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Brain Train: Closed-Loop EEG-tACS Technology

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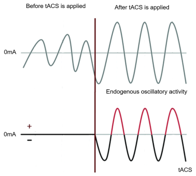
Background



In recent years, the emergence of noninvasive brain stimulation (NIBS) has gained momentum, as it allows for targeted cortical modulation. Transcranial alternating current stimulation (tACS), a specific NIBS technique, is the process of applying alternating electrical current at a set frequency to interact with the brain's natural cortical oscillations. Underlying cortical oscillations of neurons can be manipulated in a process known as entrainment. If the input sine wave (2mAor below) has a frequency closely matching that of the endogenous brain activity, phase locking will occur, allowing the input frequency to be adjusted, bringing the cortical oscillations with it. Research has suggested that tACS can help improve symptoms of ADHD, Alzheimer's, Parkinson's, and dementia through entrainment of various neuronal groups and improving the working memory of these individuals.

Problem

With products on the market today, it is not possible to ensure tACS is having a desired effect on the target region without stopping the treatment. A closed-loop tACS/EEG system is needed to advance this field of research and a large limiting factor is the lack of electrodes on the market capable of simultaneous read/write functionality.

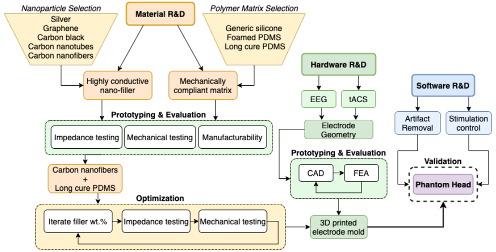
Goals & Objectives

Material Development
- High conductivity
- Ergonomic comfort
- Signal integrity
- Biocompatible
- Manufacturability

Hardware Development
- Record EEG data
- Generate stimulation waveforms
- Validate via phantom head

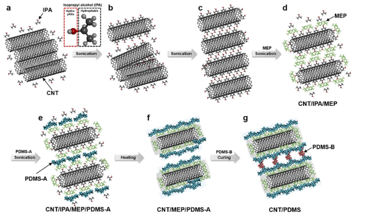
Software Development
- Cross-platform
- Filter tACS artifact from EEG signal
- Phase lock with neural oscillations
- Closed-loop algorithms

Methods & Processes

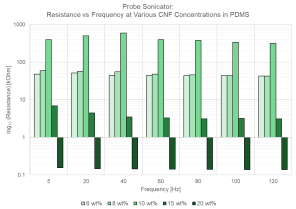


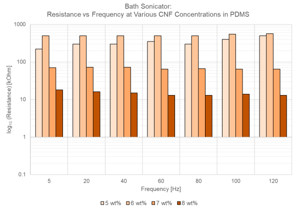
Results & Final Concepts

Material Development



Kim, et al. (2018)

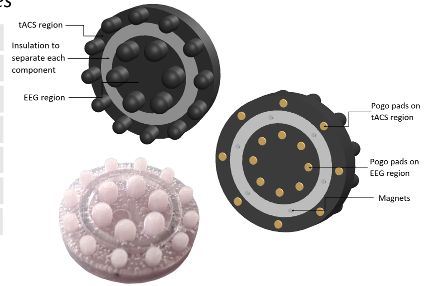




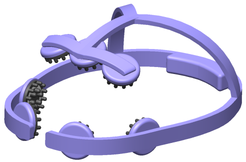
Carbon nanofiber (CNF) concentration and sonication methods were both tested in polydimethylsiloxane (PDMS). Samples become more robust to large changes in frequency as mean resistance values decrease. So far, the probe sonication method shows more promise than the bath sonication method. The use of multiple sonication steps with sequenced suspension media provides optimal dispersion of nanoparticles.

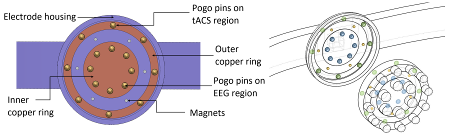
Electrode Design and Prototypes

- Localized stimulation and signal reading
- Ease of manufacturability
- Ability to penetrate hair
- Reusability
- User comfort
- Maximize surface contact with scalp
- Quick set up time



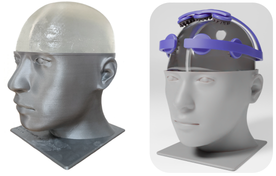
Headset Design

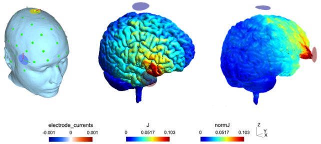




Phantom Head

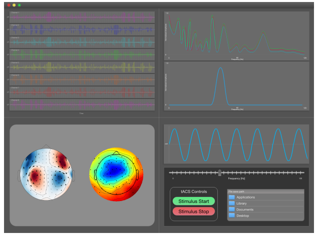
A physical phantom head was created to determine BrainTrain electrodes' ability to effectively read EEG data and administer tACS. The gelatin has an impedance matching that of gray matter in the brain. To simulate brain activity, pre-recorded EEG data is transmitted through the phantom head and electrodes are placed on the surface of the gelatin brain to determine how effectively they can acquire a signal. Additionally, the phantom head would be used to develop a model of EEG recordings with the tACS stimulation artifact present. This data would then be used to optimize the artifact removal algorithm. Complete validation and verification testing was postponed due to the current pandemic restrictions.

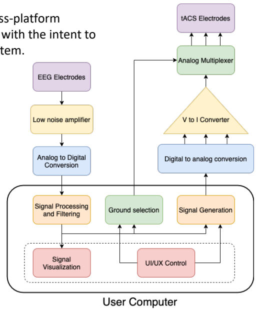




Software & Hardware

The BrainTrain software and hardware systems were developed with maximum functionality. The hardware encompasses both an EEG sub-system and a tACS sub-system which is easily expandable to additional channels of both signal acquisition and stimulation. The software was developed using open-source cross-platform frameworks. This software and hardware combination was built with the intent to further the research and develop of a closed-loop EEG+tACS system.





Future Work

Material Development
- Tensile and compression testing of electrodes
- User comfort optimization
- Reusability optimization

Hardware Development
- Record EEG data
- Generate stimulation waveforms
- Validate via phantom head
- Reduce footprint of electronics with custom PCB

Software Development
- tACS artifact removal algorithm
- Real-time control algorithm verification and validation
- Develop models of neural activity and response to stimulation

References

Kim, J., Hwang, J., Hwang, H. *et al.* Simple and cost-effective method of highly conductive and elastic carbon nanotube/polydimethylsiloxane composite for wearable electronics. *Sci Rep* **8**, 1375 (2018).
Tavakoli, Amir V., and Kyongsik Yun. "Transcranial Alternating Current Stimulation (TACS) Mechanisms and Protocols." *Frontiers in Cellular Neuroscience*, vol. 11, 2017, doi:10.3389/fncel.2017.00214.
Nan, Wenya, et al. "Individual Alpha Neurofeedback Training Effect on Short Term Memory." *International Journal of Psychophysiology*, vol. 86, no. 1, 2012, pp. 83–87., doi:10.1016/j.ijpsycho.2012.07.182.