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Effects of the axonal leak conductance on energy and information

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Ionic "leak" conductances which have little to no dependence on the membrane potential have long been known to exist in neurons and play a critical role in stabilizing them electrically. Hodgkin and Huxley measured a small total leak conductance (G_L) of approximately 0.3 mS/cm^2 in the squid giant axon in addition to much larger voltage-gated Na$^+$ and K$^+$ conductances [1]. Potassium leak currents may flow through several K$^+$ channels simultaneously [2], while a recent study [3] has identified a possible subfamily of Na$^+$ leak channels.

In this study, we use a computational model of the squid giant axon to explore the dependence of metabolic energy consumption and information rates on G_L. Energy and

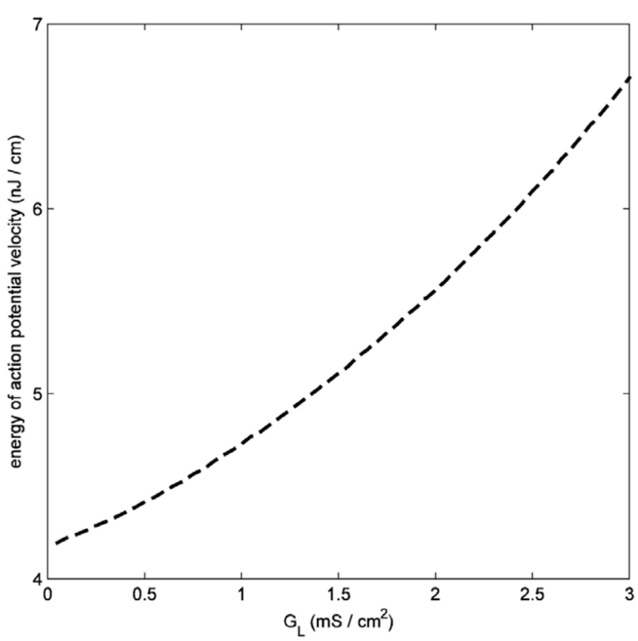

Figure 1
The metabolic energy of the AP velocity does not show a minimum as a function of G_L in the Hodgkin-Huxley model.

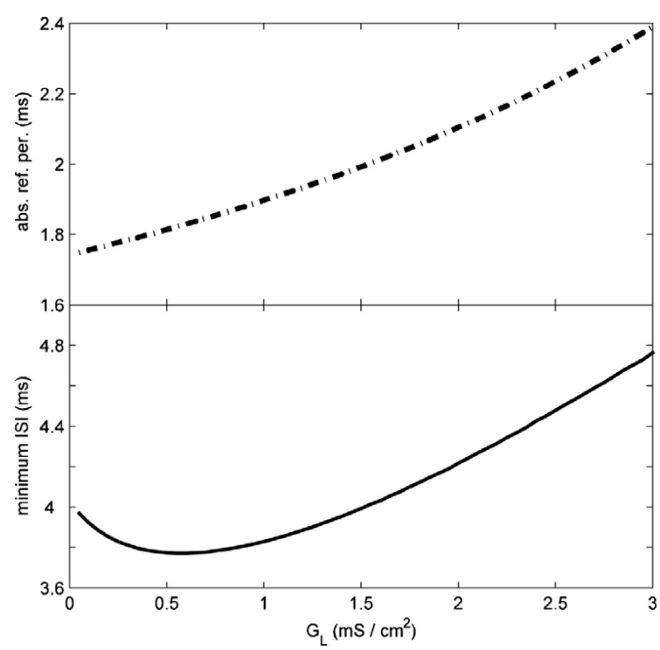

Figure 2
The minimum interspike interval (ISI) does show a minimum near the experimental value.

information, and more generally whether and how biological nervous systems are optimized for these quantities, have been the focus of much computational work in recent years. In a previous study [4], it was shown that the experimentally measured combined voltage-gated and leak conductances are at or near the optimal values that minimize the metabolic energy associated with the velocity of the action potential (AP). Here, we vary the leak conductance separately from the other conductances to see whether it is itself at an optimum for energy or information. As previously, we assume a prior constraint on the AP velocity and vary both the leak conductance and diameter so as to maintain this velocity.

While we do not find a minimum for the action potential energy as a function of G_L (Fig. 1), we do find one for the minimum interspike interval between two APs such that jitter, or the distortion of an interval between two successive APs, is below a certain limit (Fig. 2). This optimal value for G_L is fairly close to the measured value of 0.3 mS/cm^2, suggesting that nervous systems are optimized for information rates.

References

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