Detecting accidental awareness during general anaesthesia with neuromuscular blockade

Challenges and Considerations

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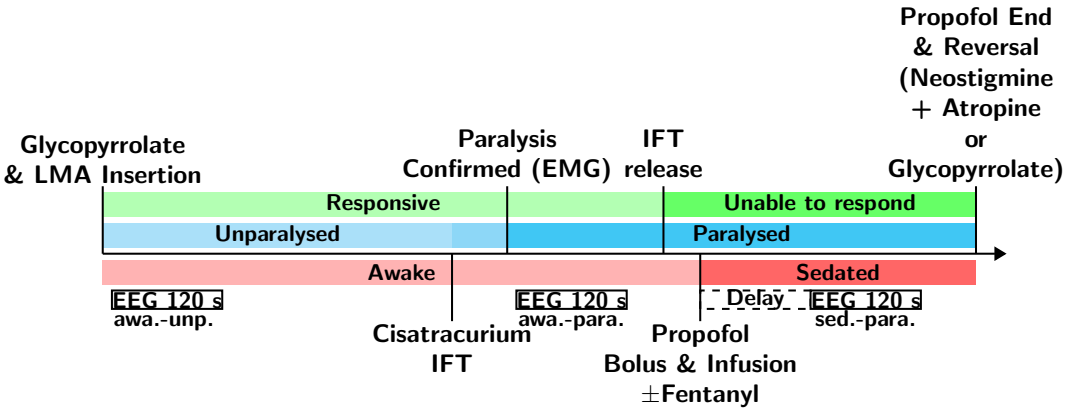
The issue of neuromuscular blockade

- Neuromuscular blocking agents (NMBAs) are routinely used to improve the quality of surgical conditions[1]
- NMBAs relax the jaw and vocal cord muscles, making it easier to insert the endotracheal tube and reduce the risk of injury during intubation
- Relaxed muscles, e.g. in the abdomen, make it easier to manipulate and access organs and prevent movement which is essential for delicate surgeries
- Thus to evaluate if a measure of consciousness is suitable to detect awareness during anaesthesia it must be evaluated with only NMBAs
- We used a data set recorded by a group recorded by a group in in Australia that investigated the effect of paralysis on the EEG[2]

[1] Martini, C. H., Boon, M., Bevers, R. F., Aarts, L. P. & Dahan, A. Evaluation of surgical conditions during laparoscopic surgery in patients with moderate vs deep neuromuscular block. BJA: British Journal of Anaesthesia 112, 498–505. doi:10.1093/bja/aet377 (Mar. 2014).

[2] Whitham, E. M. et al. Scalp electrical recording during paralysis: Quantitative evidence that EEG frequencies above 20 Hz are contaminated by EMG. Clinical Neurophysiology 118, 1877–1888. doi:10.1016/j.clinph.2007.04.027 (Aug. 2007).

Experimental design



Features and classification

- Diversity (LZc, channel-wise, 1-45 Hz)[3]
- Slope (exponent for canonical bands + "low" and "high")[4]
- Outflow (DTF connectivity metric, 8-12 Hz, 26 channels)[5]
- PSD (periodic components computed with FOOOF, canonical bands + 1-45 Hz)[6]

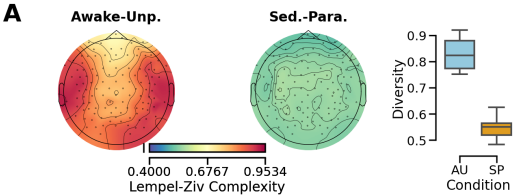
[3] Schartner, M. et al. (2015). Complexity of multi-dimensional spontaneous EEG decreases during propofol induced general anaesthesia. PloS one, 10(8), e0133532.

[4] Colombo, M. A. et al. (2019). The spectral exponent of the resting EEG indexes the presence of consciousness during unresponsiveness induced by propofol, xenon, and ketamine. NeuroImage, 189, 631-644.

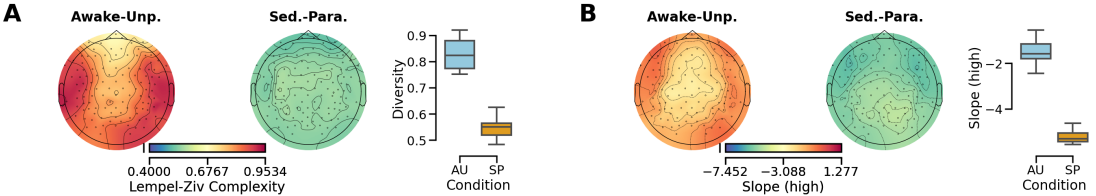
[5] Juel, B. E. et al. (2018). Distinguishing anesthetized from awake state in patients: a new approach using one second segments of raw EEG. Frontiers in Human Neuroscience, 12, 40.

[6] Donoghue T et al. (2020). Parameterizing neural power spectra into periodic and aperiodic components. Nature Neuroscience, 23, 1655-1665.

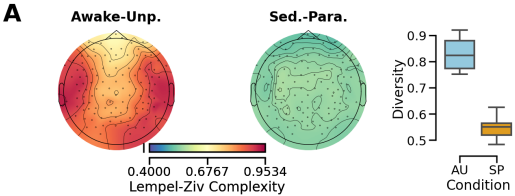
Spontaneous measures

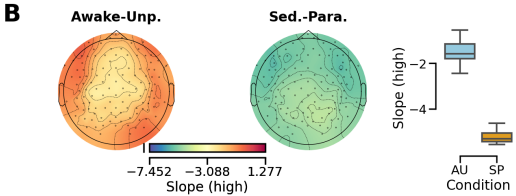


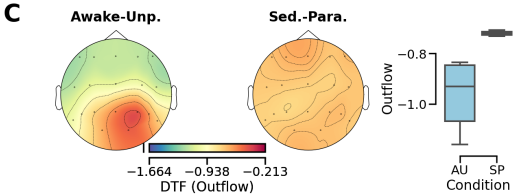
Spontaneous measures



Spontaneous measures







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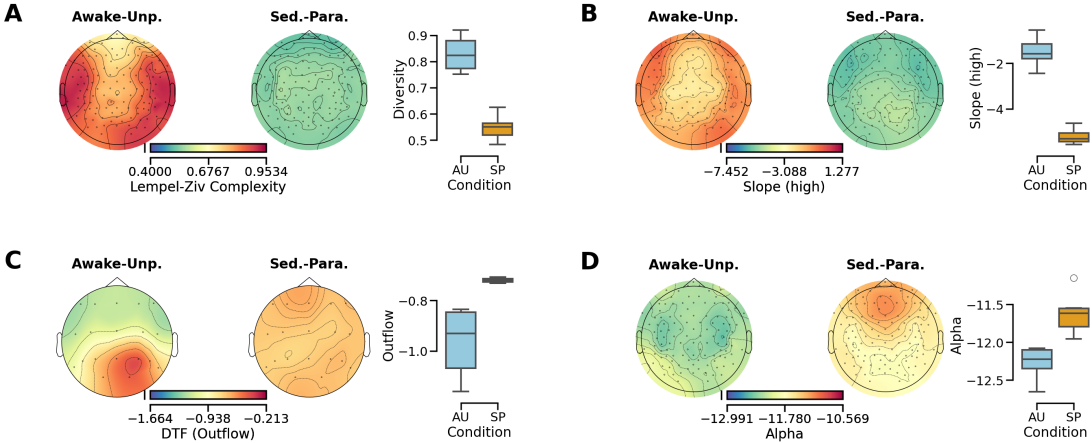
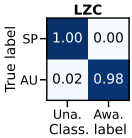
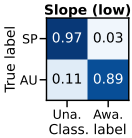
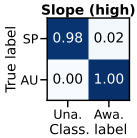
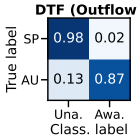


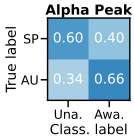
Leave-one-subject out classification excluding Awake-Paralysed

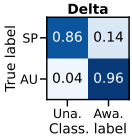


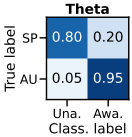


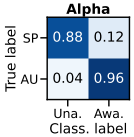


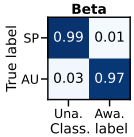


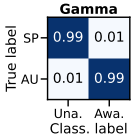




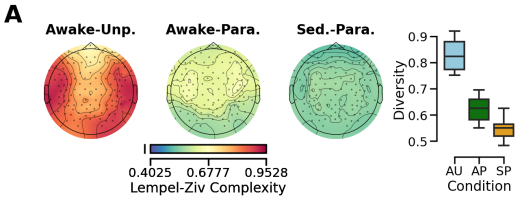








The effect of NMBAs on spontaneous measures



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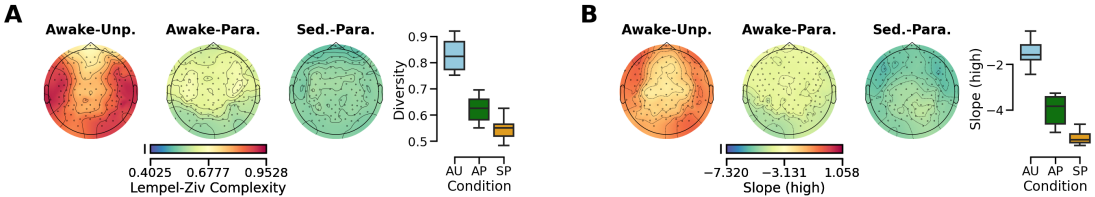

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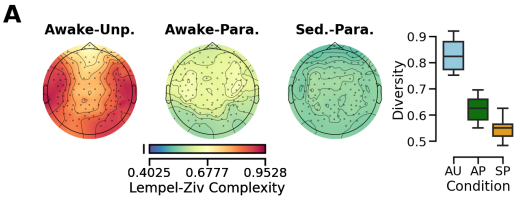

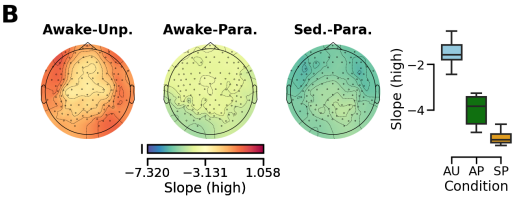

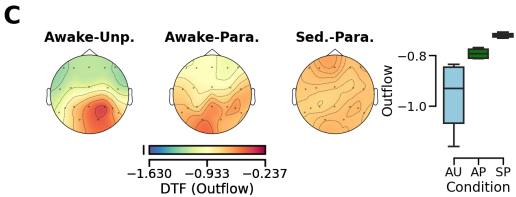

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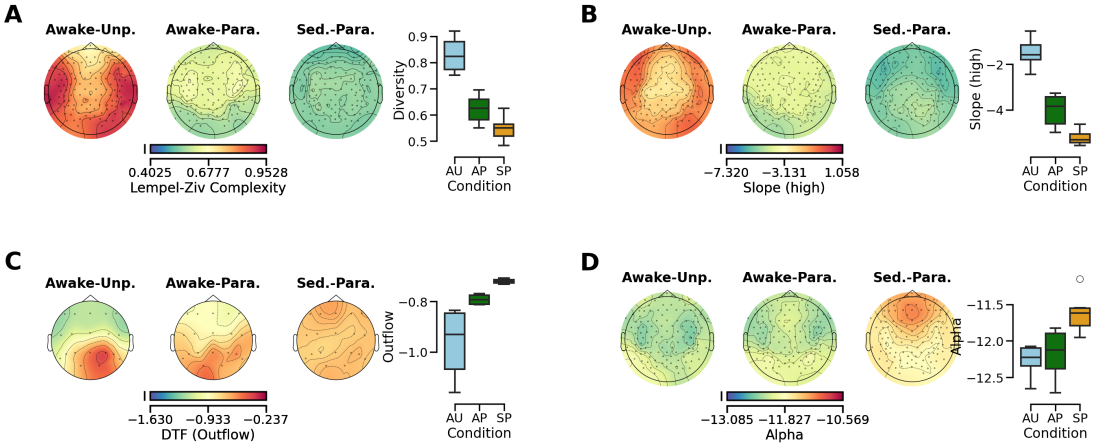
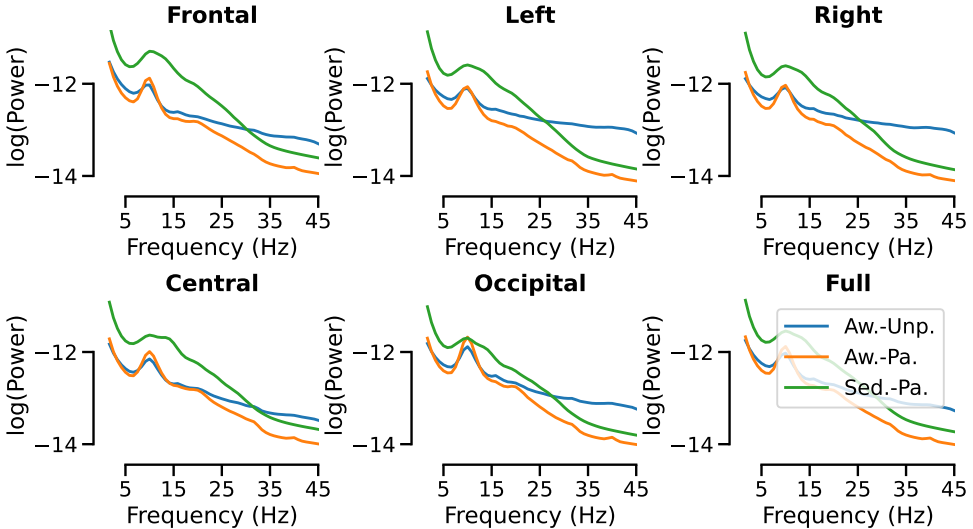
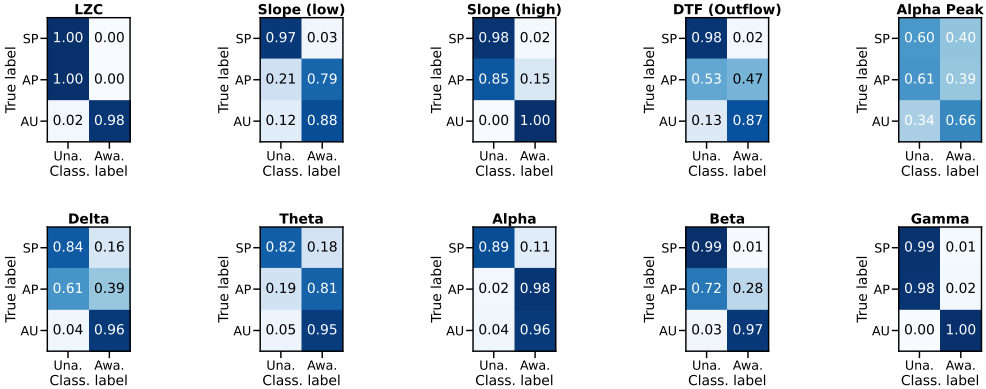


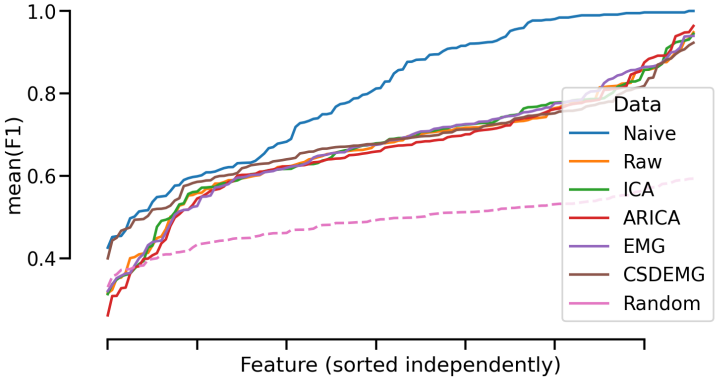
The effect of NMBA on PSD

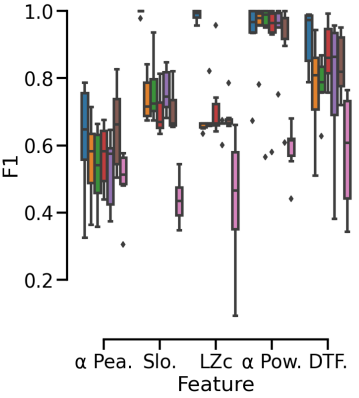


Leave-one-subject out classification including Awake-Paralysed

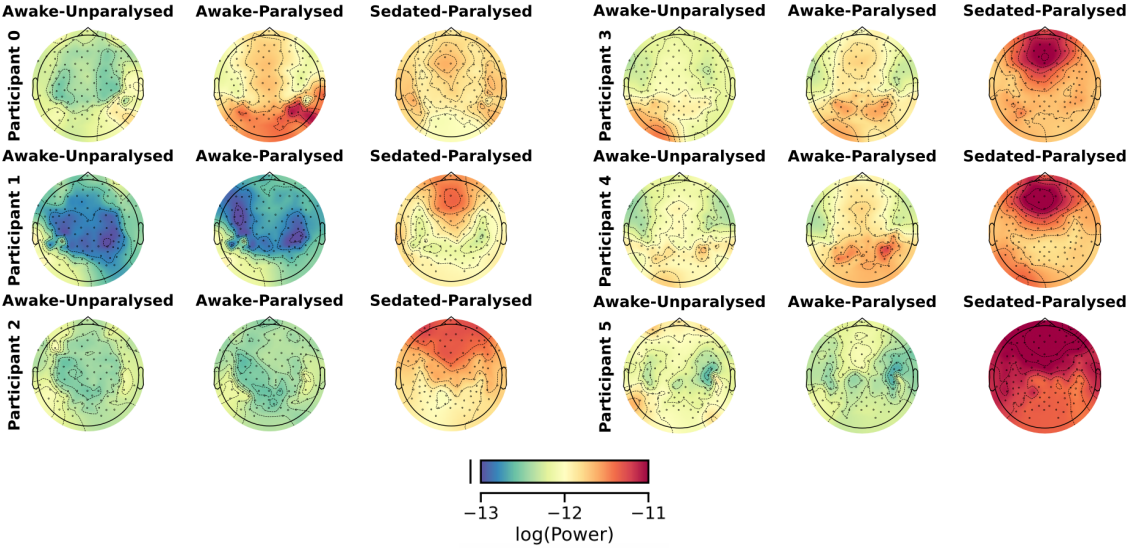


Effect of artifact removal on feature exploration





Alpha from individual participants



The changes in alpha depend on the anaesthetic

- Increase of frontal alpha is commonly observed in propofol induced anaesthesia[7]
- This is referred to as alpha anteriorization
- Alpha power may also decrease:
  - In about 31% of patients undergoing surgery alpha power drops were observed
  - Higher doses of propofol may eventually lead to decreasing alpha
- This may also be drug dependent:
  - In a study of patients anaesthetised with sevoflurane or desflurane 4% did not show any alpha
  - Half of the patients showed alpha increase, the other half decreases
  - The authors suggest using the peak frequency instead of power[8]

[7] Gutierrez, R., Maldonado, F., Egana, J. I. & Penna, A. Electroencephalographic Alpha and Delta Oscillation Dynamics in Response to Increasing Doses of Propofol. en-US. Journal of Neurosurgical Anesthesiology 34, 79. doi:10.1097/ANA.0000000000000733 (Jan. 2022).

[8] Hight, D., Voss, L. J., Garcia, P. S. & Sleigh, J. Changes in Alpha Frequency and Power of the Electroencephalogram during Volatile-Based General Anesthesia. Frontiers in Systems Neuroscience 11, 36. doi:10.3389/fnsys.2017.00036 (May 2017).

Conclusion

- Alpha power is well known to be affected by general anaesthesia
- Limitations known from other studies apply (see previous slide)
- Alpha power (especially when limited to frontal electrodes) was the most robust measure (in the sense of recognising the 'Awake-Paralysed' state as aware) in this analysis
- Nonetheless it is safe to conclude the perfect marker of **environmentally connected consciousness** (using spontaneous EEG) has not yet been found
- Perturbational methods such as PCI may be an alternative but not for online monitoring and TMS stimulation during surgery may be problematic
- Can BCIs fill this unmet need? See talks by Valérie and Sébastien!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Position

- Looking for a PostDoc for start in Q3 2026
- Detection of pain from the EEG recorded during clinical procedures
- EEG analysis and machine learning (Deep Learning, Riemannian Classifiers) skills required
- Located in England
- Travel to collaborators in Norway and for conferences included!
- 18 Months duration
- Lots of interesting data!

Thank you for listening!