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Exploring the Effects of Transcranial Alternating Current Stimulation on Neural Entrainment using Electroencephalogram

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Background

- Neural oscillations represent **rhythmic patterns** of neuron activity
- They manifest in specific frequency bands, the most prominent and the strongest in the awake human electroencephalogram (EEG) is the **alpha band**, oscillating between 8 and 13 Hz.
- Transcranial alternating current stimulation (tACS) is a non-invasive brain stimulation, that delivers sinusoidal weak alternating current on the scalp.
- The exact mechanism by which tACS modulates neural oscillations remains **elusive**.
- **Neural entrainment** is one of the hypothetical mechanisms of tACS as it involves the alignment of endogenous neural oscillations with the applied tACS frequency.

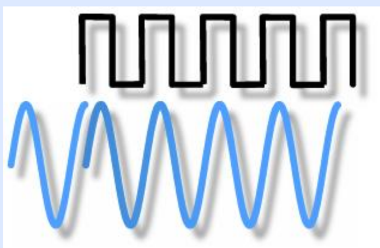

Figure 1: *Neural entrainment*

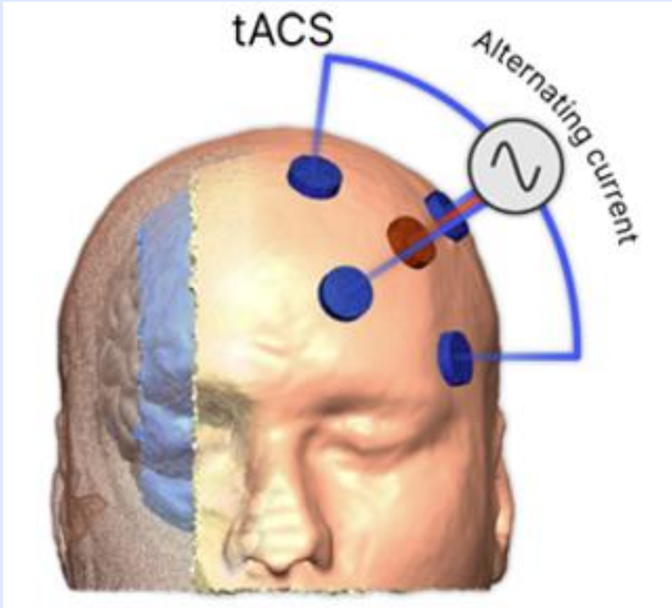

Figure 2: *Transcranial Alternating Current Stimulation*

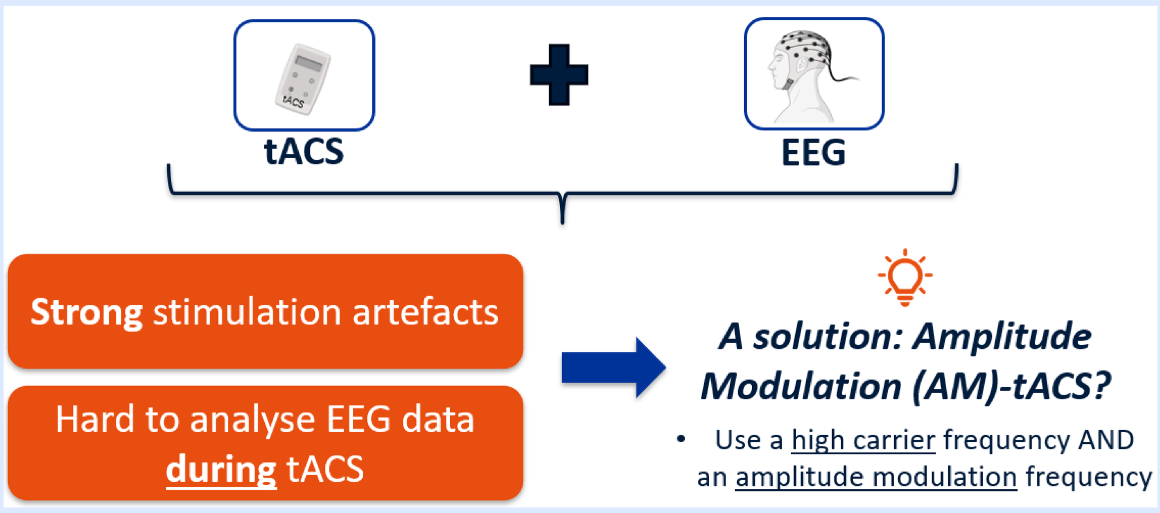

Figure 3: *Challenge of online tACS + EEG recording and potential solution, AM-tACS*

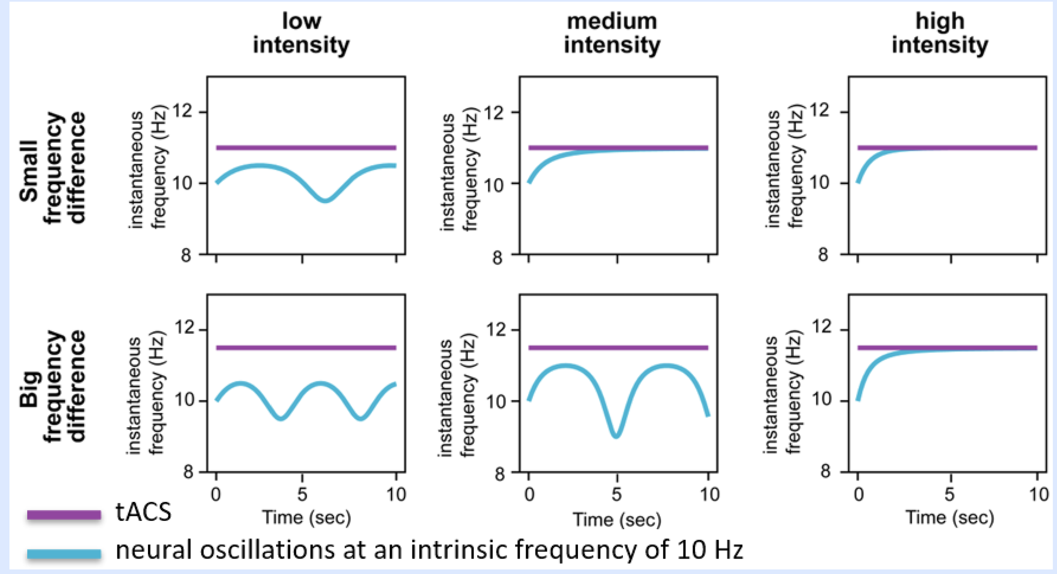

Figure 4: *Kuramoto coupling at two different frequency differences between tACS and neural oscillations, across three various intensities*

- The **Kuramoto model** is a computational model which aims to predict how the stimulation oscillators with different frequencies and intensities synchronise, considering the coupling strength, phase differences between oscillators, and their natural frequencies.
- **Figure 4** shows that when frequency gaps are substantial or tACS intensity is low, a specific pattern of instantaneous frequencies is anticipated, distinct from the tACS stimulation frequency.

? *Do the effects of **online** AM-tACS on the oscillatory coupling mechanism in the human brain **align with predictive computational models** such as the Kuramoto model, using EEG*

Experimental procedure

- 10 healthy individuals were included in the analysis → the study is still ongoing
- **tACS target**: left parietal lobe (P3); 4-in-1 electrode configuration
- 64-channel EEG system
- **No task** performed; listened to an audiobook → stay in a stable state
- **High carrier frequency**: 220 Hz
- **4 AM stimulation frequencies**: ±1.5 and ±2.5 Hz relative to the individual alpha frequency (IAF)
- **4 intensities**: 0.4, 0.8, 1.2, 1.6 mA (absolute values)
- 12-minute stimulation block, 10s ON, 4-6s OFF
- IAF measured in 3-minute blocks, eyes closed

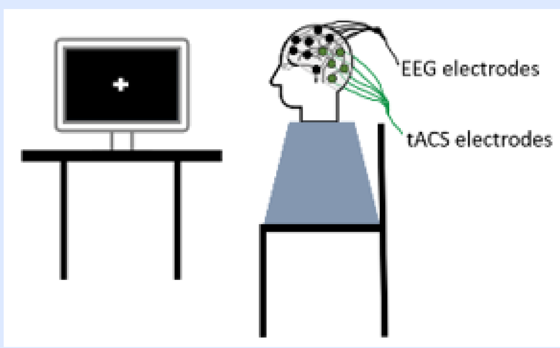

Figure 6: *Experimental setup*

Figure 5: *Experimental procedure*

Artefact removal

- **Figure 7** shows the different stages of artefact removal: Stimulation Artefact Source Separation (SASS) method – Independent Component Analysis (ICA) – Bad channels & trials removal – double notch filters (at stimulation frequency & its harmonic)

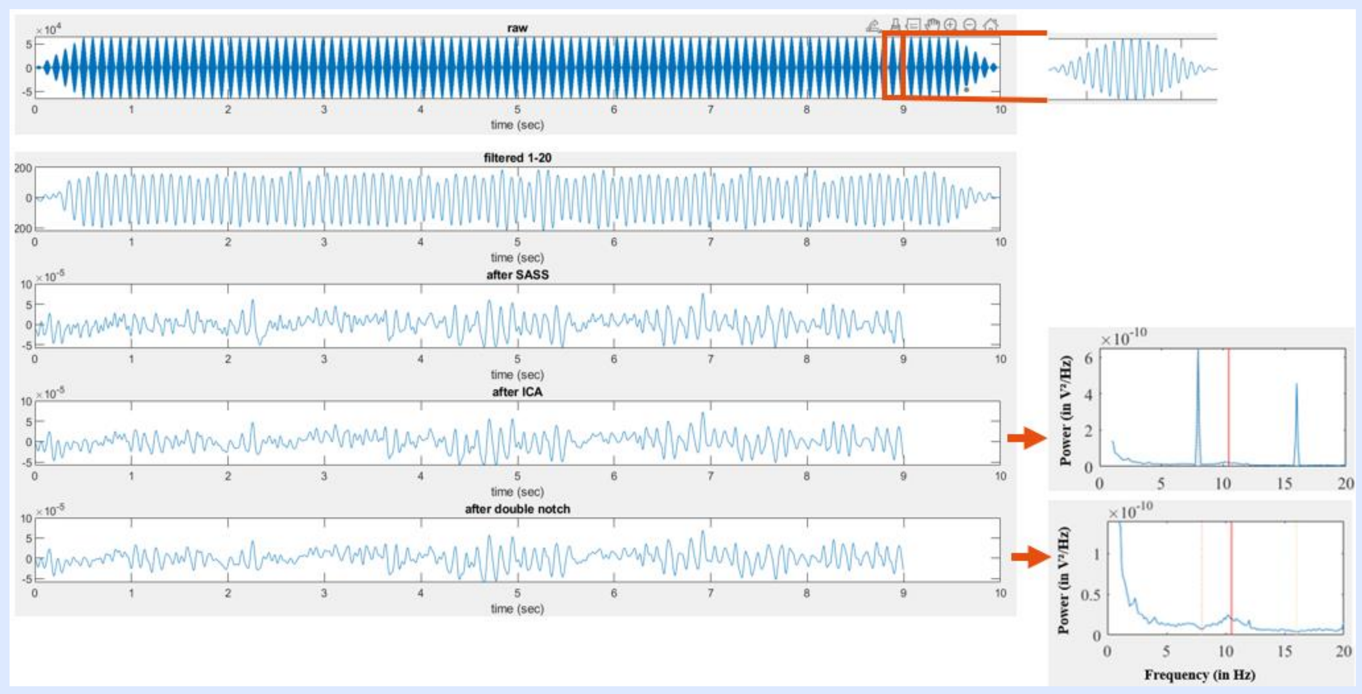

Figure 7: *Different stages of the stimulation artefact removal*

Results

- **No significant interaction** across the 16 conditions (stimulation frequencies × intensities), in all three dependent variables (peak power, oscillation peak frequency and variance of the Instantaneous Alpha Frequency – Inst-AF) both post and during stimulation.
- *Expected patterns*:
  - **Higher alpha peak power** and **frequency shifts** at stimulation frequencies **closer** to the IAF (-1.5 and 1.5 Hz) and **higher** intensities (1.2 and 1.6 mA).
  - An **inverted U-shaped pattern** at higher intensities and stimulation frequencies **closer** to IAF and **higher** intensities (1.2 and 1.6 mA) for the Inst-AF variance.

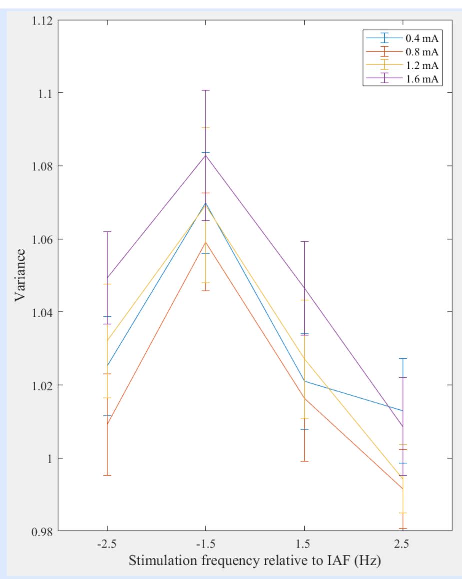

Figure 9: Instantaneous Alpha Frequency variance across the 16 conditions

→ *A few patterns aligned with these expectations.*

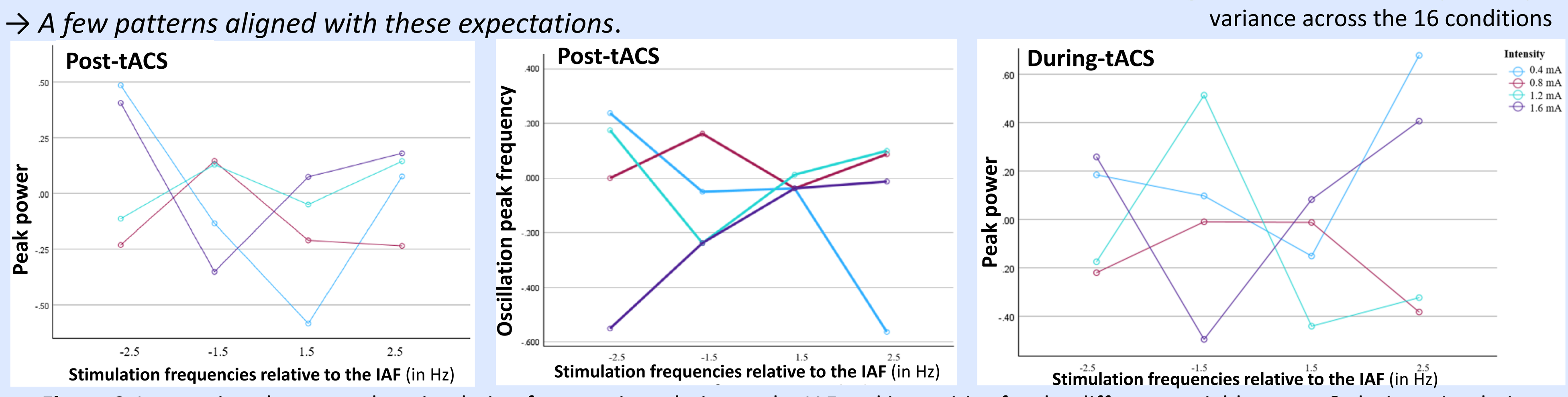

Figure 8: Interactions between the stimulation frequencies relative to the IAF and intensities for the different variables, post & during stimulation

Conclusion

- This study enabled EEG data analysis **during** stimulation, overcoming previous limitations.
- Although no significance was reached, some patterns **aligned with the hypothesis**, i.e., the Kuramoto model, suggesting promising avenues for future investigations.
- This research **underscores the complexity of understanding tACS effects on neural oscillations** and lays a solid foundation for future studies to comprehensively elucidate these mechanisms.

References

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