

2023 Annual Research Day – Oral session
April 19th, 2023, 2:00 p.m. – 4:30 p.m., PHAB 2A

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Simulation of neuronal phase response demonstrates nonstationarity with different phase shifts for excitation and inhibition

Rhythmic activity is ubiquitous neural systems, and impedance analysis has been widely used to examine frequency-dependent responses of neuronal membranes to rhythmic inputs. Impedance analysis assumes the neuronal membrane is a linear system, requiring the use of small signals to stay in a near-linear regime. However, postsynaptic potentials are often large and trigger nonlinear mechanisms. We therefore augmented impedance analysis to evaluate membrane responses in this nonlinear domain, looking at responses to injected current for subthreshold membrane voltage (V_{memb}), suprathreshold spike-blocked V_{memb} , and spiking in a validated neocortical pyramidal neuron computer model. Responses in these output regimes were asymmetric, with different phase shifts during hyperpolarizing and depolarizing half-cycles. Suprathreshold chirp stimulation gave equivocal results due to nonstationarity of response, requiring us to use fixed-frequency sinusoids. Sinusoidal inputs produced phase retreat: action potentials occurred progressively later in cycles of the input stimulus, resulting from adaptation. Conversely, sinusoidal current with increasing amplitude over cycles produced a pattern of phase advance: action potentials occurred progressively earlier. Phase retreat was dependent on I_h and I_{ahp} currents; phase advance was modulated by these currents. We hypothesize that the phase retreat and advance observed here have roles in phase precession seen in place and grid cells (among others), and the phase roll observed in non-place cells in hippocampus in vivo. Our results also suggest differential responses of cortical neurons depending on the frequency of oscillatory input in the delta -- beta range.