The effects of thalamic temporal interference stimulation on steady-state visually evoked potentials

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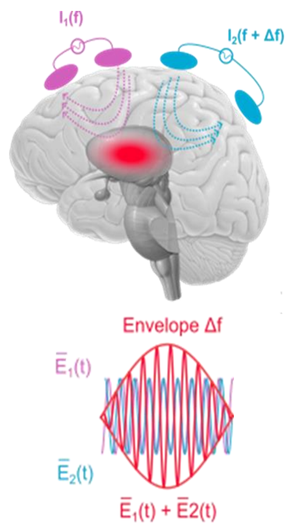
Introduction

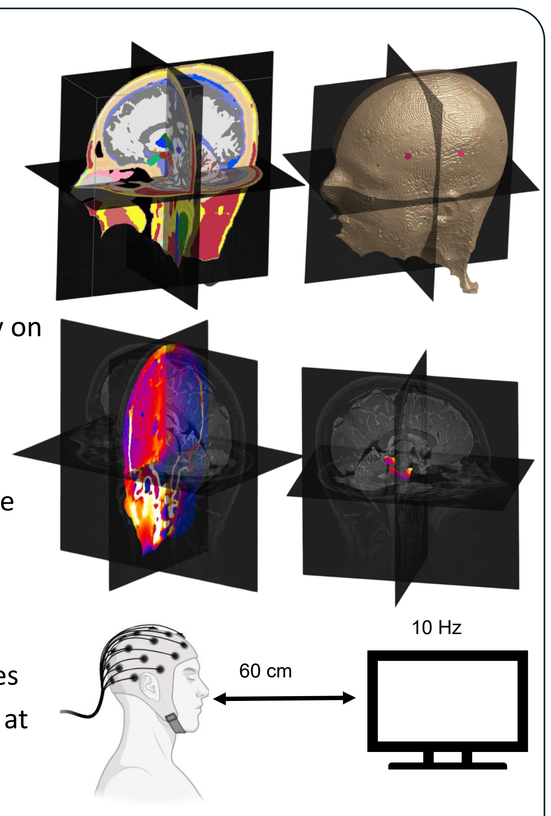
- **Temporal interference stimulation** (TIS) is a non-invasive technique that enables **deep brain neuromodulation** using an envelope generated by two high-frequency electric currents[1]
- The **thalamus** plays a critical role in sensory processing, particularly in **visual perception** and oscillatory alpha activity (8 – 12 Hz)
- **Steady-State Visually Evoked Potentials** (SSVEPs) are brain responses to repetitive visual stimuli, largely driven by **thalamocortical interactions**[2]
- **We probe SSVEP dynamics using thalamic TIS.**



Methods

Participants: N = 21 (F = 9), age = 18-34 (*m* = 23)

- **FEM**: Finite Element Method (FEM) modelling predicted optimal TIS montage for achieving the highest possible EM field strength in the thalamus
  Montage used: *1. FC5 + F8 ; 2. CP5 + P8*
- **SSVEP**: 10 Hz flicker was presented using PsychoPy on a PC monitor (60 Hz refresh rate). Stimulus times were measured using an optical sensor (StimTrak, BrainProducts, DE)
- **Electrode Digitisation**: TIS electrode positions were recorded against skull landmarks using Brainsight Neuronavigation (BrainBox, UK), EEG electrode positions using CapTrak (Brain Products, DE)
- **HD-EEG**: High-density EEG with 64 active electrodes (actiChamp, actiCap, BrainProducts) was recorded at 500 Hz sampling rate using LabStreamingLayer (*labstreaminglayer.org*)
- **TIS**: Temporal Interference Stimulation was delivered using a TI stimulator (TI Solutions AG, CH) with two alternating current sources at: f_1 = 2000 Hz, f_2 = 2130 Hz, , Δf = 130 Hz

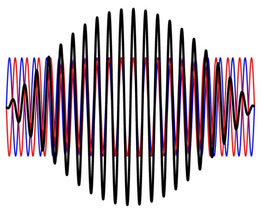


TI stimulation parameters	
f_1	2000 Hz
f_2	2130 Hz
Δf	130 Hz
ramp on/off	5 s
TI ON	5 s
Current amplitude	2 mA

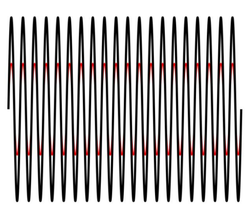
- **Conditions:**
  - **TIS** (Δf = 130 Hz, I = 2 mA)
  - **High-frequency control** (Δf = 0 Hz, I = 2 mA)
  - **OFF** (Δf = 0 Hz, I = 0 mA)
  - 60 trials per condition, counterbalanced

60 x

Temporal Interference
f_1 = 2000 Hz, 2 mA
f_2 = 2130 Hz, 2 mA



High-frequency control
f_1 = 2000 Hz, 2 mA
f_2 = 2000 Hz, 2 mA

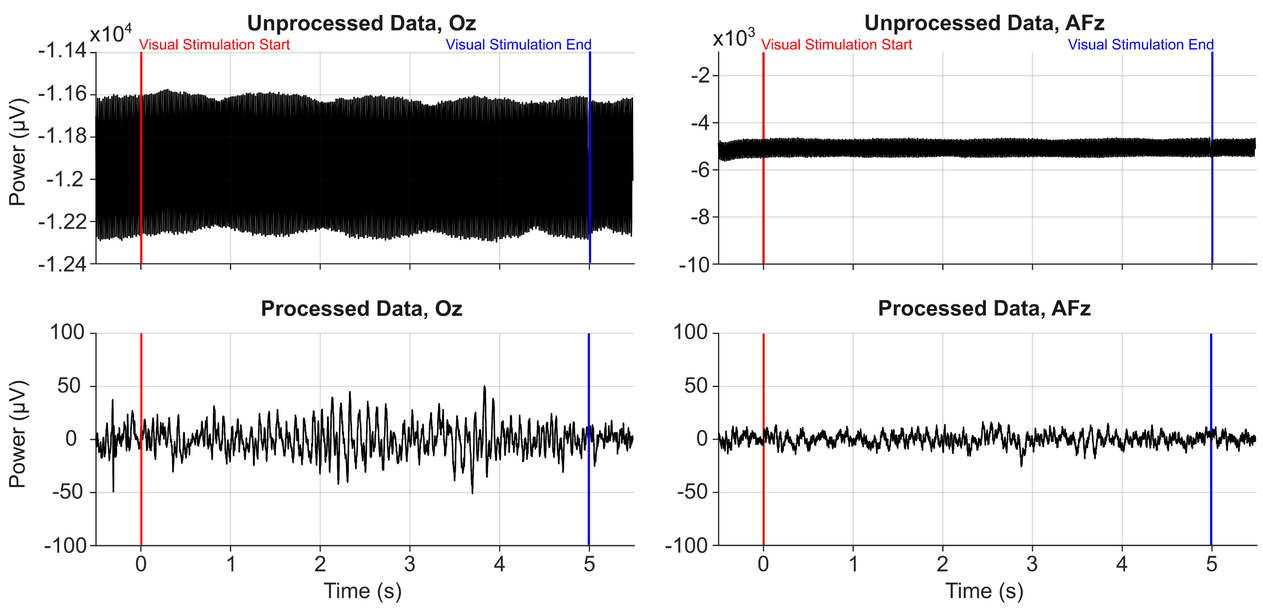


Off
f_1 = 0 Hz, 0 mA
f_2 = 0 Hz, 0 mA

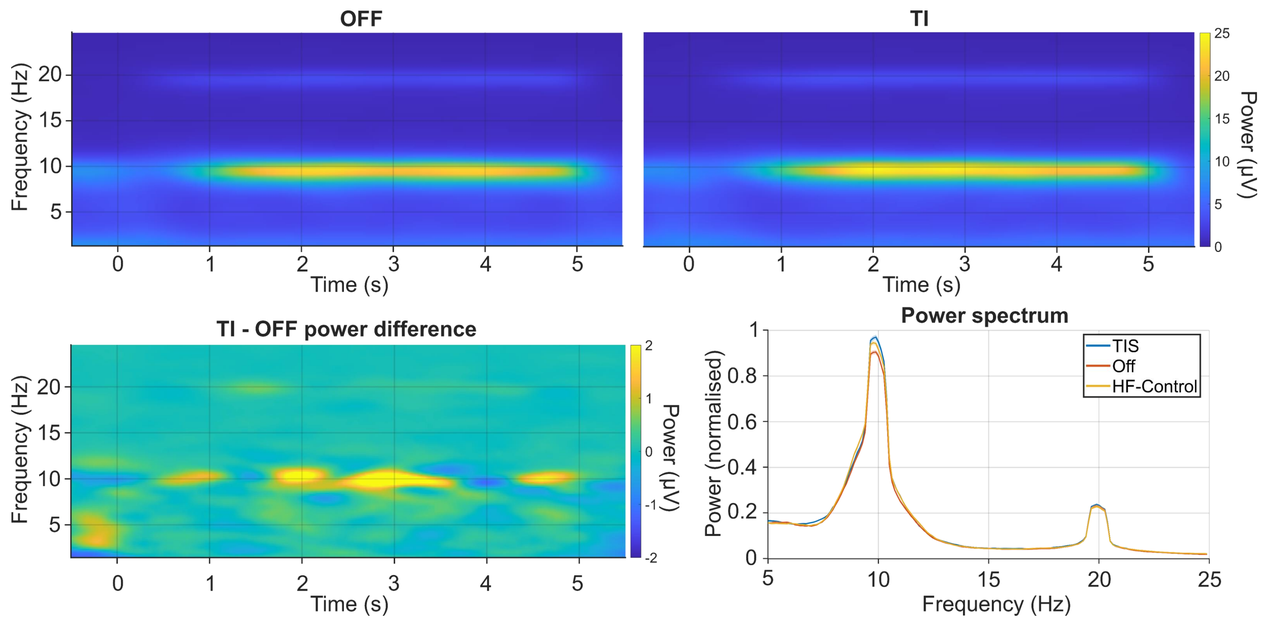
Results

1 Minimal EEG artefacts during TIS

- TIS artefacts are strongest close to TIS electrode positions
- EEG artefact rejection is possible during ongoing TIS trials
- 1 Hz high-pass filter, 150 Hz low-pass filter, notch filter, ICA eye-blink removal

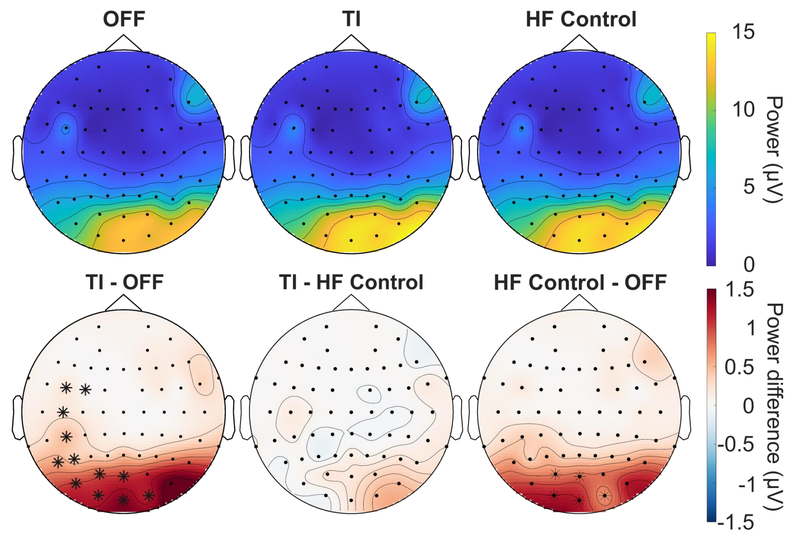


2 Flicker evokes reliable SSVEP



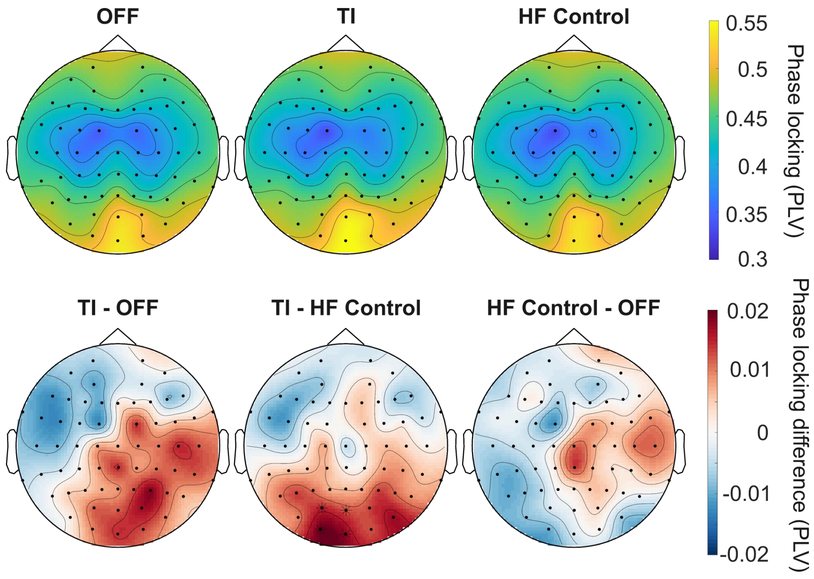
3 TIS increases SSVEP response power

- SSVEP is strongest occipitally
- Occipital / Left-parietal SSVEP is **significantly stronger during TIS** compared to OFF (cluster-corrected, p = .007)
- HF-Control shows a trend towards increased occipital SSVEP (cluster-corrected, p = .088)
- No significant difference in power between TIS and High-Frequency Control)



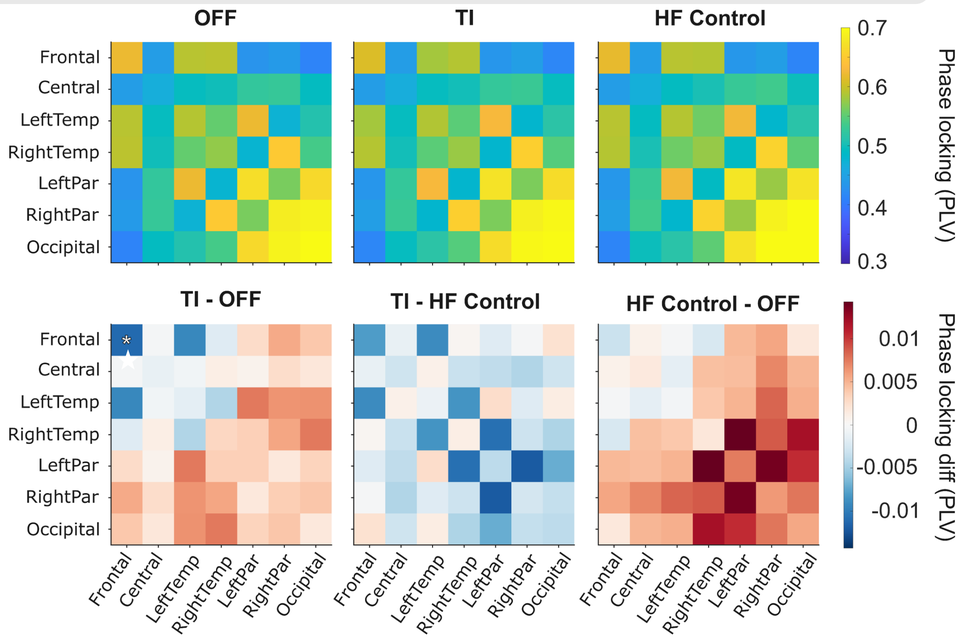
4 TIS increases phase-locking to visual stimulus

- Phase-locking to visual stimulus is highest occipitally
- Left occipital electrodes show a trend towards **increased phase-locking during TIS** compared to HF-Control (cluster-corrected, p = .079)
- A linear mixed-effects model including all trials shows a significant difference between TIS and HF-Control
  (PLV ~ Condition + Trial + (1|ID)
  t(2369)= 2.04, p =.04)



5 TIS decreases frontal alpha-band synchronisation

- Phase-locking at stimulus frequency between brain regions is highest occipitally/parietally
- Phase-locking within frontal electrodes is **significantly decreased during TIS** compared to OFF (FDR-corrected LMMs between region pairs, PLV ~ Condition + (1|ID), p = .003)



Conclusion

- We successfully implemented concurrent HD- EEG and TIS with minimal artifacts
- FEM predicts EM field strengths of up to 0.6 V/m (AM envelope amplitude) in the posterior thalamus
- Thalamic TIS increases the amplitude of the SSVEP response
- HF stimulation shows a trend towards increasing SSVEP amplitude
- Thalamic TIS increases the phase-locking of occipital EEG to the SSVEP stimulus
- Thalamic TIS decreases alpha-band synchronisation in frontal areas

References: 1 Grossman et al., *Cell*, 169(6):1029-1041.e16, 2017; 2 Bayram et al., *J. Clin. Neurophysiol.*, 42(2), 2011