Classification of Mental Workload Frequential Effects using Riemannian Manifold

A. Choplin[1,2], T. Rakotomamonjy[1], L. Perrinet[2], N. Lantos[1], S. Angelliaume[1]

[1] DTIS, ONERA, Salon-de-Provence, France ; [2] INT, Aix-Marseille Université, France.

Introduction

Goal: Investigate ***frequential effect*** using Riemannian geometry on EEG covariance matrices to classify mental workload levels (low vs. high) in an aeronautical context.

The growing complexity of systems in fields like aeronautics demands understanding operators' ***cognitive states***.

Computing ***covariance matrices*** from ***EEG signals*** and analyzing them using ***Riemannian geometry*** provides a robust and state-of-the-art method for their classification.

Method

Power Spectral Density (PSD)

- ***Notch filter (50 Hz, 60Hz)***
- ***Welch's*** method (4-second time windows with 25% overlap)
- [***0.1–100 Hz***] range

Windowing

- ***Usual*** bands ***without overlap*** *(θ, α, β, γ)*

Model

- *pyRiemann & scikit-learn toolbox*
- Riemannian Minimum Distance to Mean (***RMDM***) classification of ***Spatial Covariance Matrices***
- 15 sensors
  - F_1, F_z, F_2, FC_1, FC_z, FC_2, C_1, C_z, C_2, CP_1, CP_z, CP_2, P_1, P_z, P_2
- ***Shuffle-split cross-validation***
  - 20 folds (80% train)

This research was supported by ONERA and the Provence-Alpes-Côte d'Azur Region.

We gratefully acknowledge Deshayes C., Berberian B., and Ficarella S.C., for providing access to their dataset and granting us permission to utilize it in our study.

Experimental setup

EEG (64 sensors)
N = 16 subjects

Workload Induction

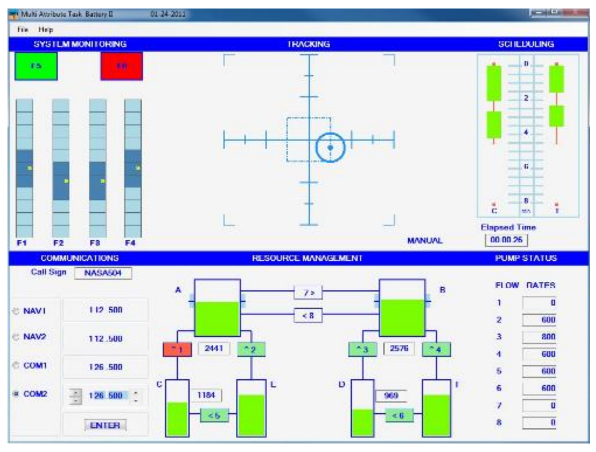
MATB-II task (NASA)

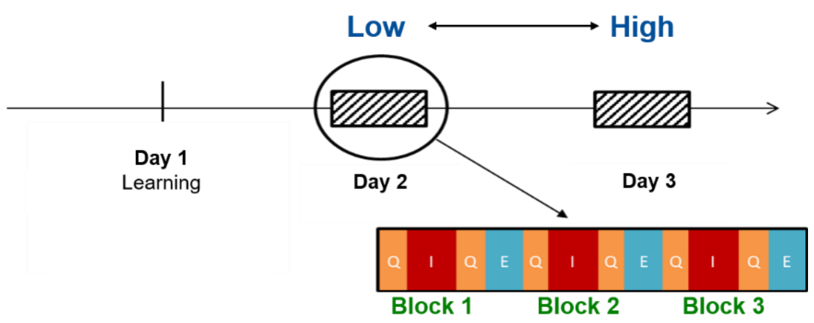
- Low & High workload conditions

Evaluation

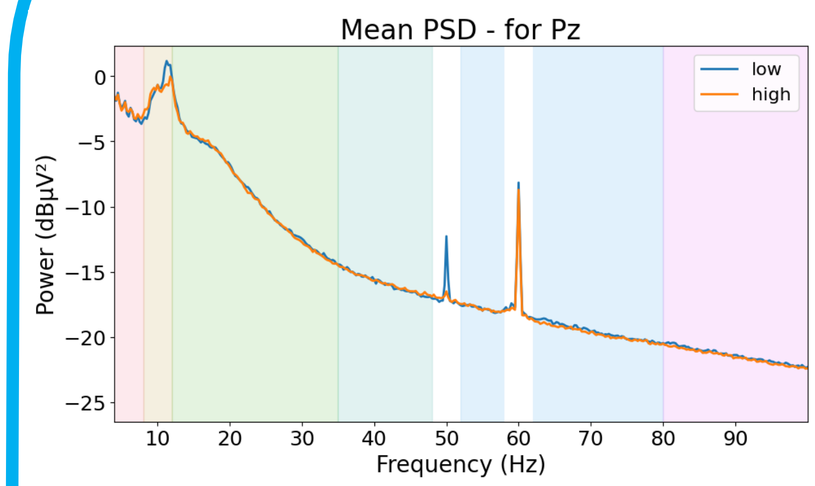
Simon task

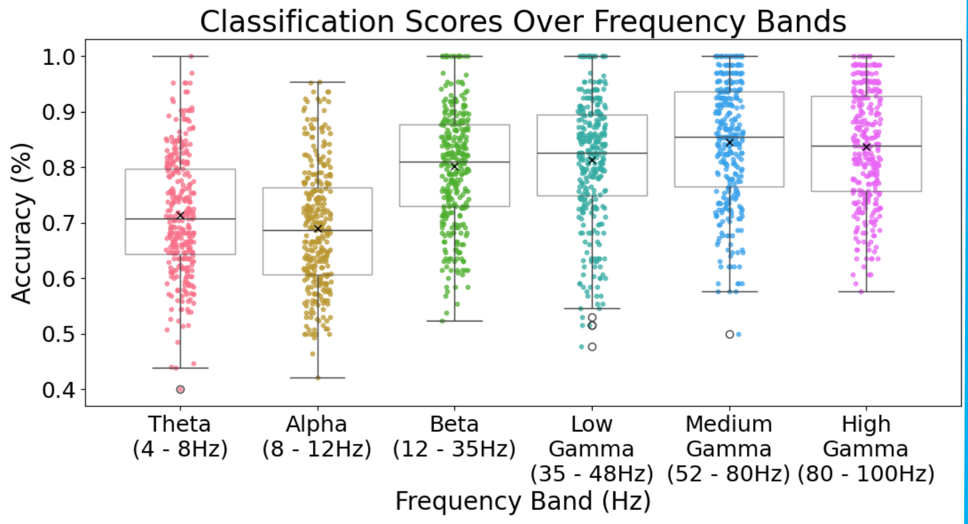
- Motor inhibition





Results





Power Spectral Density (PSD)

- ↘ P_α (8–12 Hz) & ↗ P_β (12-35 Hz) under high workload

Classification Performance (RMDM)

- Full spectral domain – mean accuracy: 76% ± 3 %
- Spectral windows – mean accuracy : **79% ± 12%**

Conclusion

Within-subject EEG-based classification of mental workload using Riemannian geometry yields robust results.

- Mean accuracy: ***76%.***

Spatial covariance-based classification with sub-band decomposition suggest a ***workload-related effect*** across the ***whole frequency spectrum***, especially in high-frequency range.

Classification scores over sub-bands

- Mean accuracy: ***79% ± 12%***
- Higher mean classification on the high frequency bands, mainly '***Medium Gamma***' (***86% accuracy***).

Barachant, A., Bonnet, S., Congedo M., & Jutten, C. (2011). Multiclass Brain–Computer Interface Classification by Riemannian Geometry. IEEE Transactions on Biomedical Engineering, 59(4), 920–928.https://doi.org/10.1109/tbme.2011.2172210

Borghini, G., Astolfi, L., Vecchiato, G., Mattia, D., & Babiloni, F. (2012). Measuring neurophysiological signals in aircraft pilots and car drivers for the assessment of mental workload, fatigue and drowsiness. Neuroscience & Biobehavioral Reviews, 44, 58-75. https://doi.org/10.1016/j.neubiorev.2012.10.003

Congedo, M., Barachant, A., Bhatia, R. (2017). Riemannian geometry for EEG-based brain-computer interfaces; a primer and a review. Brain-Computer Interfaces, 4(3), 155–174. https://doi.org/10.1080/2326263X.2017.1297192

Deshayes C., Angelliaume S., Berberian B., and Ficarella S. C. The quest for a task-independent (neuro) physiological signature of cognitive fatigue. [Article in preparation]