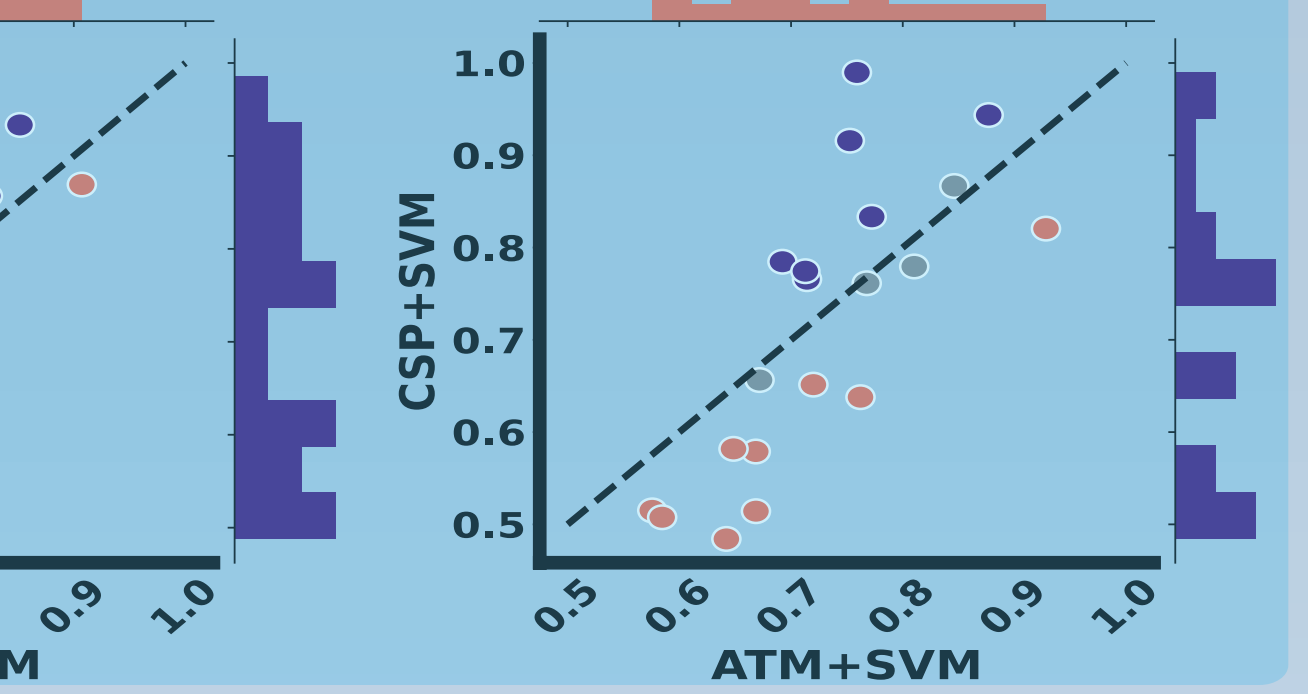
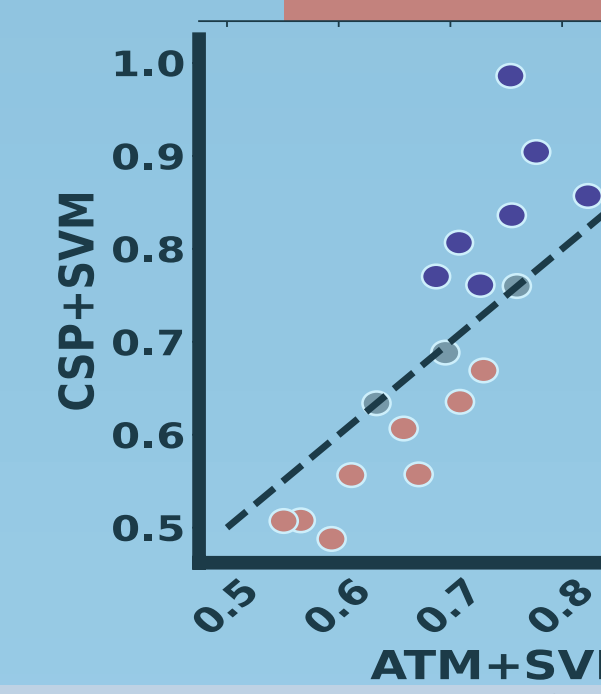
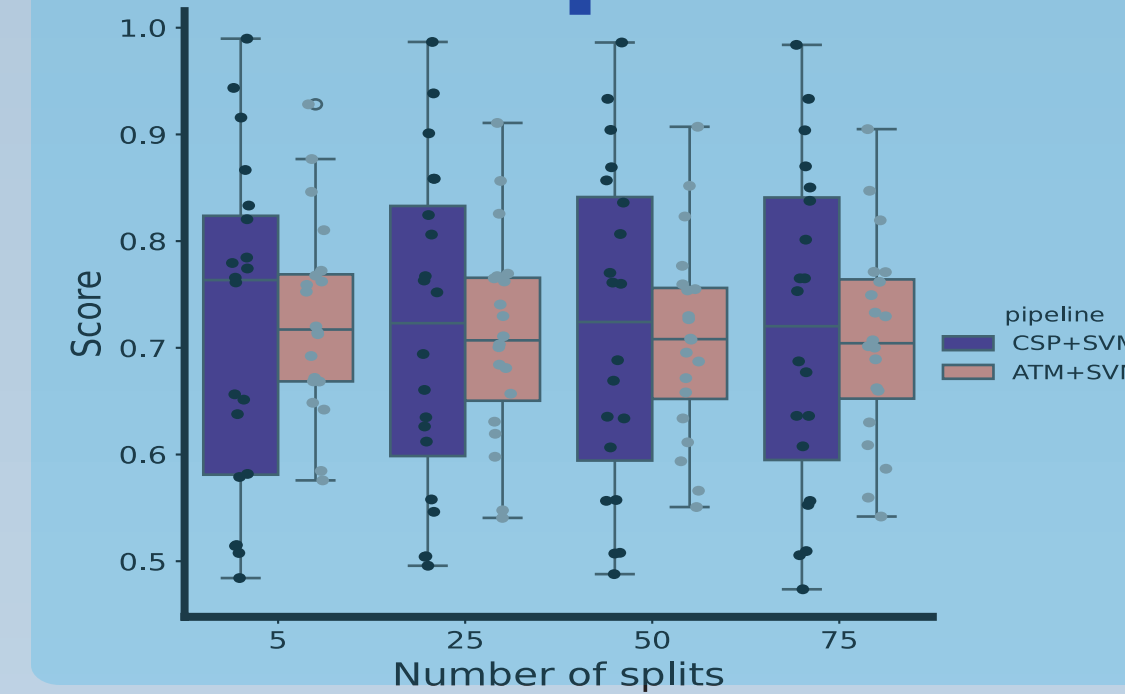
Performance was **robust across splits** for both CSP+SVM and ATM+SVM pipelines (one-way ANOVA p>0.05), It gives us the possibility to **closely mimic a real-time setup**.

AT SUBJECT LEVEL:

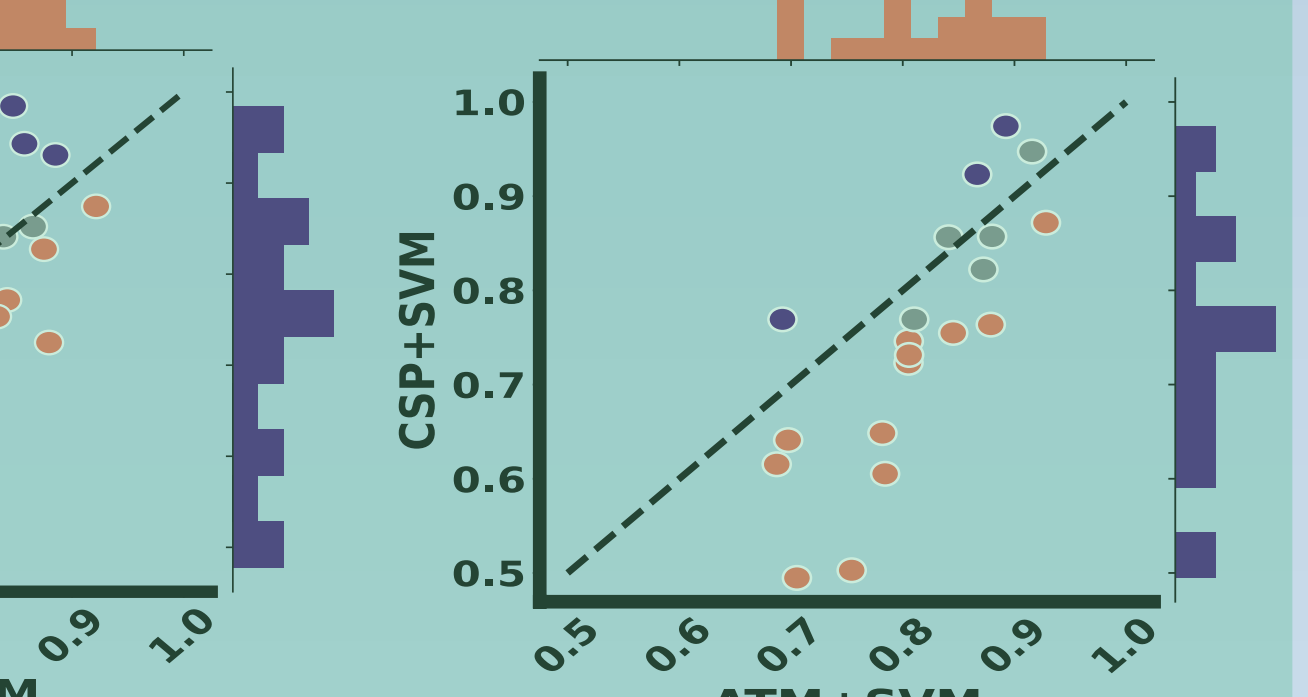
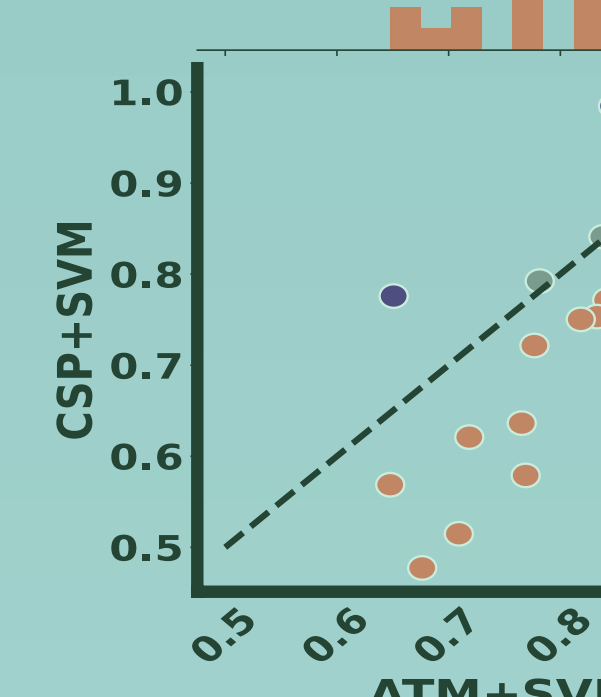
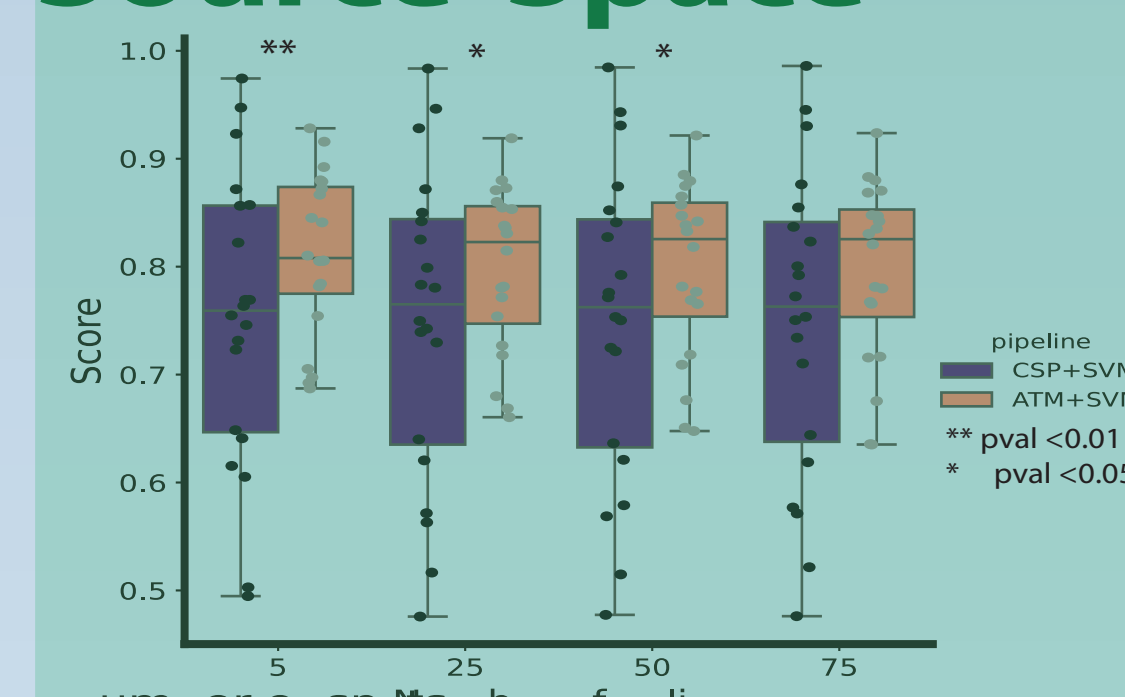
In **sensor-space** CSP+SVM pipeline led to a **larger number of subjects** with a performance **below the chance level**, set to 58% here (6 subjects) with respect to ATM+SVM (1 subject).

EEG source-reconstructed data, ATM+SVM demonstrated **superior performance in 12 subjects**, whereas the opposite was observed in 3 subjects with CSP+SVM

Sensor-space



Source-Space

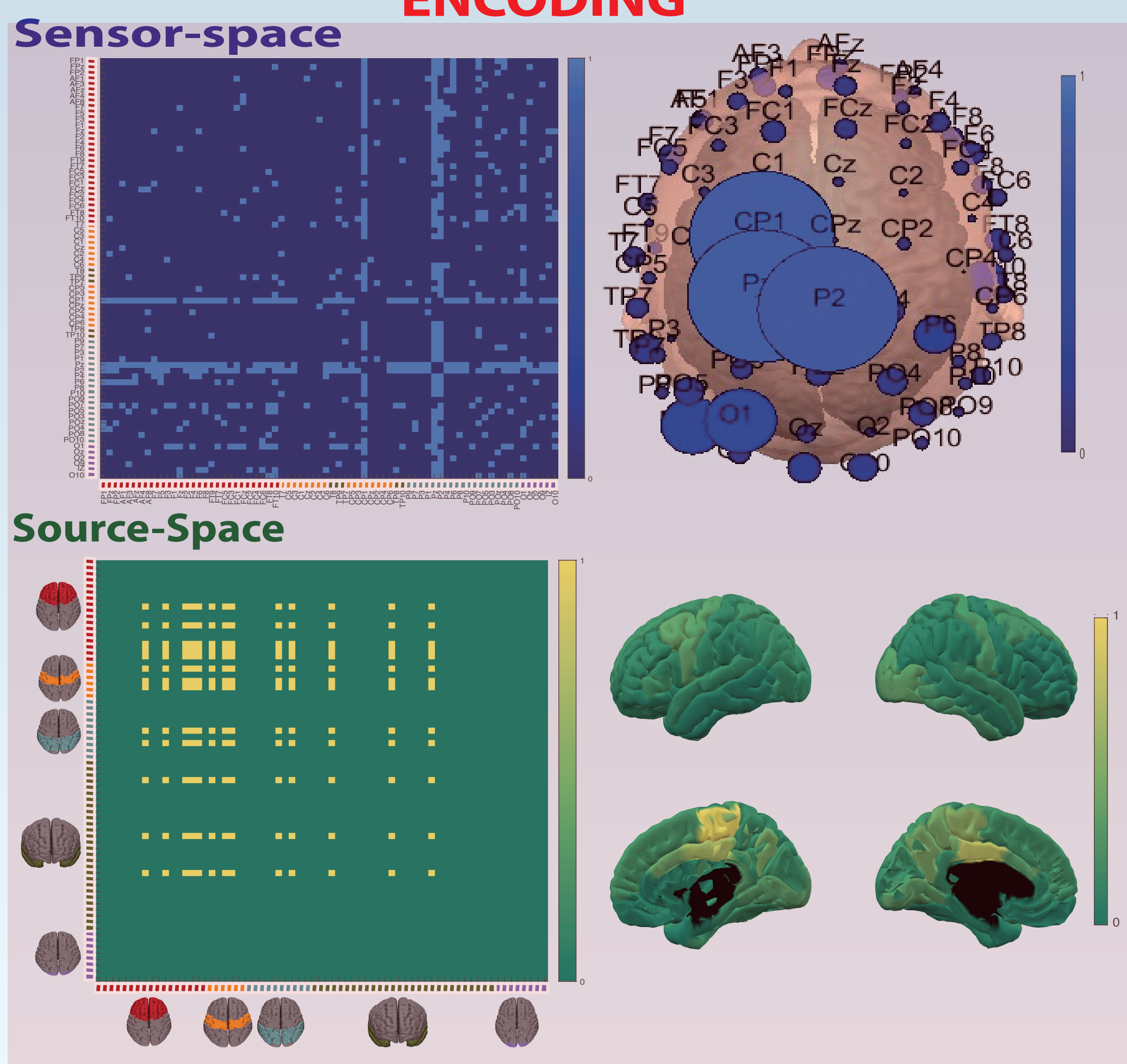


What we can observe directly from the data

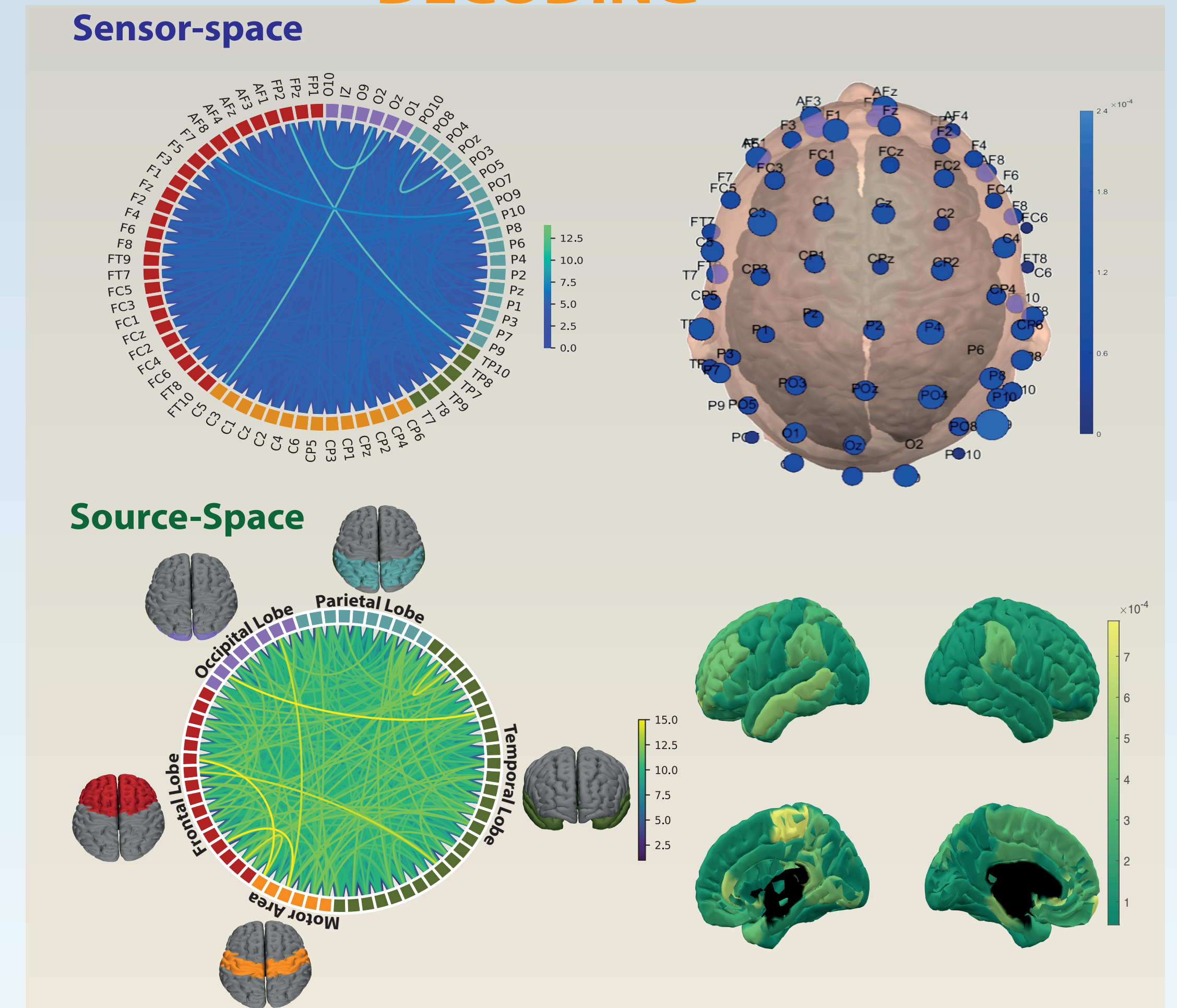
FOCUS ON ATM PIPELINE

Features selected in classification algorithm

ENCODING

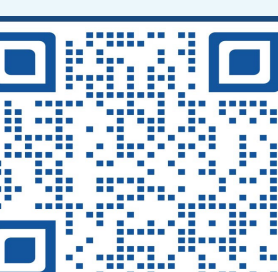


DECODING



Reliably edges identified in encoding framework & selected by classification algorithm

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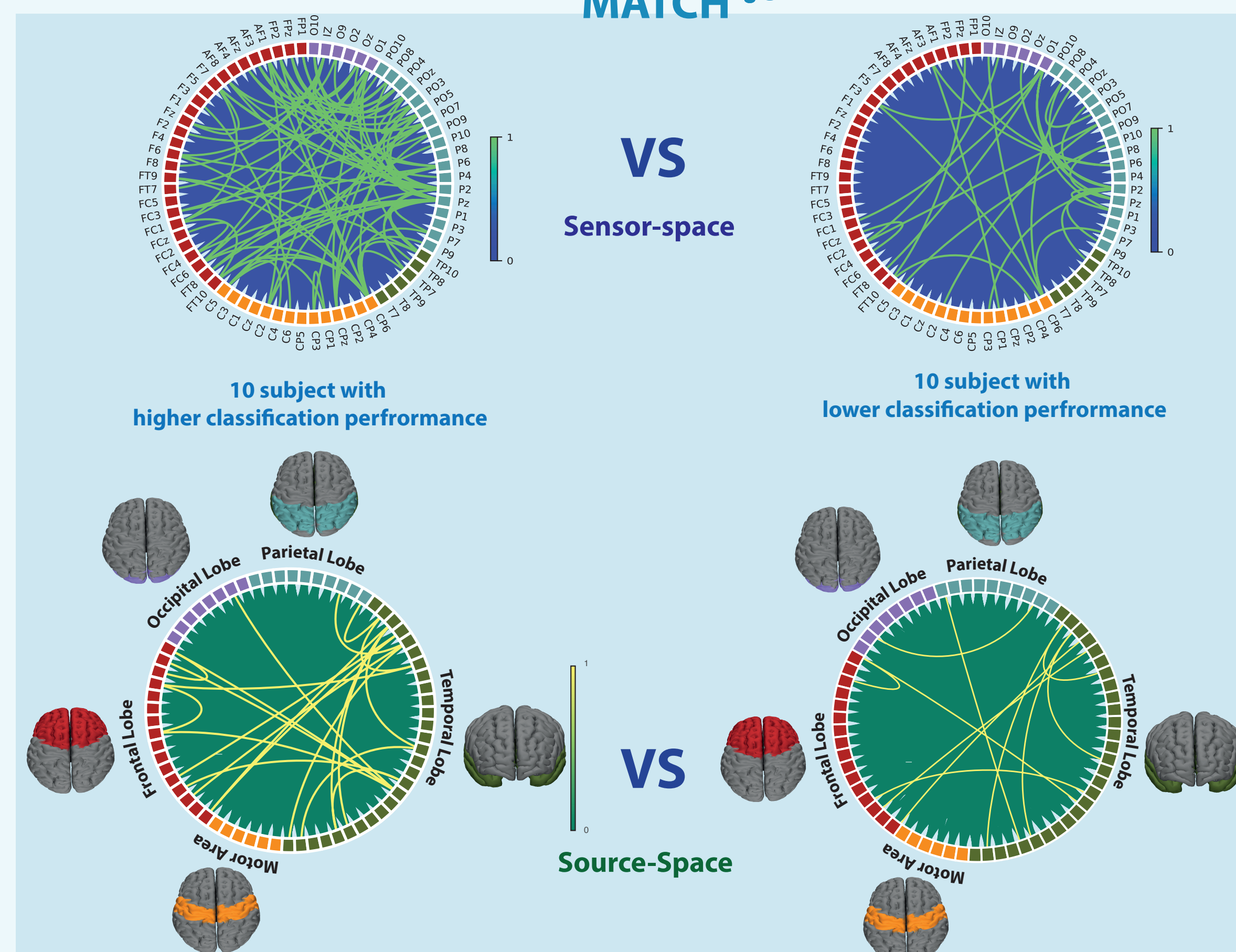


Comparison Sensorspace & Sourcespace

The most frequently selected features involved **central electrodes (C-CP)** at sensor-space, as the **paracentral area** in the source-reconstructed data implying **left motor-area**.

Our observations, obtained applying the ATM method, suggest that working in the **sensor space could provide enough spatial resolution** to perform the classification and to identify the reliably functional connections with a simpler framework than in the source space. Nevertheless, for deeper analysis investigating the **involvement of precise regions of interest**, work in the **source space would be advisable**.

MATCH



Comparison Encoding vs Decoding

Comparison between the reliability edges and features selected with hugest weight. denoted a **higher level of match score with the ten subjects with a highest classification performance** as compared to the ten subjects with the lowest classification performance.

37% (Highest) vs 6% (Lowest) in Sensor-Space
48% (Highest) vs 24% (Lowest) in Source-Space

This finding suggests a possible way to apply a **dimensionality reduction in the features used in the decoding step**, to **improve classification performance and to reduce the computational time** as well.

CONCLUSION

Our observations suggest that the **integration of periodic and aperiodic features** would be a straightforward way to capture functionally relevant processes. Hence, **neural avalanches** could be apply to the **design of BCIs** and to **improve task classification**. The good performance of the ATMs on the EEG data is relevant to **translate our methodology to real-world scenarios**.

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