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# Benchmarking one-class Riemannian EEG classifiers to detect wakefulness under general anesthesia

V. Marissens Cueva<sup>1,2\*</sup>, S. Rimbart<sup>1</sup>, A. M. Cebolla Alvarez<sup>3</sup>, G. Cheron<sup>3</sup>,  
C. Meistelman<sup>4</sup>, S. J. Bidgoli<sup>5</sup>, F. Lotte<sup>1</sup>, L. Bougrain<sup>2,6</sup>

<sup>1</sup>Inria Center at the University of Bordeaux / LaBRI, Talence, France; <sup>2</sup>Université de Lorraine, CNRS, LORIA, Nancy, France; <sup>3</sup>Laboratory of Neurophysiology and Movement Biomechanics, Université Libre de Bruxelles, Bruxelles, Belgium; <sup>4</sup>DevAH, University of Lorraine, Nancy, France; <sup>5</sup>CHU Brugmann, Bruxelles, Belgium; <sup>6</sup>Sorbonne Université, ICM, CNRS, Inria, Inserm, AP-HP, Hôpital de la Pitié Salpêtrière, Paris, France;

\*LORIA, Campus Scientifique, BP 239, 54506 Vandœuvre-lès-Nancy, France, E-mail: valerie.marissens@loria.fr

**Introduction:** Current brain monitors for detecting Accidental Awareness during General Anesthesia (AAGA) remain debated, as robust evidence supporting their effectiveness in reducing AAGA's incidence is lacking [1]. To address this, we propose a new brain-computer interface based on Median Nerve Stimulation (MNS), a painless stimulation that elicits motor patterns, to monitor depth of anesthesia [2]. Specifically, we train our algorithm with post-MNS EEG patterns recorded while patients are awake, enabling the detection of the return to an arousal state during the surgery under anesthesia. Since the anesthesia data is unavailable pre-surgery for BCI calibration, we focus on One-Class (OC) approaches. In this study, we evaluate three OC Riemannian methods for this task: K-Means (OC-RKM) [3], Minimum Distance to the Mean (OC-RMDM) [5] and Support Vector Machine (OC-RSVM) [4, 6].

**Material, Methods and Results:** This study includes 12 patients (6 women;  $50 \pm 14.3$  years) undergoing surgery under general anesthesia with propofol as the hypnotic agent, at CHU Brugmann in Belgium [7]. EEG data were collected in two sessions: preoperatively (awake) and intraoperatively (under anesthesia). Each session involves several recordings, each with 150 MNSs delivered at a frequency of 0.25 to 0.33 Hz. Features were extracted as covariance matrices 250 to 1000 ms post-MNS in the 8–30 Hz frequency band. Classification performances of the three OC Riemannian algorithms are summarized in Figure 1. A Student's t-test with Benjamini-Hochberg correction shows OC-RKM and OC-RMDM significantly outperform OC-RSVM ( $p < 0.05$ ).

**Conclusion:** Results indicate that both OC-RKM and OC-RMDM effectively delimit an awake state in most subjects, though not all. In contrast, OC-RSVM has a lower performance, possibly due to the use of a Riemannian kernel reference point  $C_{ref}$  computed as the mean covariance matrix of the awake class, which may inadequately capture the geometry of both classes. Additionally,  $\nu$  was not optimized, as its tuning in a one-class context remains challenging. Future work will assess performance regarding the number of electrodes, alternative  $C_{ref}$ , and comparisons with other one-class algorithms. An ensemble method will also be considered to improve robustness for depth of anesthesia estimation across subjects, leveraging the strengths of each model.

**Acknowledgments:** The authors thank the Brugmann Foundation and the BCI4IA ANR project.

## References:

- [1] Laferrière-Langlois P, et al. Depth of Anesthesia and Nociception Monitoring: Current State and Vision For 2050. *Anesth. Analg.*, 2024.
- [2] Rimbart S, et al. Median Nerve Stimulation Based BCI: A New Approach to Detect Intraoperative Awareness During General Anesthesia. *Front Neurosci.* 2019.
- [3] Navarro-Sune X, et al. Riemannian Geometry Applied to Detection of Respiratory States From EEG Signals: The Basis for a Brain-Ventilator Interface. In *IEEE Trans. Biomed. Eng.*, 2017.
- [4] Barachant A, et al. Classification of covariance matrices using a Riemannian-based kernel for BCI applications. *Neurocomputing*, 2013.
- [5] Marissens Cueva V, et al. One-Class Riemannian EEG Classifier to Detect Anesthesia. In *5th Intern. Neuroergonomics Conf.*, 2024.
- [6] Schölkopf B, et al. Support Vector Method for Novelty Detection. *NIPS*. 1999.
- [7] Rimbart S, et al. Detection of Motor Cerebral Activity After Median Nerve Stimulation During General Anesthesia (STIM-MOTANA): Protocol for a Prospective Interventional Study. *JMIR Res Protoc.* 2023.

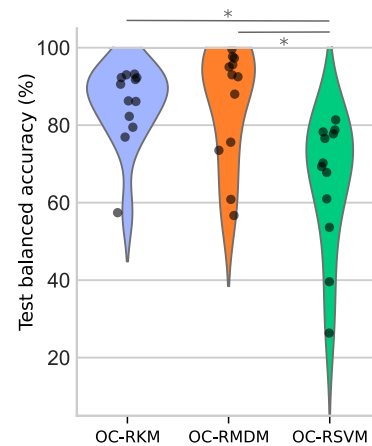


Figure 1: Test balanced accuracies obtained with 12 patients using OC classifiers trained on data when patients are awake. Best results with OC-RKM are with 2 prototypes, and thresholds of median +  $3 \times$  median absolute deviation. For OC-RSVM,  $\nu = 0.5$ . For OC-RMDM parameters, see [5]. \* $p$ -value  $< 0.05$ .

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Poster: P3-D-59

## Background

Current brain monitors for detecting **Accidental Awareness during General Anesthesia** (AAGA) remain debated, as robust evidence supporting their effectiveness in reducing AAGA's incidence is lacking [1]. We propose a **new BCI based on Median Nerve Stimulation** (MNS), a painless stimulation that elicits motor patterns, to **monitor depth of anesthesia** [2]. Since the anesthesia data is unavailable before the surgery for BCI calibration, we focus on **One-Class** (OC) approaches **trained on awake data**.

### OBJECTIVE

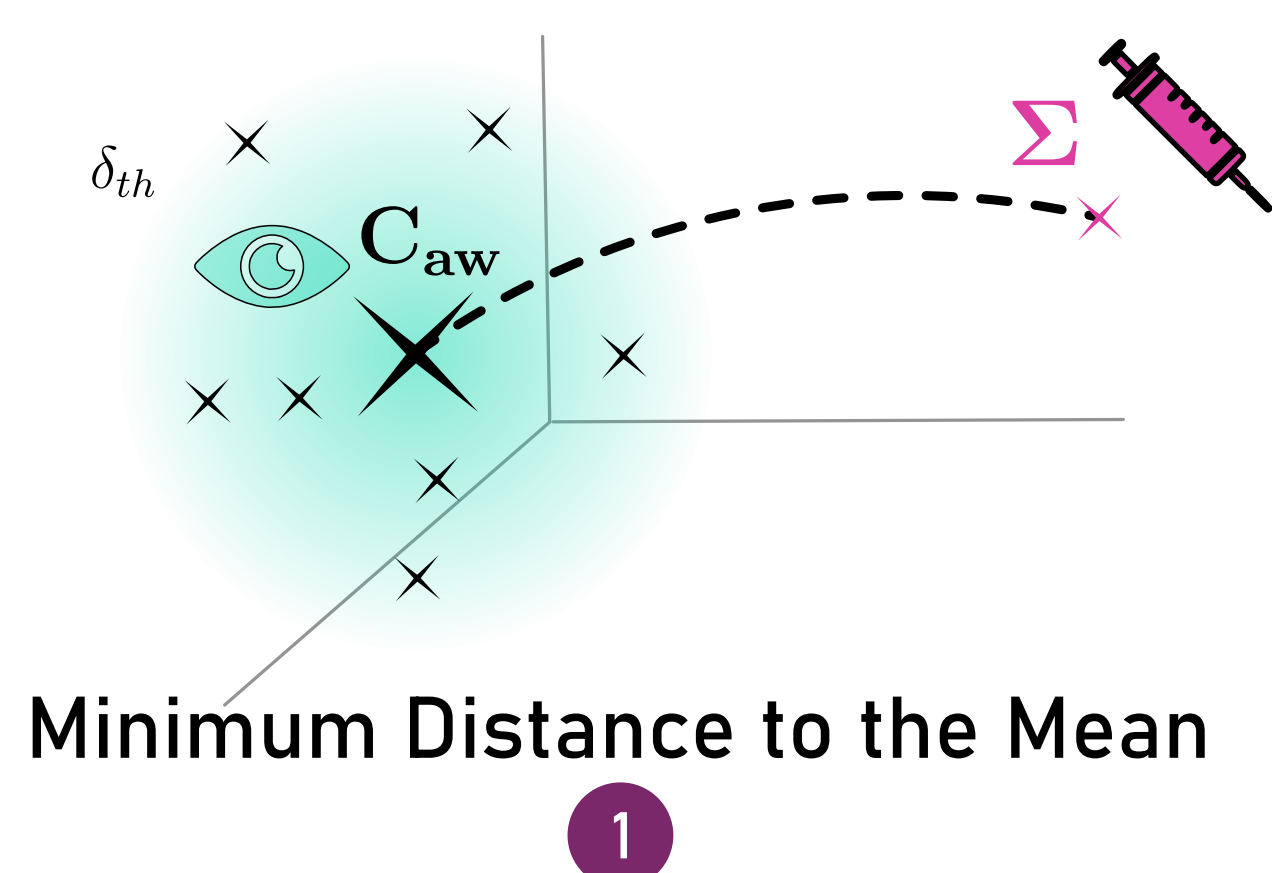
Evaluation of **One-Class Riemannian** methods trained on post-MNS EEG patterns recorded while patients are awake to **detect the return to an awake state** during the surgery under anesthesia:

- K-Means (OCR-KM)[3]
- Minimum Distance to the Mean (OCR-MDM) [4, 5]
- Support Vector Machine (OCR-SVM) [4, 6]

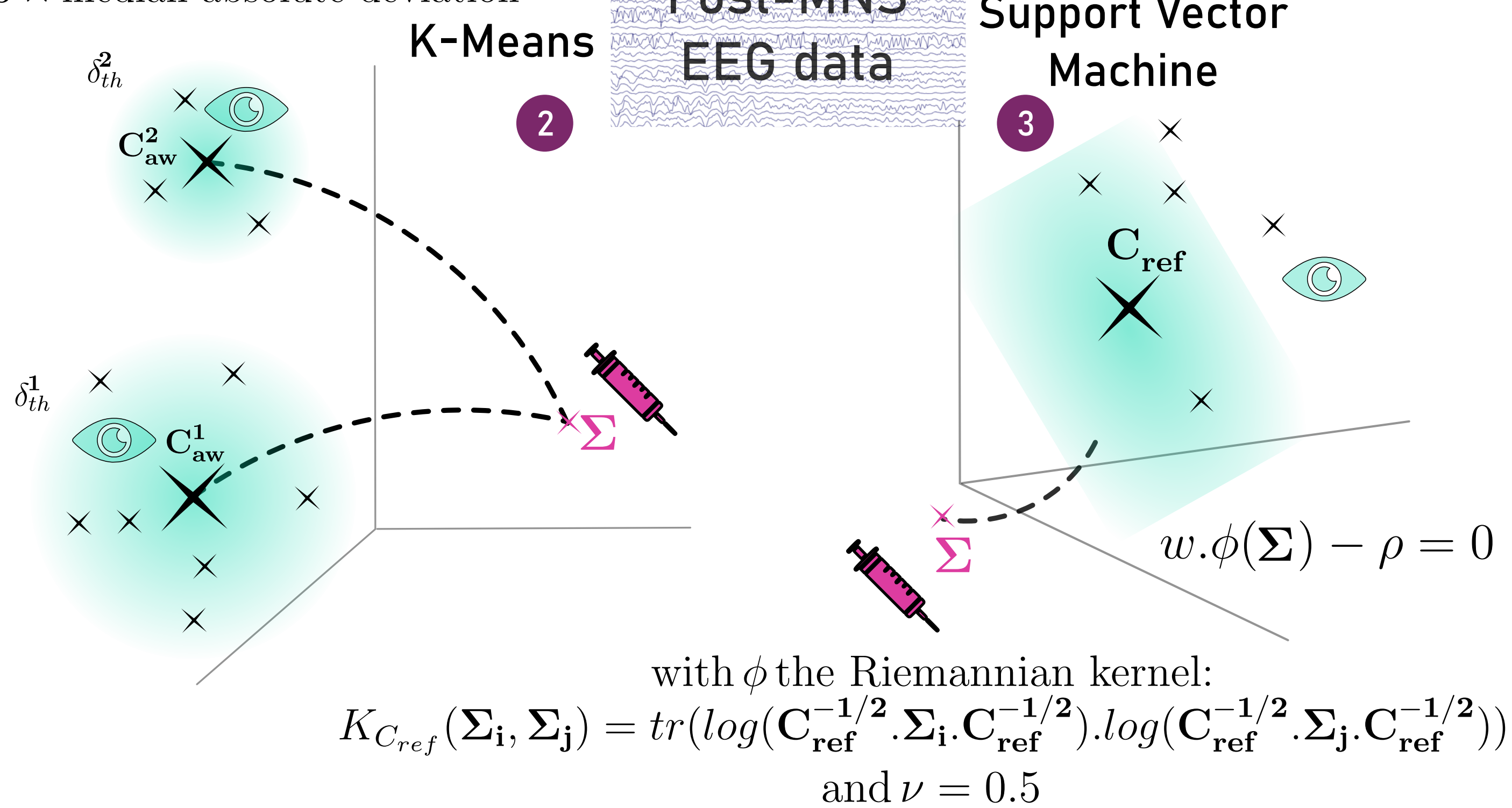
## Methodology

Features: covariance matrices  $\Sigma$ , 250 to 1000 ms post-MNS in the 8–30 Hz frequency band, computed with all 64 electrodes.

threshold  $\delta_{th}$  is median + 3 × standard deviation  
 $\hat{k} = \text{awake}$  if  $\delta_R(\Sigma, C_{aw}) \leq \delta_{th}$  else anesthesia  
 with  $\delta_R(\Sigma, C_{aw}) = \|\log(\Sigma^{-1/2} \cdot C_{aw} \cdot \Sigma^{-1/2})\|_F$

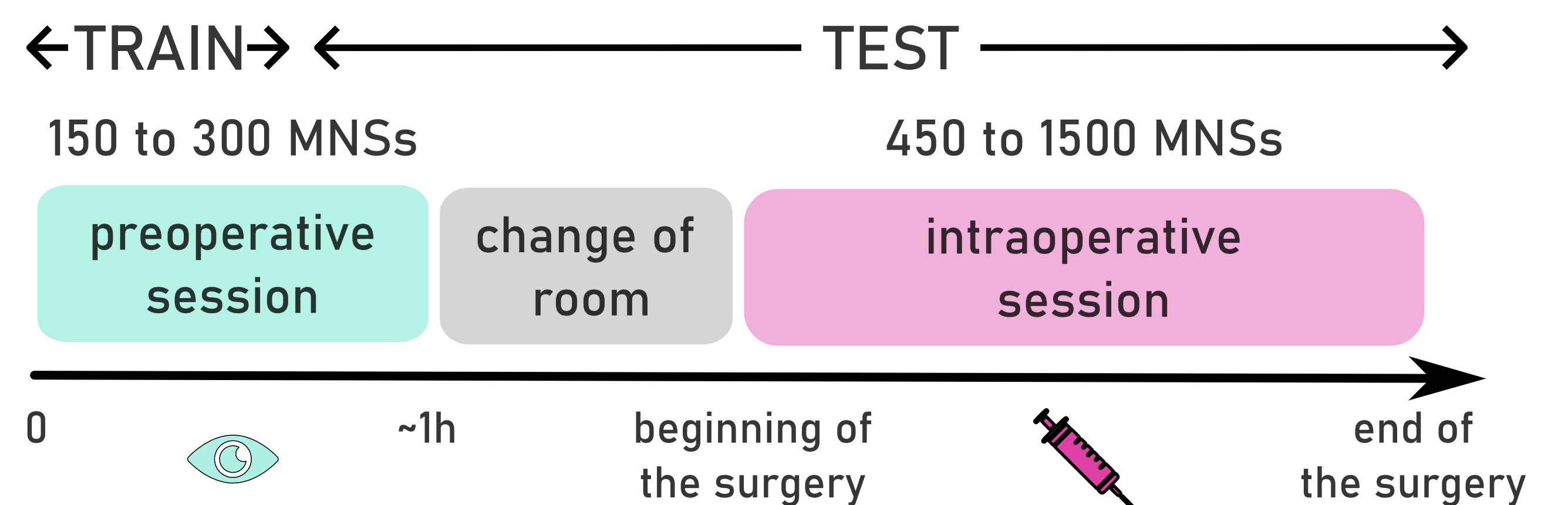


thresholds  $\delta_{th}^i$  are median + 3 × median absolute deviation



## Data description

**12 patients** (6 women;  $50 \pm 14.3$  years) underwent surgery under general anesthesia with **propofol** as the hypnotic agent, at CHU Brugmann in Belgium [7]. EEG data were collected in two sessions, where Median Nerve Stimulation was delivered with an **interstimulus interval of 3–4 s**.



## Results

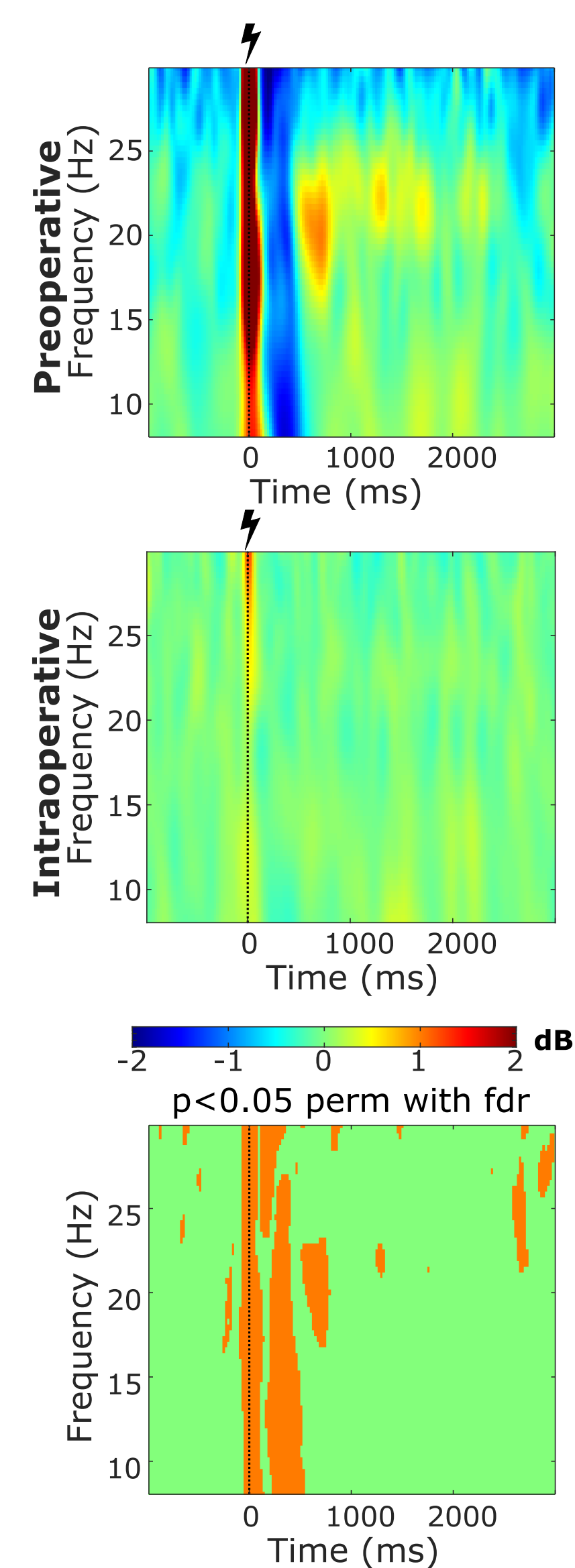
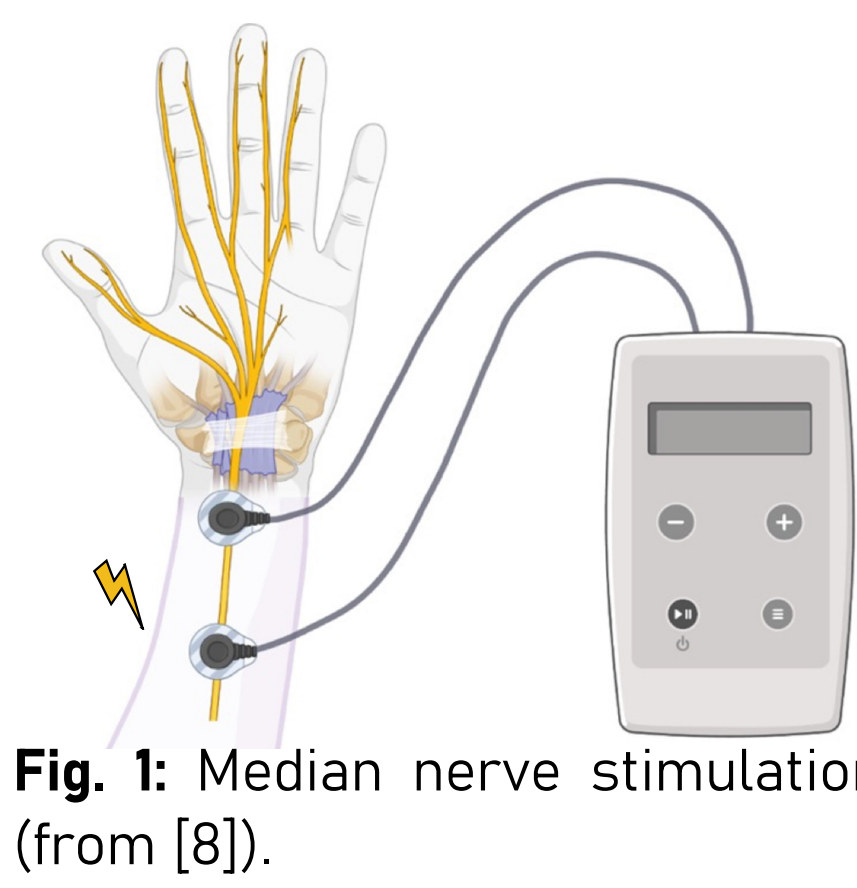


Fig. 2: Grand average time-frequency across the subjects at electrode C4 after median nerve stimulation. Statistical differences at a significance level of 0.05 are shown on the bottom figure. The flash icon indicates the beginning of the stimulation. Red color corresponds to a strong ERS and blue to a strong ERD.

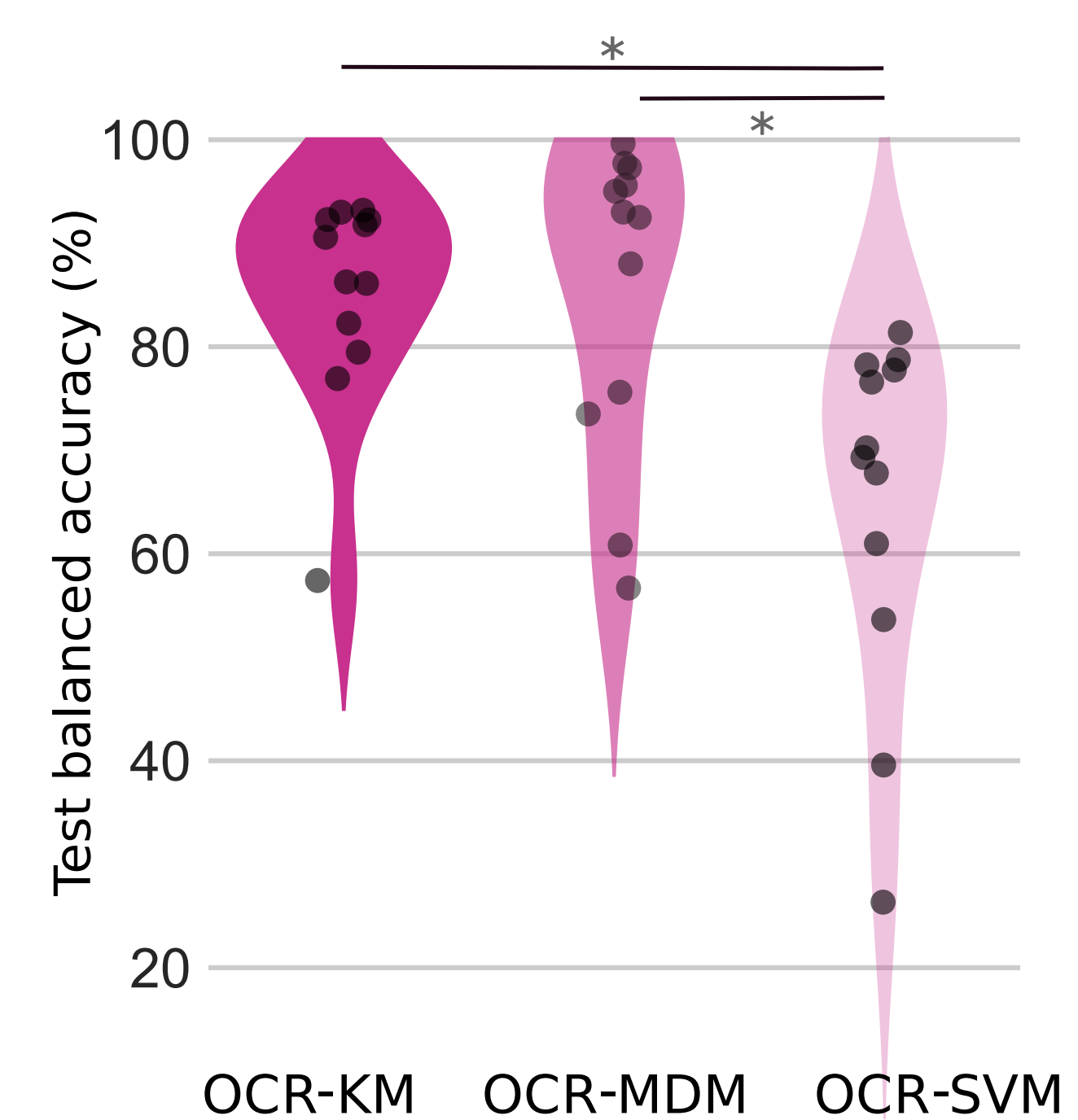


Fig. 3: Test balanced accuracies of all 12 subjects obtained with OC classifiers trained on data when patients are awake. Best results with OCR-KM are with 2 prototypes. Student's t-test with Benjamini-Hochberg correction results are shown (\*p-value < 0.5).

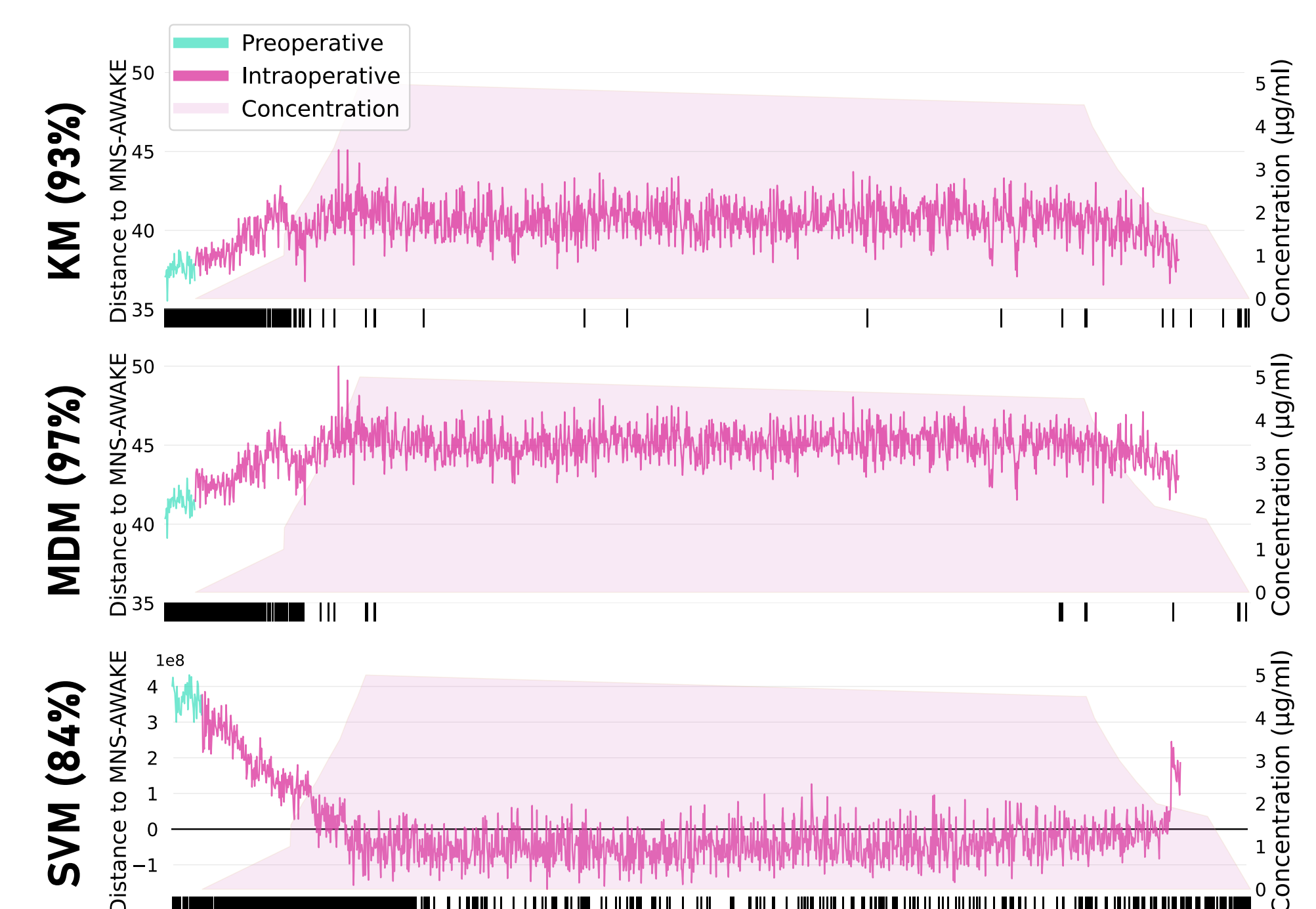


Fig. 4: Distances between test trials covariance matrices and the (closest) MNS-awake centroid or the hyperplane (only subject 8). The evolution of propofol target concentrations is presented by the shaded area in the background. Below, a bar indicates when the classifier predicted MNS-awake.

## Conclusion

- OCR-KM (mean test accuracy of 85%) and OCR-MDM (85%) effectively delimit an awake state in most subjects, though not all.
- OCR-SVM has a lower performance (65%), possibly due to:
  - the use of a Riemannian kernel reference point  $C_{ref}$  computed as the mean covariance matrix of the **awake class**, which may inadequately capture the geometry of both classes
  - **v was not optimized**, as its tuning in a one-class context remains challenging

### PERSPECTIVES

- Assess performance **reducing the number of electrodes**, **alternative  $C_{ref}$** , and comparisons with other one-class algorithms.
- An **ensemble method** will also be considered to improve robustness for depth of anesthesia estimation across subjects, leveraging the strengths of each model.

## Acknowledgements

The authors thank the Brugmann Foundation and the BCI4IA ANR project.

## References

- [1] Laferrière-Langlois P. et al. Anesth. Analg., 2024.
- [2] Rimbert S. et al. Front Neurosci. 2019.
- [3] Navarro-Sune X. et al. IEEE Trans. Biomed. Eng., 2017.
- [4] Barachant A. et al. Neurocomputing, 2013.
- [5] Marissens Cueva V. et al. 5th Int. Neuroerg. Conf., 2024.
- [6] Schölkopf B. et al. NIPS. 1999.
- [7] Rimbert S. et al. JMIR Res Protoc. 2023.
- [8] Thomas Hendry E. et al, Neuromod, 2024.

Contact: valerie.marissens@loria.fr

