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Overview of hardware artefacts during simultaneous tES and EEG

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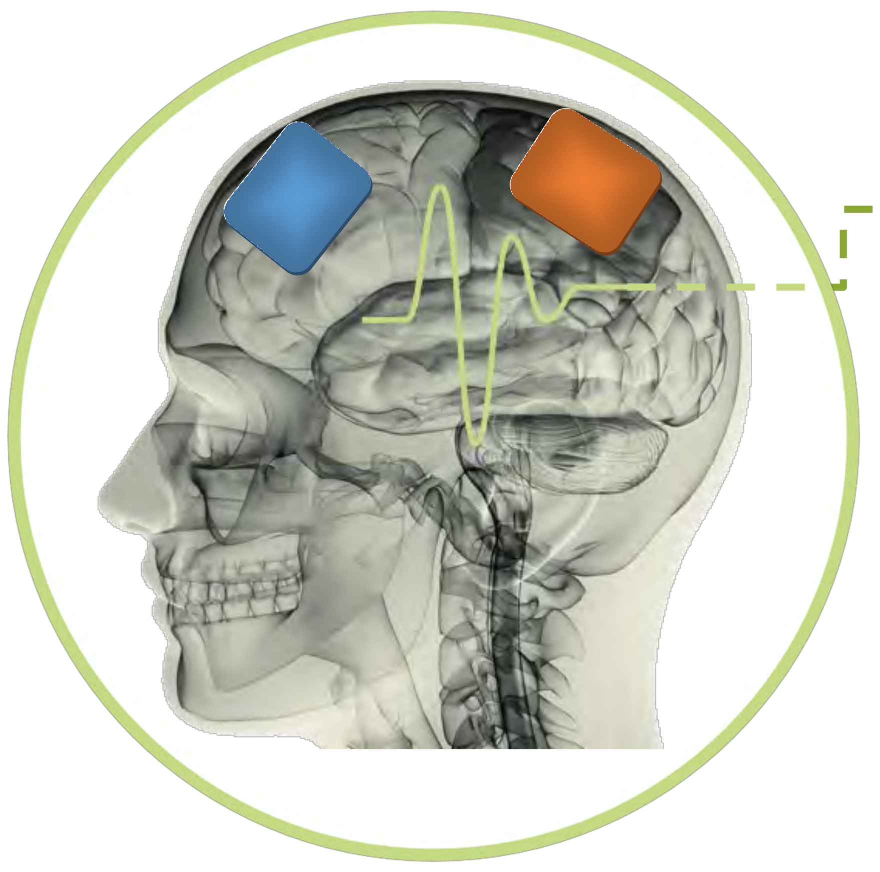
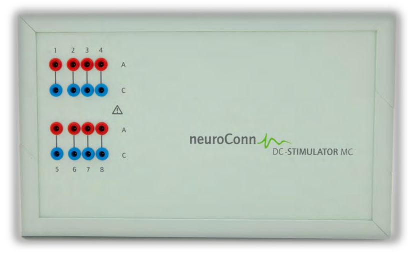


Introduction

There is a need of understanding the mechanisms behind transcranial electric stimulation (tES) due to its high inter- and intra-individual variability in response [1]. Since brain oscillations can be used as rapid markers of brain states in a variety of brain functions, targeting brain oscillations using tES might elucidate and clarify its mechanisms [2]. However, linear and non-linear artefacts emerge on the combination of tES with electroencephalography (EEG), particularly obscuring the small voltages measured from brain activity. Different methods have been proposed for the rejection of these artefacts [3, 4, 5]. Though, to our knowledge, no ultimate solution has become available for distinguishing truly amplitude- and phase-related tES effects on brain oscillations from residual artefacts [6, 7]. Here, we present some of the relevant hardware implementations that should be considered in order to reduce unwanted artefacts when combining tES and EEG. We described the improvements in noise performance, synchronisation and avoidance of power line interferences having a single- and multi-channel tES-devices on hand. We present a summary of hardware requirements for optimizing the combination of tES and EEG.

Single channel (**SC**) tES device
16 bits, 2,048 sps



Multi channel (**MC**) tES device
16 bits, 16,000 sps

Electrode artefacts

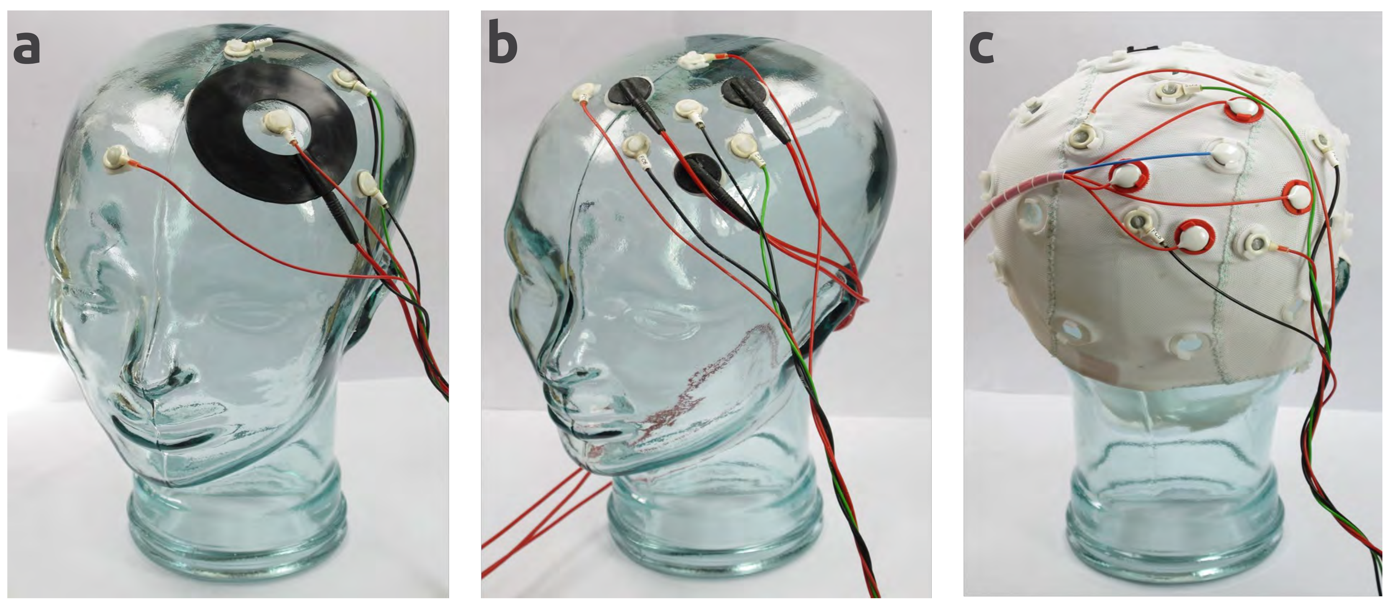


Fig. 1: Montages for EEG-tES: a) donut electrode , b) rubber circular electrodes , c) Ag/AgCl lentil electrodes.

Avoid any short-circuit between the EEG and tES electrodes.

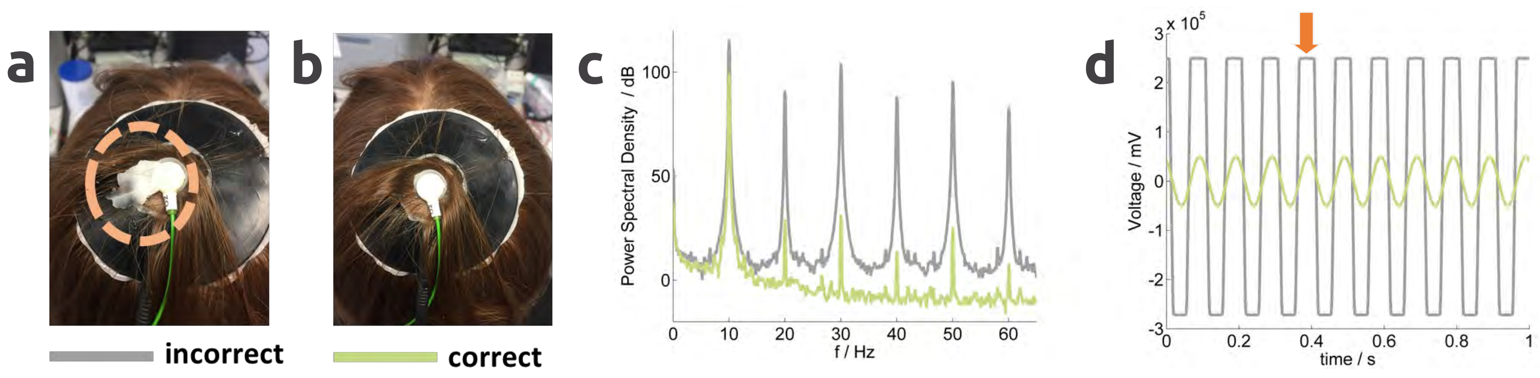
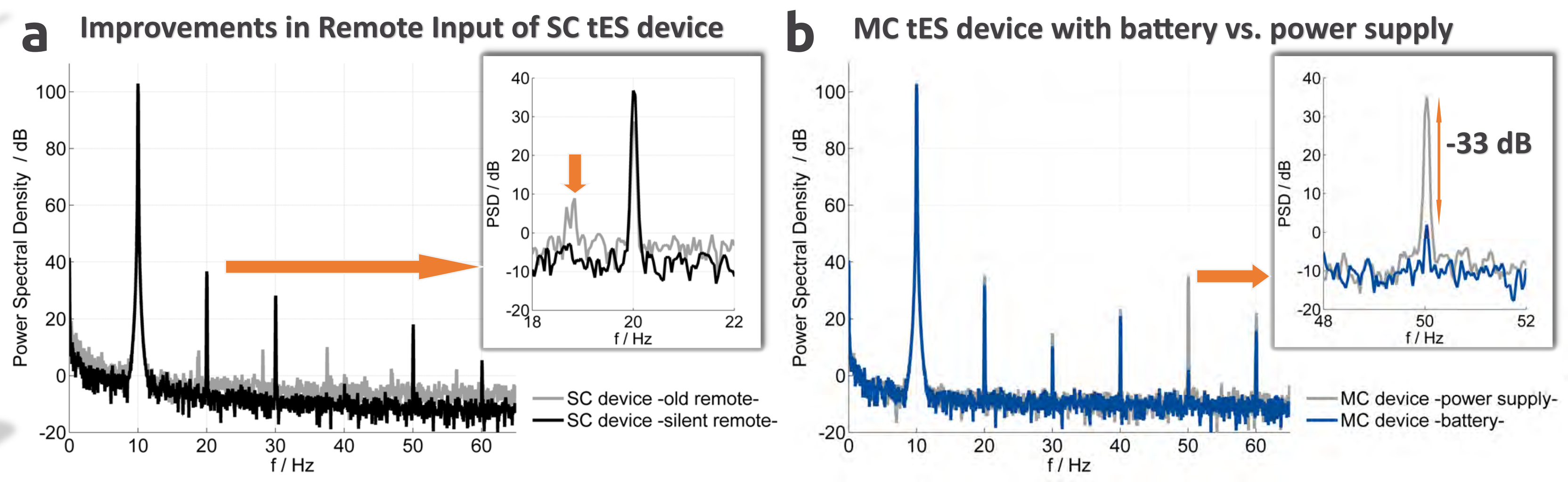


Fig. 2: EEG-tES montages: a) correct mounting , b) incorrect mounting with short-circuit between tES and EEG electrodes. c) EEG power spectrum of tACS at 10Hz of 1mA and, d) corresponding time course during tACS. The green line represents the EEG signal when there is no short-circuit between the EEG and tES electrodes (a), the grey line represents the EEG signal when there is a short-circuit (b). The short-circuit leads to an increase of noise and saturation of the EEG amplifier.

Noise artefacts



Use battery–operated tES devices with best noise profiles.

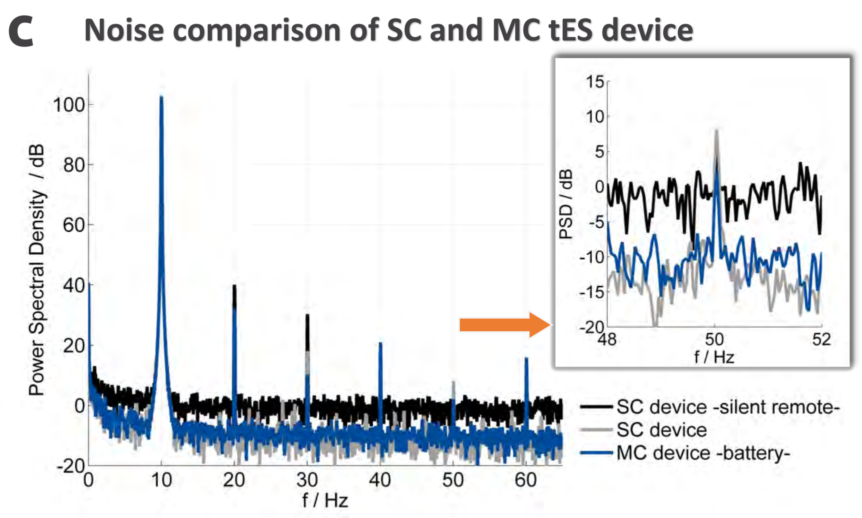
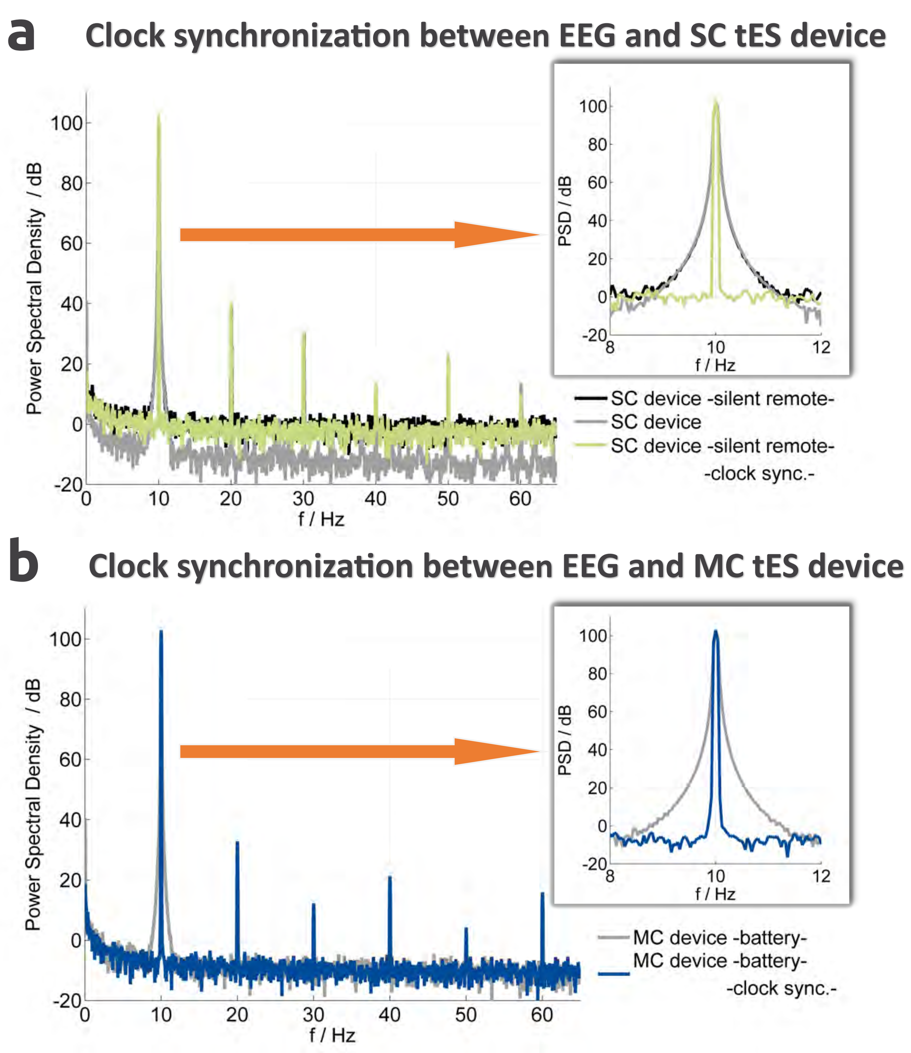


Fig. 3: Power spectrum showing the EEG signal acquired over a resistor (100Ω) during tACS at 10Hz of 1mA. a) Improvements of the analogue circuit for controlling the SC tES device remotely. The silent Remote Input shows a cleaner spectrum (no distortion at 9.3Hz and its harmonics). b) Using a battery solution for the MC tES device, which is normally operated by power supply, reduced the noise at 50Hz by 33dB (factor 2000). c) Comparison between the MC tES device and the SC tES device and its Remote Input. An increase in broadband noise is observed when the SC tES device is operated remotely, due to the external signal generator.

Leakage artefacts



Use clock synchronization for best EEG quality.

Fig. 4: Power spectrum showing the EEG signal acquired over a resistor during tACS at 10Hz of 1mA. a) Clock synchronization between the EEG device and the SC tES device (using remote control) narrowed the tACS artefact at 10 Hz and its harmonics. b) Clock synchronization between the EEG device and the MC tES device (using Active Sync) narrowed the tACS artefact at 10 Hz and its harmonics as well. Clock synchronization reduces the spectral leakage error, which results in a sharp peak at the tACS frequency.

Conclusion

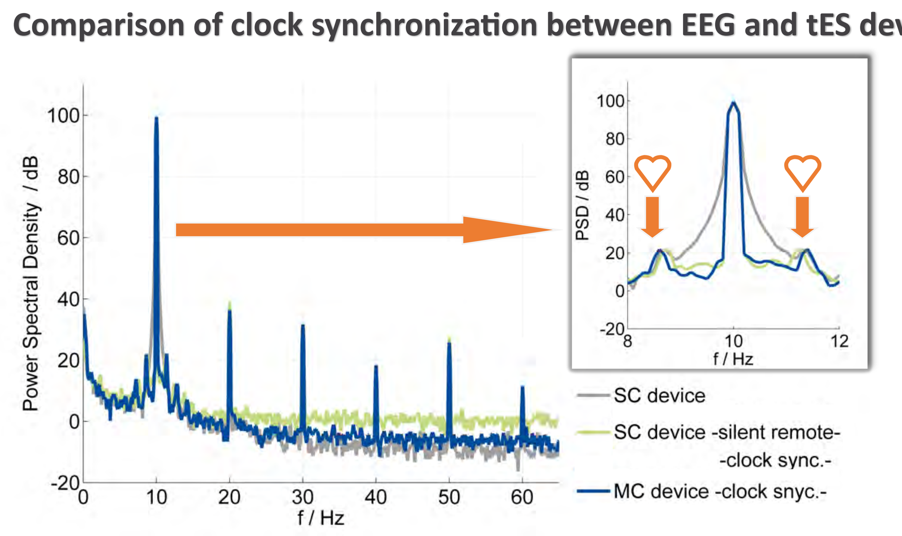


Fig. 5: Power spectrum of a human EEG during tACS at 10Hz of 1mA. Having a sharper tACS peak is important for tACS artefact correction and also allows to discriminate side bands due to heart-beat and respiration [6] from the stimulation artefact clearly.

Opportunities

- tES-EEG recordings free of powerline noise and inside the stimulation area
- tACS artefact correction at the precise stimulation frequency
- Analysis of non-linear artefacts due to physiological processes

References

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