Dendritic excitability controls overdispersion

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A neuron's input-output function is a central component of network dynamics and is commonly understood in terms of two fundamental operating regimes: 1) the mean-driven regime where the mean input drives regular and frequent firing, and 2) the fluctuation-driven regime where input fluctuations drive responses at relatively low firing frequency but with variable intervals. Active dendrites are expected to profoundly influence the input-output function by either controlling gain modulation or through the additive modulation by dendritic inputs that have been transformed nonlinearly as in an artificial neural network. However, both additive and gain modulations are thought to be weak in the presence of background fluctuations. Here we investigate how active dendrites, falling in either regime, shape the input-output function. Extending cable theory with features of generalized integrate and fire models, we develop a mean-field theory for neurons with active dendrites, capturing the integrative properties of dendrites and the soma in the presence of noise. We find that dendritic input controls interspike interval dispersion, reaching overdispersed states unaccountable by Poisson processes, but commonly observed in vivo. This effect appears in the fluctuation-driven regime, largely before dendritic input makes additive or multiplicative modulation of the firing frequency. We show that this mechanism implies that increasing the strength of somatic inputs can increase interval dispersion as long as dendritic spikes are not consistently above threshold. Consequently, neurons display not two but three fundamental operating regimes, depending on whether dendritic spikes or the somatic input reaches threshold. We validate our prediction that dendritic input controls overdispersion by re-analyzing previously published patch clamp recordings of cortical neurons. This perspective of neuronal input-output functions has implications for theories of neural coding, the credit-assignment problem, control of trial-to-trial variability, and how attractor networks can reach highly dispersed firing states.

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