BMC Neuroscience

BioMed Central

Poster presentation

Statistical properties of noise-induced firing and quiescence in a Hodgkin-Huxley model

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from Eighteenth Annual Computational Neuroscience Meeting: CNS*2009
Berlin, Germany. 18–23 July 2009

Published: 13 July 2009

BMC Neuroscience 2009, **10**(Suppl 1):P40 doi:10.1186/1471-2202-10-S1-P40

This abstract is available from: http://www.biomedcentral.com/1471-2202/10/S1/P40

Introduction

The electrical behavior of neurons can show a significant amount of variability. Three sources of randomness contribute to this variability: fluctuating pre-synaptic inputs, variability in synaptic transmission and stochastic channel dynamics. Here we focus on how stochastic channel dynamics can influence the behavior of a single neuron. Previous work has shown that this variability may induce or suppress firing. This variability is also reflected in the distribution of inter-spike intervals (ISI). We aim to further investigate the effect of channel noise in neuronal dynamics by exhaustive numerical simulation for a wide range of both noise parameters and applied currents.

Methods

To simulate the classical Hodgkin-Huxley model [1] (HH) with stochastic channel dynamics, we use several previously described methods. Our first approach tracks the opening and closing of a fixed number of sodium (each consisting of 3 m gates and 1 h gate) and potassium (each consisting of 4 n gates) channels [2-4]. Since this is computationally expensive, we also consider directly adding multiplicative noise to the original equations that model channel dynamics following [5-8]. We also explore the behavior of neurons with different applied currents.

Results

Regardless of the number of channels, we find that the firing rate always increases as the applied current increases. For low applied currents, we find that stochasticity induces neuronal firing. The firing rate in the presence of low amplitude currents increases as the channel density decreases (more variability). Past a threshold applied current, the deterministic Hodgkin-Huxley equations show repetitive firing. This firing is also captured in our stochastic simulations. However, unlike lower amplitude currents, lower channel densities can cause slower rather than faster spiking in this case. A simplified model can explain how the firing rates depend on the channel density and noise level. We also find that noise from sodium channels has a smaller effect on the firing behavior of the neuron than noise from potassium channels. As the potassium channel density decreases, we find that the shape of the ISI distribution changes from a multi-modal to an exponential-tailed function with each peak roughly symmetrical. On the other hand as the sodium channel density changes, both the shape of the ISI distribution and the spiking frequency remain almost unchanged. As the applied current decreases the tail of the distribution gets heavier and spikes typically occur only after a long waiting time. Our studies show that noise can play significant and counterintuitive roles in determining the firing behavior of a neuron and lead to testable predictions of the real channel density based on the spiking frequency and shape of the inter-spike interval distribution.

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