tACS induces neural entrainment in neocortical neuron models

Harry Tran[1], Sina Shirinpour[1], Alexander Opitz[1]
[1] Department of Biomedical Engineering, University of Minnesota, Minneapolis, MN USA

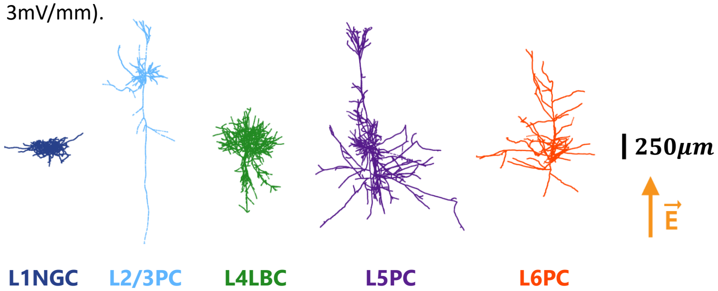
University of Minnesota

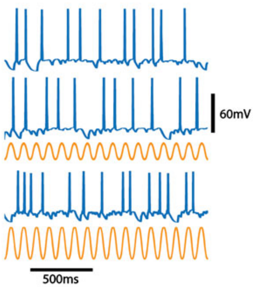
Introduction

Neural oscillations are a key mechanism for information transfer in brain circuits. Transcranial alternating current stimulation (tACS) is a non-invasive neuromodulation method which can directly interact with brain oscillatory activity by imposing an oscillating electric field on neurons. One of the main hypotheses for tACS is the idea of neural entrainment: a synchronization of neural activity with the applied stimulation waveform. However, entrainment is only one specific form of more general changes in spike-timing, meaning a deviation from regular spiking activity due to the applied stimulation. Despite a growing body of experimental studies, the exact mechanisms involved in the alteration of neural activity due to tACS are still not fully understood. Here, we investigate in a computational study the effects of tACS on morphologically realistic neurons with ongoing spiking activity.

Methods

A set of 25 neocortical cells have been used (5 cells for each layer). NEURON environment was used to reproduce the cell morphologies based on cable theory with proper biophysics. All cells were stimulated by a 10Hz tACS in the y-direction for 4 minutes with amplitudes achievable in humans (0.1 – 3mV/mm).

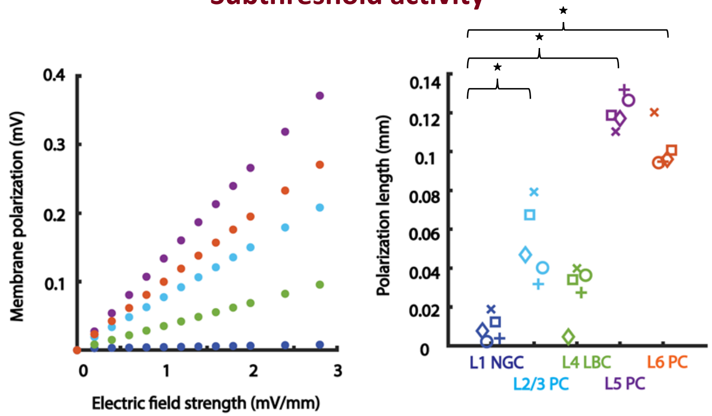




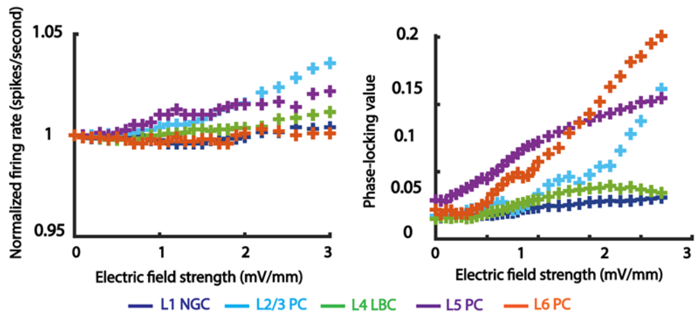
Spiking activity was generated through a randomly located synapse with a Poisson distribution. ***Top.*** Baseline neural spiking activity. ***Middle.*** Spiking activity for an electric field strength of 0.5 mV/mm. ***Bottom.*** Spiking activity for an electric field strength of 1 mV/mm.

Results

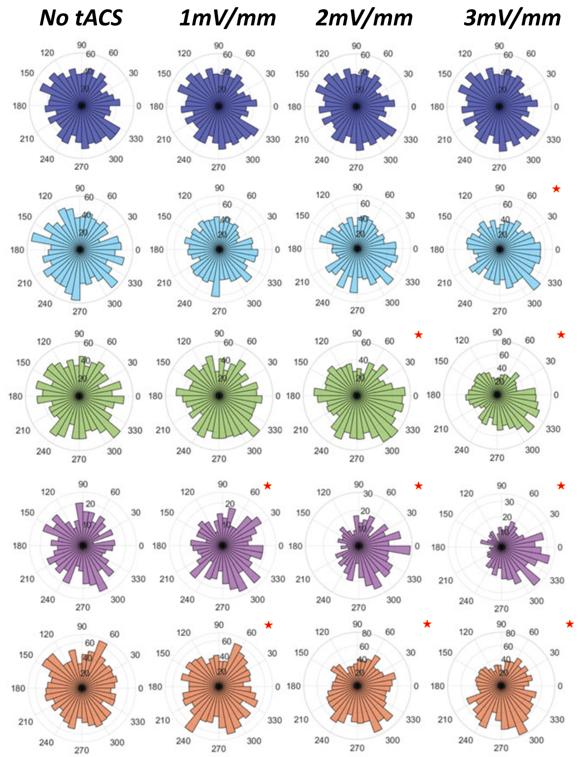
Subthreshold activity



Suprathreshold activity



Phase histograms



Conclusion

We demonstrate: 1) a linear relationship between membrane cell polarization and the applied subthreshold electric field strength, **2)** varying polarization lengths across different cell types resulting from their different morphologies **3)** no changes in the firing rate of investigated neurons for electric field strengths applicable to human experiments and **4)** spike timing changes and neural entrainment occurs at low electric field strengths with largest effects observed in pyramidal neurons.

Our findings support experimental results in non-human primates showing that changes in spike timing can already occur at low electric field strengths achievable in human studies, most prominent in pyramidal neurons.

Correspondence: htran@umn.edu

Reference: TRAN *et al.2020.* [in revision]

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