Experimental and Modeling Insights into Neural Dynamics Under Alternating Current Stimulation (tACS)

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Transcranial electrical stimulation (TES) has been widely used to probe neural functions and explore psychiatric treatments. However, its effect on neural populations remains poorly understood, given the high variability in results1. Among TES modalities, alternating current stimulation (tACS) has been shown to modulate firing rate and dampen oscillations2. While sinusoidal waveforms at specific frequencies are commonly used in tACS protocols, numerous parameters – such as waveform shape and frequency range - could significantly impact neural dynamics. To investigate the effects of tACS on neural activity, we first analyzed neural recordings captured with an electrode array implanted in the V4 area of a rhesus monkey (Macaca mulatta)2. During these recordings, the pre-trained subject performed a fixation task while a TES device delivered sinusoidal currents at 5, 10, 20 and 40 Hz repeatedly. SHAM stimulation periods were interspersed to capture baseline activity. During SHAM, power spectral analysis revealed a distribution dominated by low-frequency activity. This pattern was replicated using a sparsely and recurrently connected Izhikevich spiking neural network (SNN)3 (Fig. 1A). We then compared normalized power spectra for the four tACS input frequencies in both experimental data and simulations (Fig. 1B). Notably, the 40 Hz input produced the largest relative increase in power at its respective frequency compared to SHAM (Fig. 1C). While 10 Hz resulted in the smallest relative increase in the experimental data alone, other frequencies showed more consistent effects across both experiments and simulations, demonstrating the model's ability to replicate relevant patterns of experimental results. These findings validate the Izhikevich

SNN model as a tool for further exploration of stimulation waveforms and frequencies (Fig. 2). Remarkably, the 5 Hz square wave might be an optimal choice to increase network synchrony, while the positive sawtooth does the opposite. Together, these results highlight the potential of the Izhikevich model as a tool for optimizing tACS parameters in both research and clinical applications.

References:

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