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A model for assessing ATP demands of sustained high frequency firing

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The continuous electric organ discharge (EOD) of the weakly electric fish, <i>Eigenmannia</i>, reflects action potentials (APs) fired by the EO's muscle-derived electrocytes. EODs enable electrosensing and communication. AP frequency is neurally controlled, with acetylcholine-gated channels (AChRs) mediating synaptic transmission. According to EOD-linked whole-fish O₂ consumption (for fish with EODs between ˜300-500 Hz) ATP demand per AP grows exponentially with frequency. The unimodal task, continual firing, and simple homogeneous structure of the EO render it especially suitable for probing excitable system energetics in relation to molecular, cellular and tissue features. We develop a model, Epm, to depict currents at the electrocyte's energy-dissipating Excitable posterior membrane. In situ, 3Na/2K-ATPases (pumps) counteract the dissipation of electrocyte E_{Na} (and E_K). Using Epm we calculate AP frequency-dependent "Na⁺ -entry budgets"for synaptic activation (pulsatile and/or steady-state, with/without noise). Comparison of Epm-calculated ATP consumption (inferred from total Na⁺ -entry) against published EOD-linked whole-fish O₂ consumption suggests that EOD-linked energy demands external to electrocytes (neuronal, circulatory etc) exceed, several-fold, those of electrocyte excitability per se. Well-understood conductance processes (as modeled by Epm) proved fully adequate for generating sustained APs (including during jamming avoidance responses) from 200-600 Hz. By contrast, although we computationally impose the equivalent of fast stimulatory variations in [ACh], even at the bottom of this frequency range the means by which synaptic transmission machinery so reliably achieves the requisite fast variations is a mystery. The simple <i>Eigenmannia</i> EO therefore continues to emerge as a fascinating model system for studying not only the energetics but the subcellular and broader-level dynamics of high frequency excitability.

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