

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

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BCI Meeting 2025 - Master Class

# Anesthesia

**PROBLEM:** **Awareness still occurs** with current monitors [1, 2, 3, 4, 5] : indices were developed from adult cohorts [5], might be falsely increased with EMG activity [3, 4] and are less accurate with age [5]

**OUR SOLUTION:** Actively analyze EEG responses to **Median Nerve Stimulation** (MNS) [6]



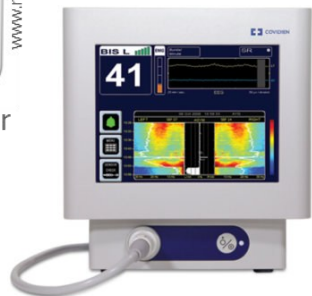
NeuroSENSE monitor



SedLine monitor



Narcotrend monitor



Bispectral Index monitor



Thomas Hendry, Neuromod, 2024

[1] Bruhn et al. Anesth, 2000.

[2] Myles et al. Lancet, 2004.

[3] Sebel et al. Anesth. Analg. 2004.

[4] Aho et al. Acta Anaesthesiol Scan, 2012.

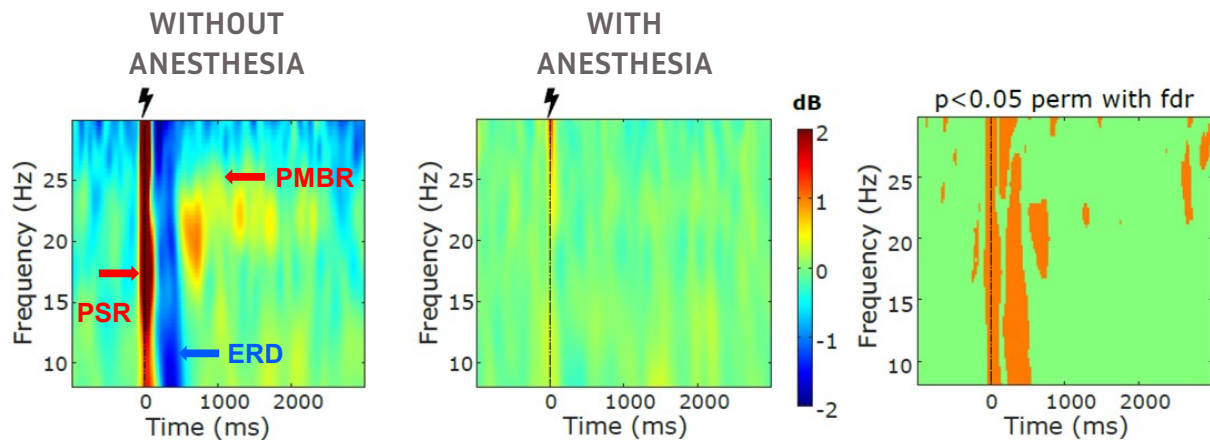
[5] Laferrière-Langlois et al. Anesth. Analg., 2024.

[6] Rimbart et al, Front. Neurosci, 2019.

# Median Nerve Stimulation-based BCI to monitor anesthesia

MNS induces sensorimotor modulations visible via EEG and variable with the depth of anesthesia [7].

**IDEA:** Follow this pattern through the anesthesia.



Grand average time frequency analysis across 8 subjects for electrode C4

PSR: Post-Stimulation Rebound  
ERD: Event Related Desynchronization  
PMBR: Post-Movement Beta Rebound

# Data collection: clinical protocol at CHU Brugmann

14 patients: 8 females;  $50 \pm 14.3$  years old [8]

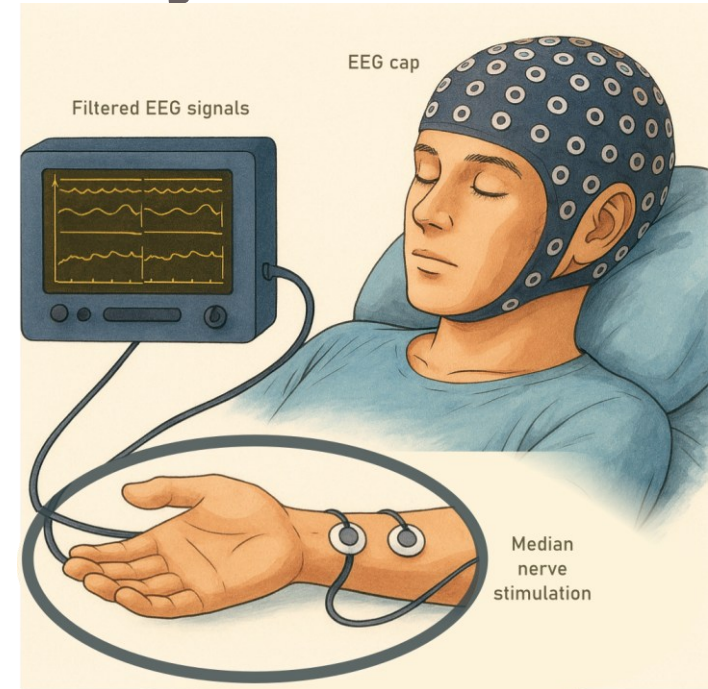
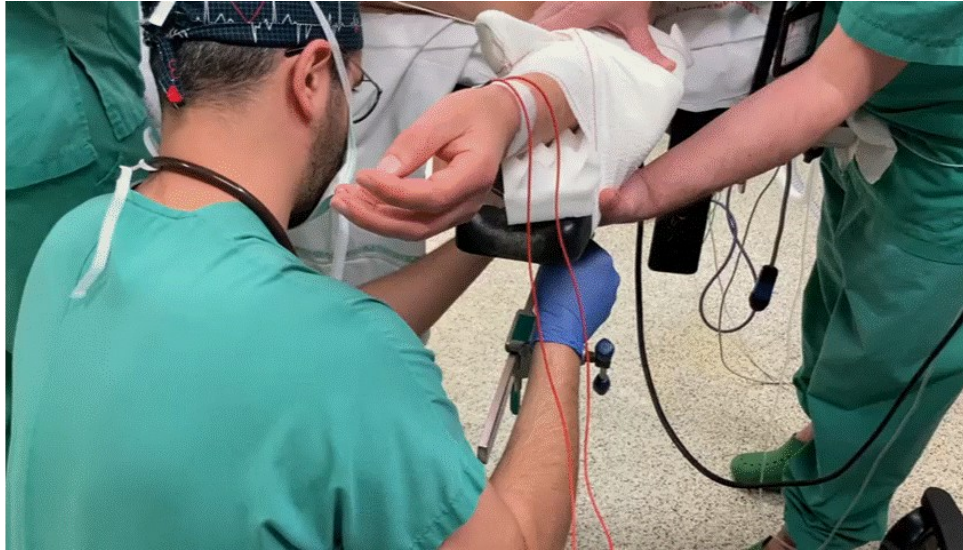


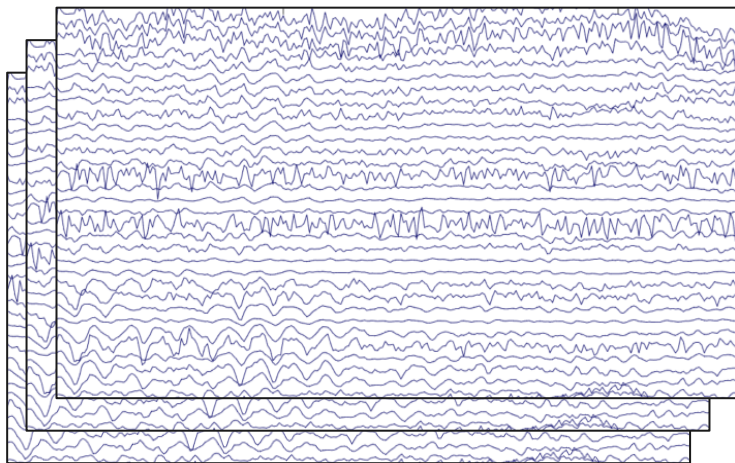
Figure inspired by Sigl and Chamoun, J Clin Monit, 1994

# Data collection: awake & anesthetized states

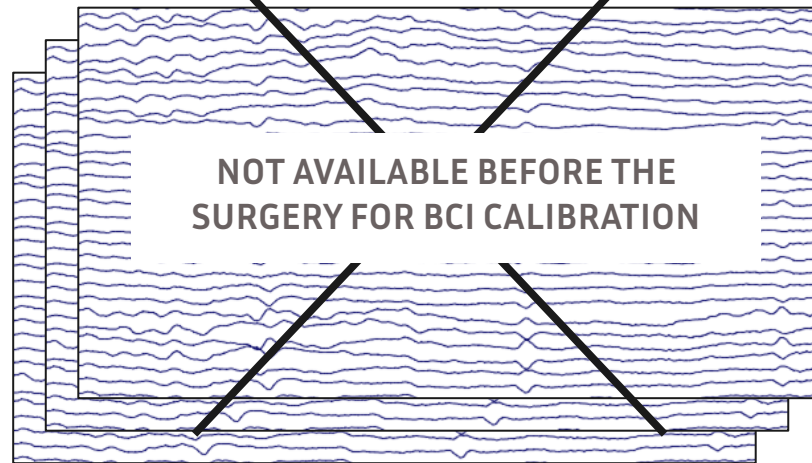
GOAL: Classify brain state as either **MNS-awake** or **MNS-anesthesia** using a BCI.



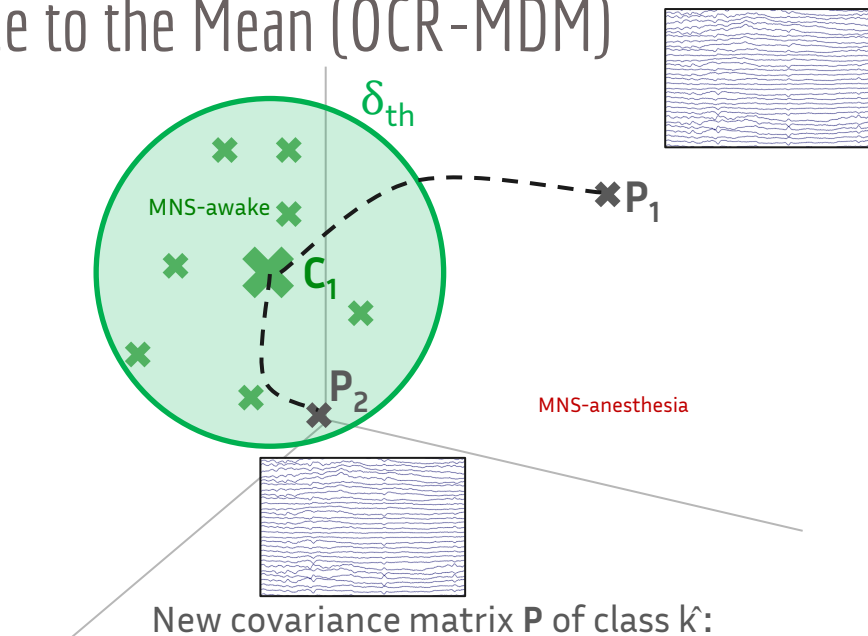
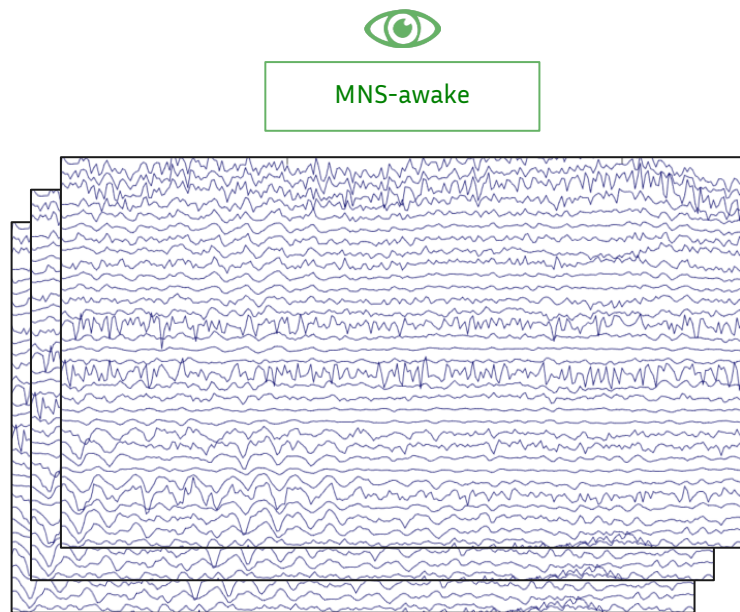
MNS-awake



MNS-anesthesia



# One-Class Riemannian Minimum Distance to the Mean (OCR-MDM)



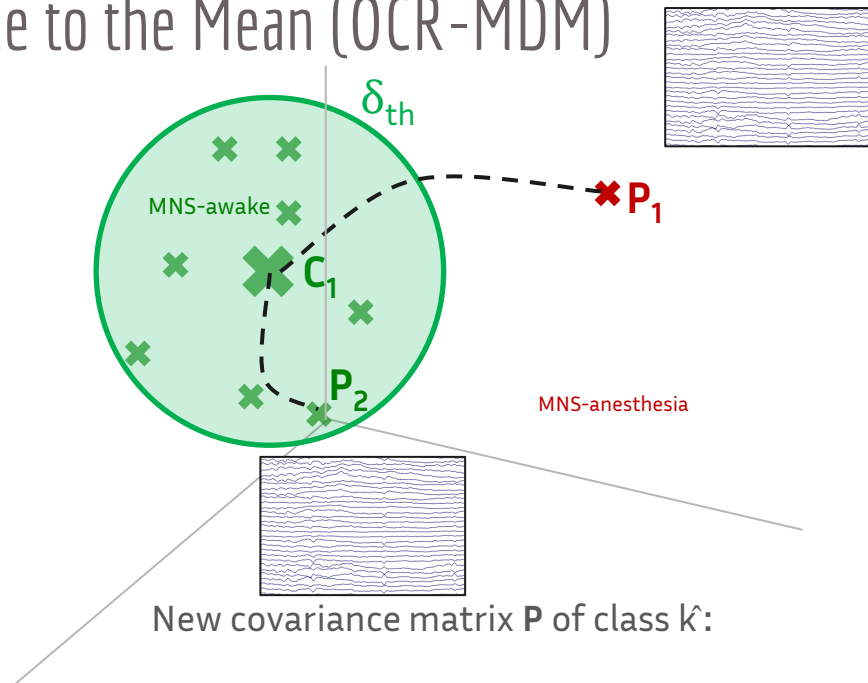
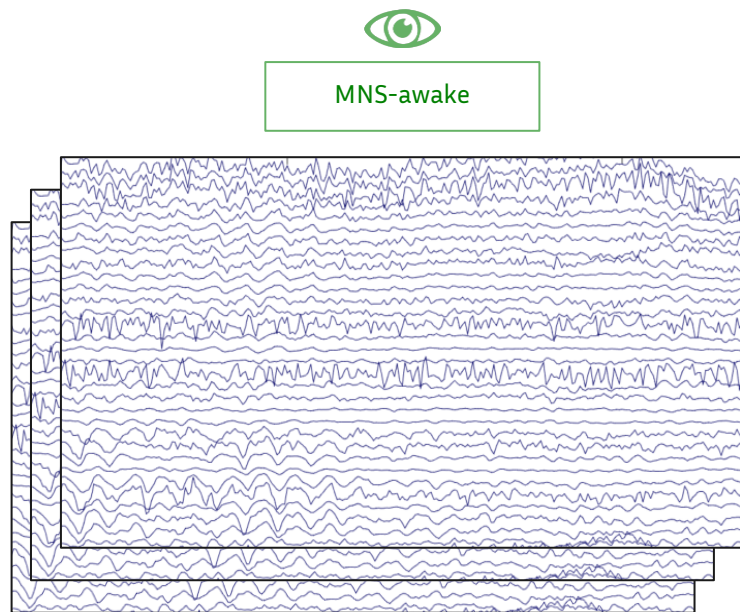
$\mathcal{K} = \mathcal{C}_1$  if  $\delta_R(\mathbf{P}, \mathbf{P}_i) \leq \delta_{th}$  else  $\mathcal{C}_2$   
 with  $\delta_R$  the Riemannian distance:  
 $\delta_R(\mathbf{P}, \mathbf{P}_i) = \|\log(\mathbf{P}^{-1/2} \mathbf{P}_i \mathbf{P}^{-1/2})\|_F$

[9] Congedo et al. 8th Inter. BCI Conf. 2019.

[10] Barachant et al. IEEE Trans. Biomed. Eng. 2012.

[11] Marissens Cueva et al. 5th Int. Neuroergonomics Conf, 2024.

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[9] Congedo et al. 8th Inter. BCI Conf. 2019.

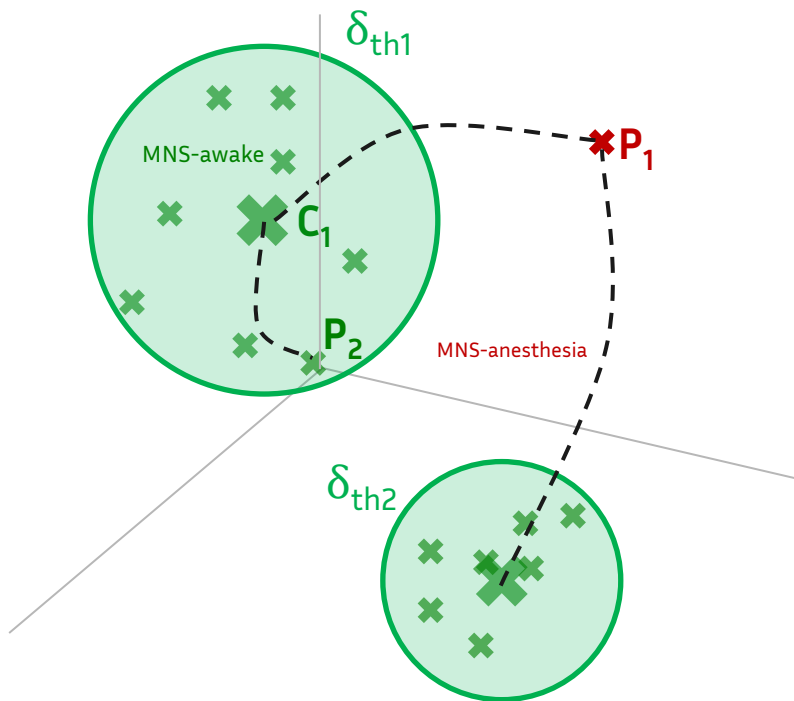
[10] Barachant et al. IEEE Trans. Biomed. Eng. 2012.

[11] Marissens Cueva et al. 5th Int. Neuroergonomics Conf, 2024.

# Comparison with other One-Class Riemannian classifiers

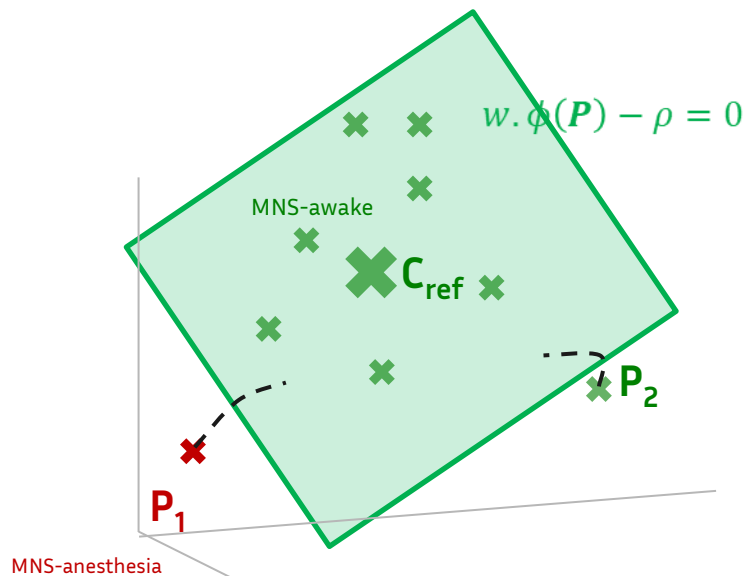
## One-class Riemannian K-Means

[12] Navarro-Sune et al, IEEE Trans. Biomed. Eng., 2017



## One-class Riemannian Support Vector Machine

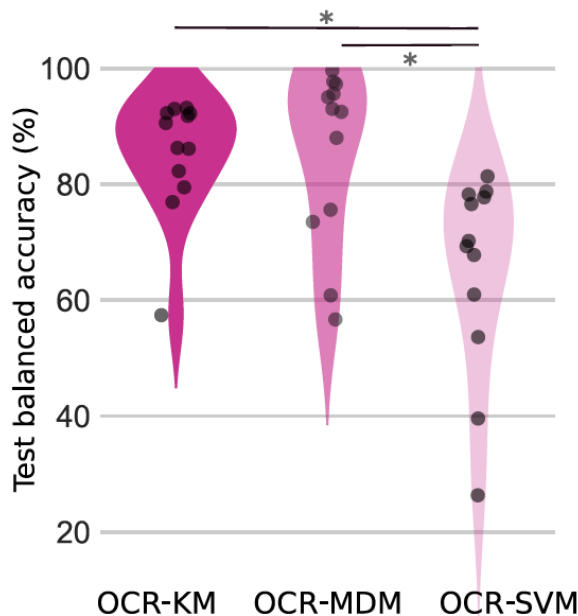
[13] Schölkopf et al, NIPS, 1999



With  $\phi$  the Riemannian kernel:

$$K_{i,j} = \text{tr}(\log(C_{ref}^{-1/2} X_i C_{ref}^{-1/2}) \cdot \log(C_{ref}^{-1/2} Y_j C_{ref}^{-1/2}))$$

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Test balanced accuracies of **OC classifiers trained on data when patients are awake** [19] (12 subjects).  
Best results with OC-RKM are with 2 prototypes, and thresholds of median + 3 × median absolute deviation.  
For OC-RSVM,  $\nu = 0.5$ . \*p-value < 0.05

# Perspectives for a new MNS-based BCI to detect AAGA

- Alternative  $C_{\text{ref}}$  matrix (e.g. identity)
- Comparison with other one-class algorithms (e.g. SVDD [15])
- Ensemble method
- Reducing the number of electrodes (e.g. only sensorimotor+frontal)

# Acknowledgments



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Associate Professor  
Université de Lorraine



Sébastien Rimbart  
Inria Starting Faculty Position  
Inria Center at the University of Bordeaux



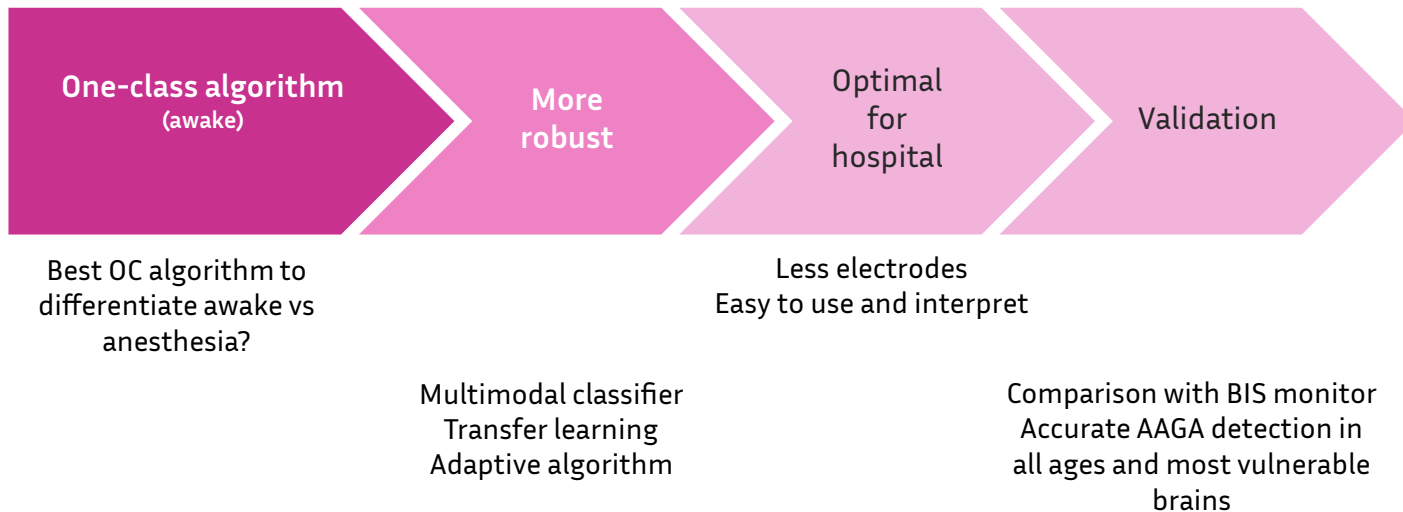
# Thank you for your attention!

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# Perspectives for a new MNS-based BCI to detect AAGA



# Towards a quantitative anesthesia index

Distance to the (closest) **MNS-awake centroid** or the hyperplane evolves gradually with the depth of anesthesia:

