

Mirror-Box Pretraining to Evoke Sensorimotor Activation to Facilitate Motor Imagery Detection in Brain-Computer Interface Stroke Rehabilitation

Nina Evetović¹, Roman Rosipal¹, Adrián Hodúr¹, Zuzana Rošáková¹

¹Institute of Measurement Science, Slovak Academy of Sciences E-mail: nina.evetovic@savba.sk



INTRODUCTION

BACKGROUND

Motor imagery (MI)-based BCI rehabilitation relies on modulation of sensorimotor (SM) rhythms, particularly in the alpha and beta bands, to detect motor-related brain activity.

CHALLENGE

MI-BCI calibration after stroke is challenging: affected-limb movement may be limited, while MI is highly individual and difficult to verify, making physiologically meaningful BCI training difficult.

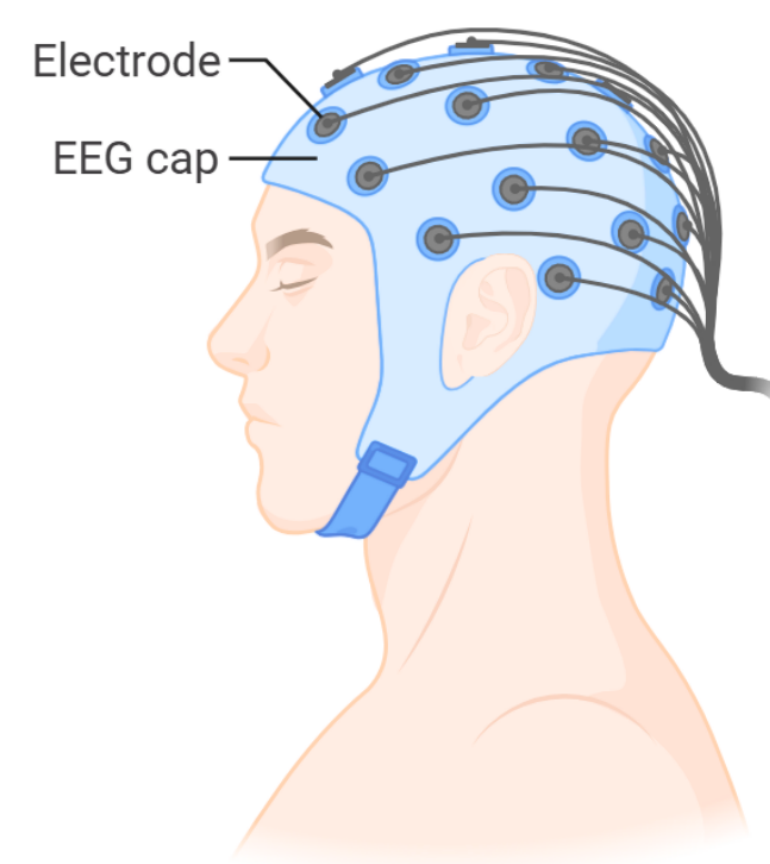
APPROACH

We propose mirror-box (MB) pretraining to evoke physiologically grounded SM activation and identify subject-specific oscillatory components for subsequent MI-BCI detection.

MATERIALS AND METHODS

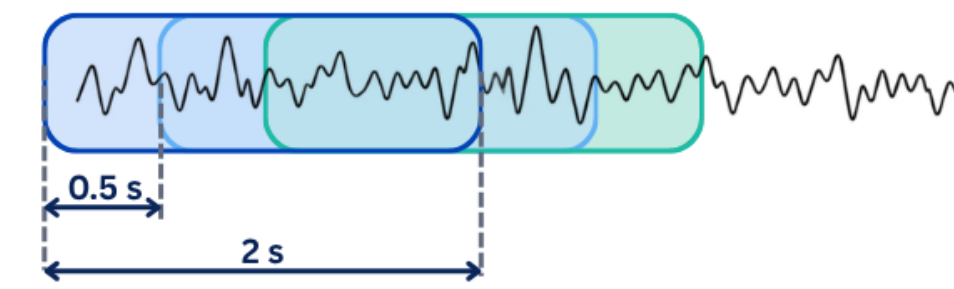
EEG Recording

- g.Nautilus PRO FLEXIBLE
- 19-channels
- International 10–20 system
- Sampling rate: 250 Hz

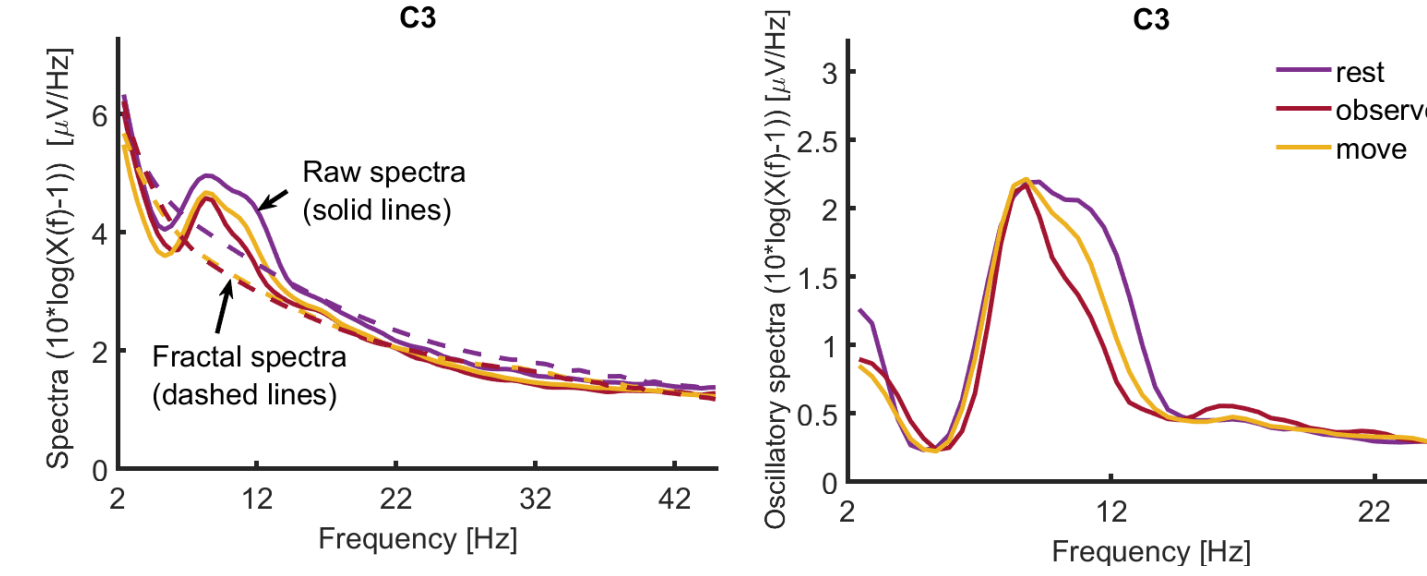


Preprocessing

- Bad-channel interpolation
- Artifact + EMG detection
- Windowing

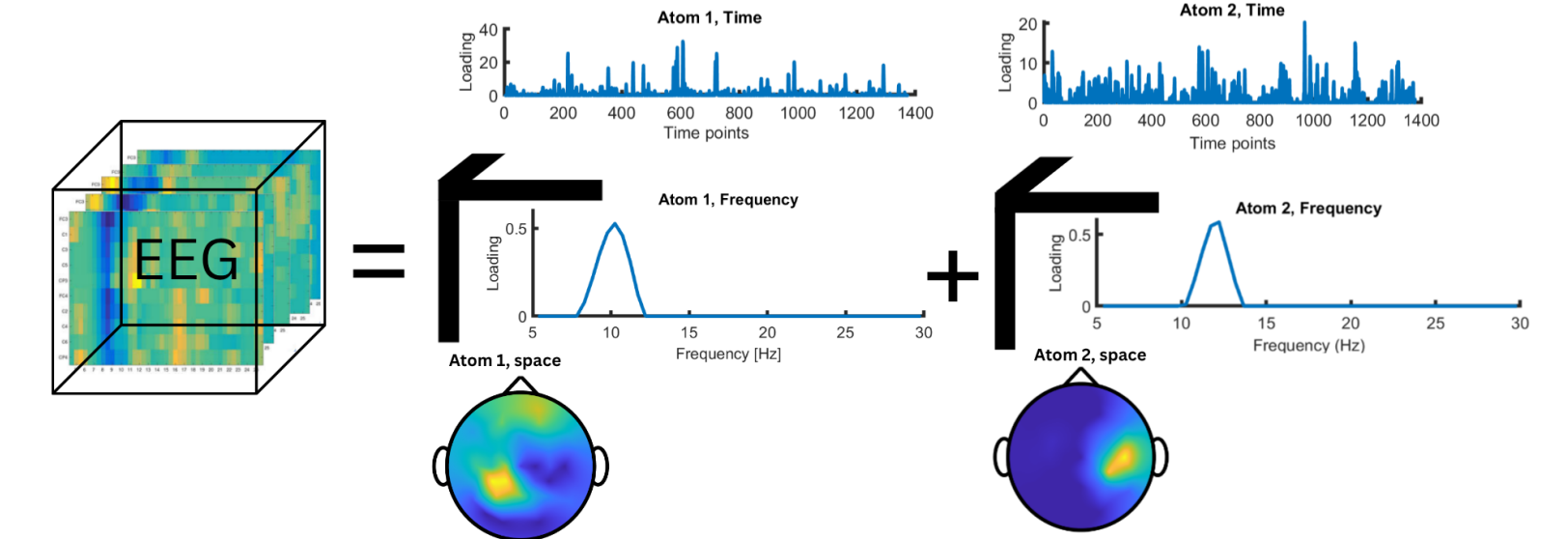


- Irregular Resampling Auto-Spectral Analysis (IRASA)



Tensor Decomposition

- EEG represented as a channels x time x frequency tensor
- Parallel Factor Analysis (PARAFAC) decomposes EEG into components (atoms)

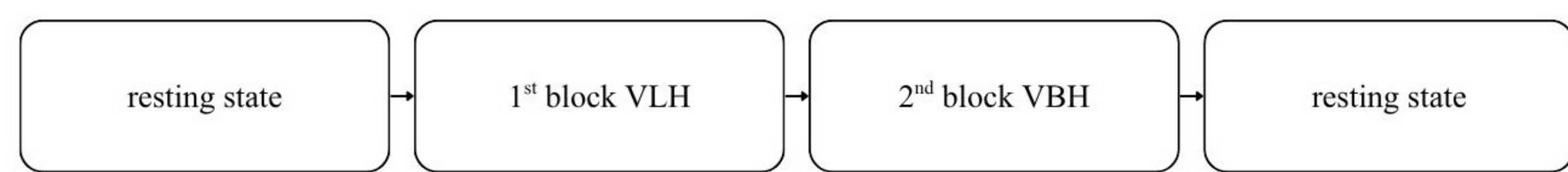
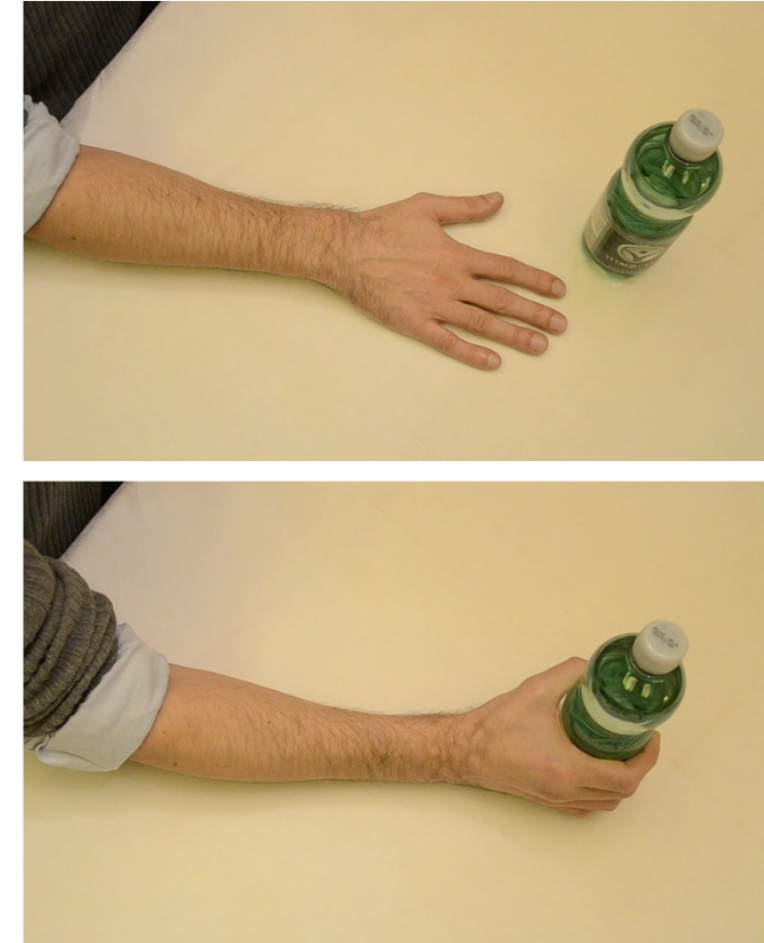


- Each atom characterized by spatial, temporal, and spectral loadings

EXPERIMENT PROTOCOL

Six MB training sessions were recorded. Each session included two MB blocks: Visual Left Hand (VLH) and Visual Both Hands (VBH).

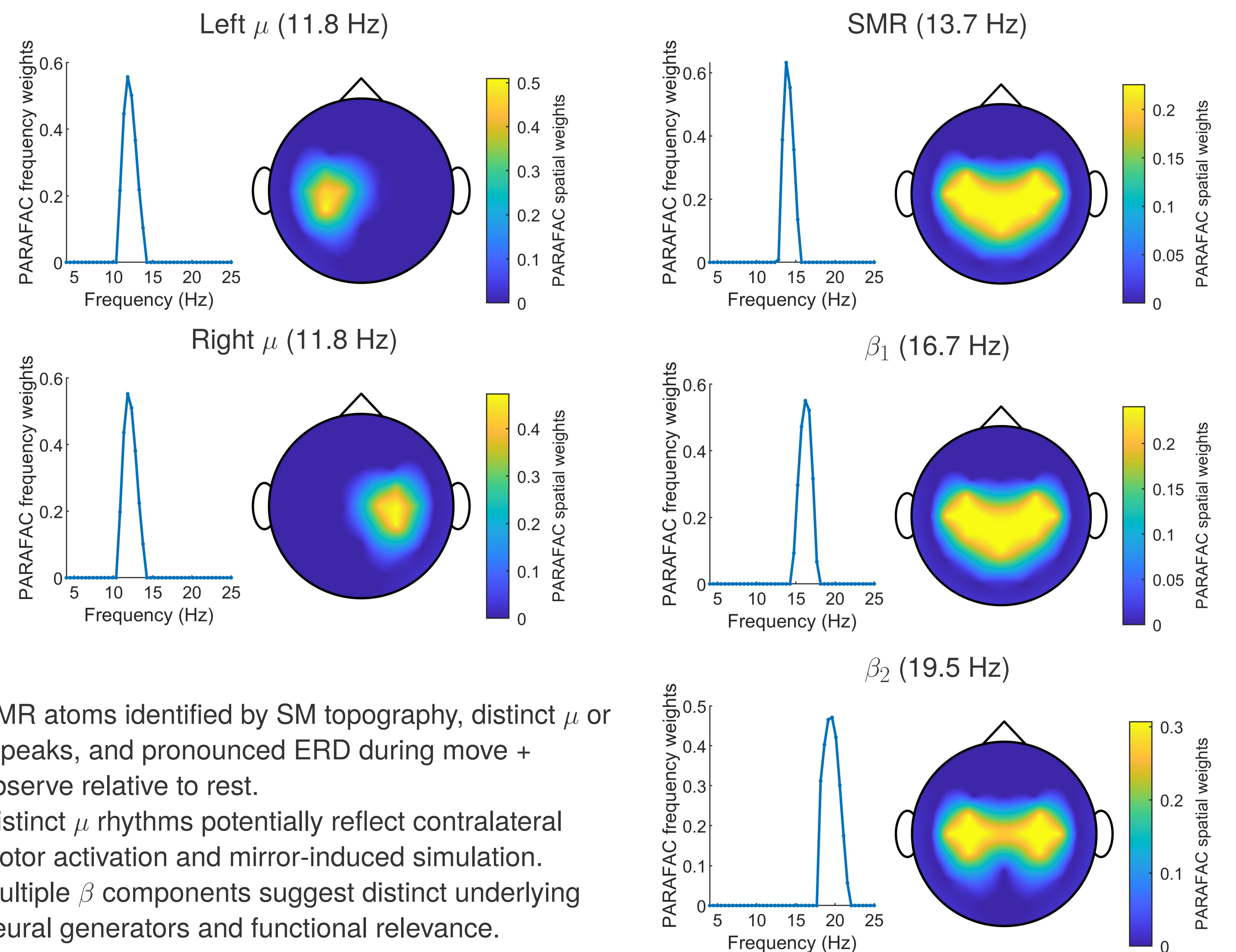
- VLH: participant moved the unaffected hand while observing its mirror reflection.
- VBH: participant additionally attempted synchronous movement with the paretic hand.



Each block included 10 upper-limb movements, performed for approximately 7–10 repetitions. Trials consisted of three functional phases: rest, observe, and move. VLH and VBH trials were pooled to capture diverse motor activations and improve classifier generalizability.

SENSORIMOTOR RHYTHM COMPONENTS

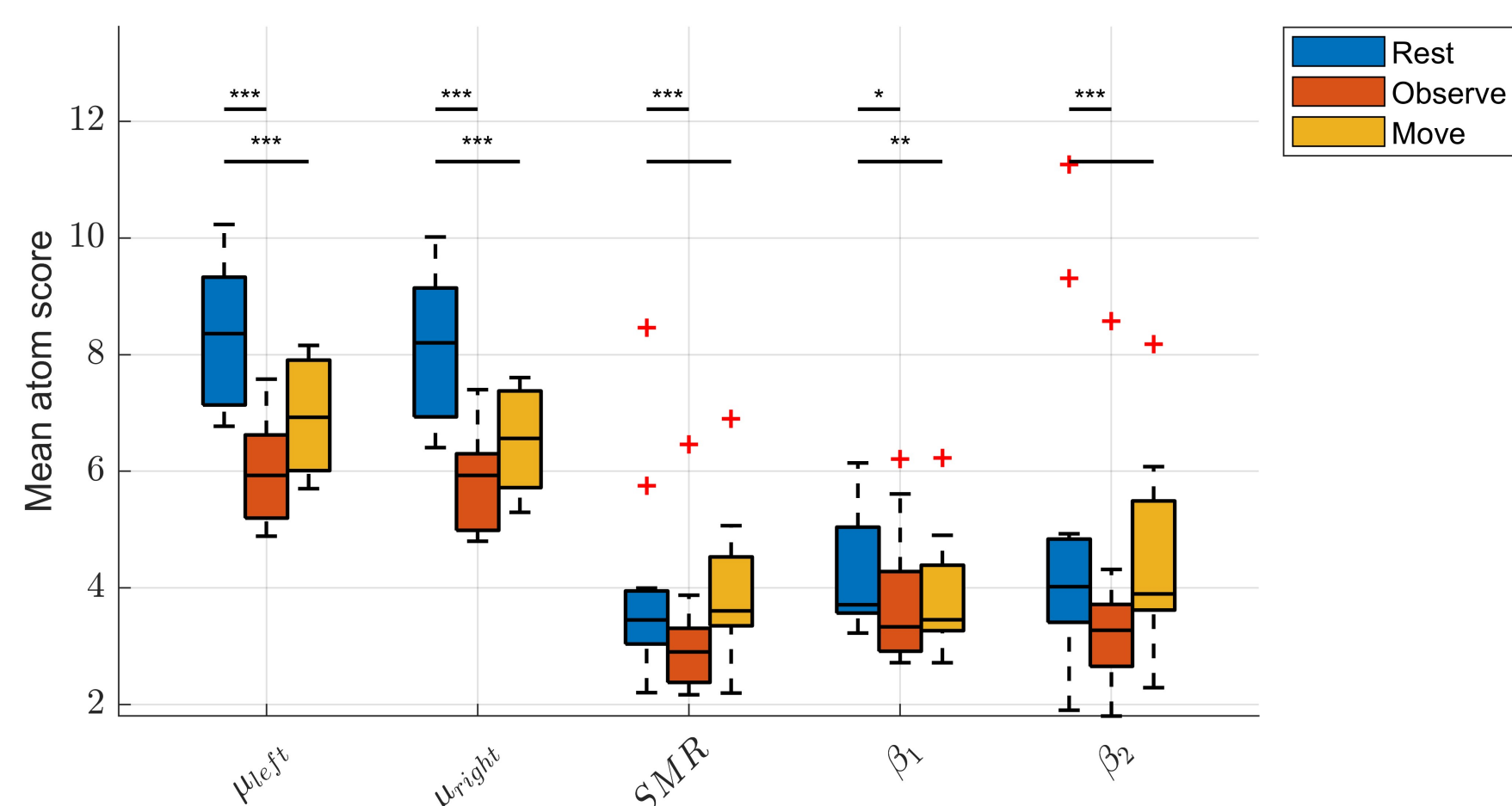
PARAFAC decomposition identified distinct, physiologically meaningful, subject-specific SM μ and β components with task-related modulation.



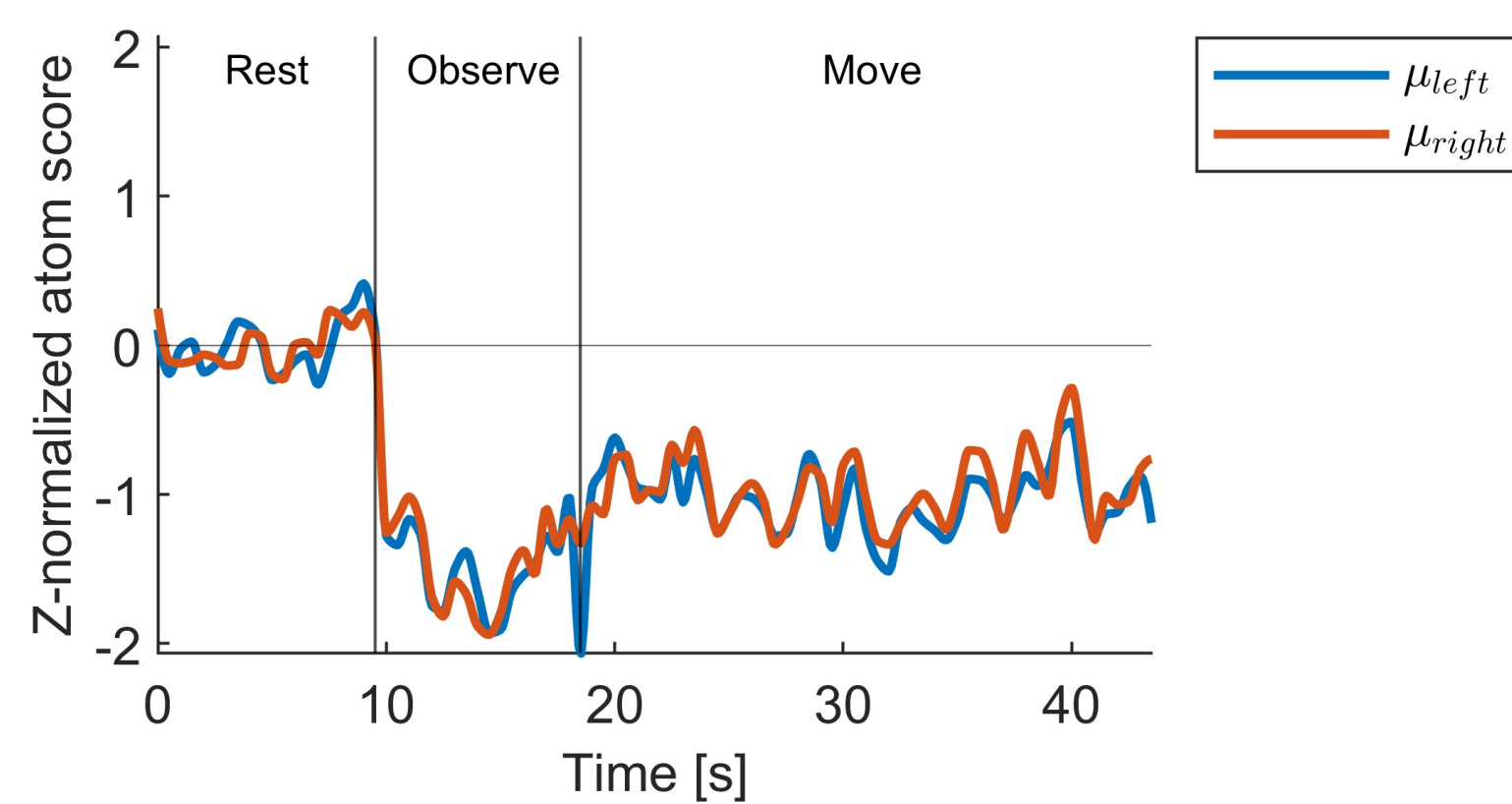
SMR atoms identified by SM topography, distinct μ or β peaks, and pronounced ERD during move + observe relative to rest. Distinct μ rhythms potentially reflect contralateral motor activation and mirror-induced simulation. Multiple β components suggest distinct underlying neural generators and functional relevance.

RESULTS

MB pretraining with PARAFAC enables extraction of subject-specific SMR (μ , β) components in a post-stroke participant.



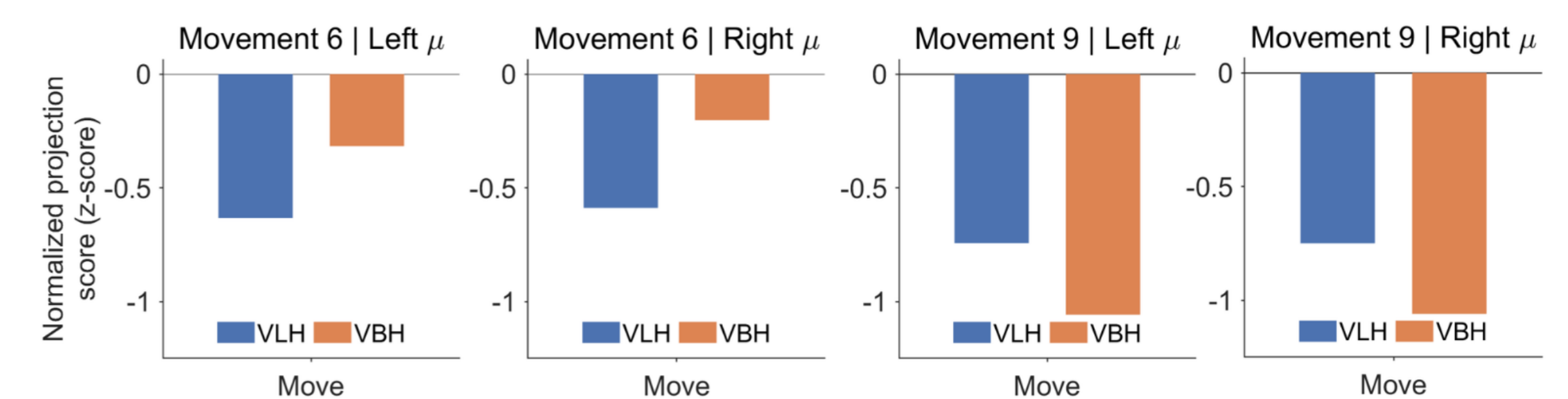
Rest vs. observe/move SM atom scores were compared using Bonferroni-corrected Wilcoxon signed-rank tests ($p < 0.05$, $p < 0.01$, $p < 0.001$).



Strong task-related desynchronization enables near-perfect rest vs. motor discrimination with LDA (98.8% accuracy, AUC = 0.990).

PRELIMINARY CONDITION COMPARISON

A preliminary comparison between experimental conditions (VLH, VBH) was performed to explore possible differences in SM activation.



Some movements show stronger desynchronization in VLH, while others show stronger desynchronization in VBH.

Combining VLH and VBH may capture a broader range of SM activation, yielding more generalizable SMR components for robust BCI pretraining.

CONCLUSION

- MB pretraining combined with PARAFAC decomposition identified physiologically meaningful, subject-specific μ and β SMR components.
- Extracted components showed task-related desynchronization during observation and movement.
- Results support MB pretraining as a promising calibration strategy for MI-BCIs, particularly when voluntary movement is limited.

Future Directions

- Project individualized MB SMR atoms onto MI EEG.
- Learn latent temporal interactions of μ and β components using supervised machine learning.
- Develop transferable, subject-specific representations for improved MI decoding and adaptive BCI calibration.