A minimal integrate-and-fire model for Mossy Cells

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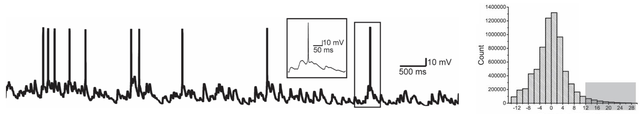
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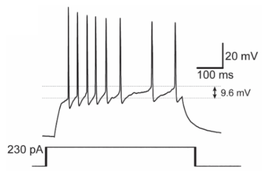
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Mossy cells (MCs) are glutamaergic interneurons in the hilus. They receive synaptic inputs mainly from Granule cells (GCs), CA3 pyramidal cells and hilar inhibitory interneurons (IN), and project their outputs back to GCs, and hilar interneurons. They have an intermediate firing rate as compared to GCs and inhibitory inter-neurons, and fire action potentials as a response to the animal passing through specific spatial positions. These positions that elicit firing are called place fields, making MCs place cells of multiple place fields. MCs participate in many processes involving the storage and retrieval of memories, spatial navigation, fear conditioning, and separation of patterns [1]. However, its membrane potential dynamics is often overlooked in theoretical and computational models of memory.

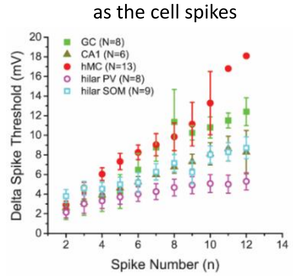
MC spontaneous activity



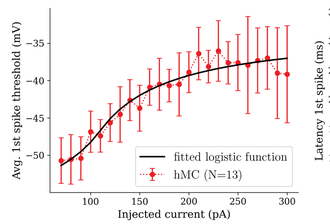
MC threshold dynamics



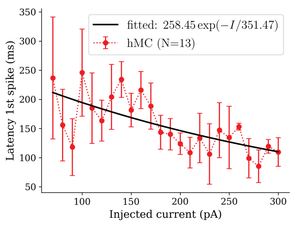
2) Relative threshold increases as the cell spikes

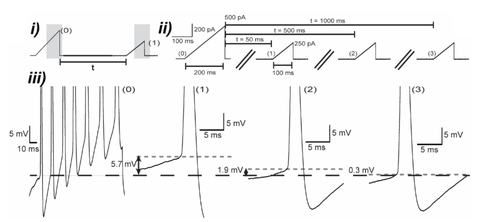


3) Initial threshold increases together with inj. current.

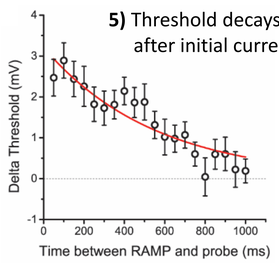


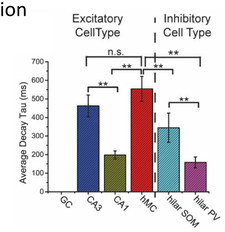
4) Spike latency decays with inj. current.



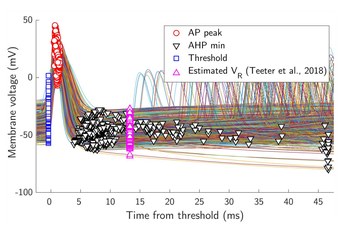


5) Threshold decays exponentially after initial current injection

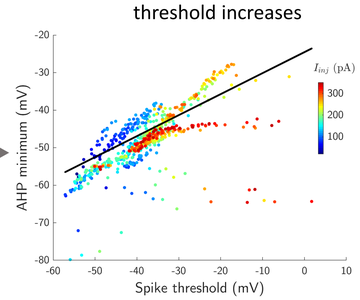


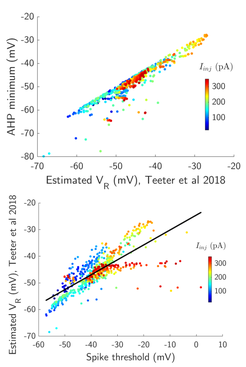


MC AHP dynamics

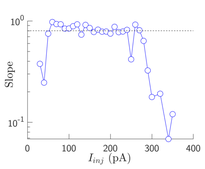


6) AHP minimum increases as threshold increases





7) AHP slope constant for a wide range of currents



Building a model

Membrane noise

$$\frac{dY}{dt} = -\frac{Y}{\tau_Y} + f$$

$$\frac{df}{dt} = \frac{f_0 - f}{\tau_f} + J\,x(t)$$

$J = 18$ mV (intensity of EPSP)
$f_0 = -72/\tau_Y$ mV/ms (baseline value of RMV)
$\tau_Y = 2$ ms (rise time constant)
$\tau_f = 200$ ms (decay time constant)
$x(t) = 0$ or 1 (Poisson process with rate r)
$r = 0.001$ (rate of Poisson process)

Exponential Integrate-and-fire with dynamic threshold

If $V(t) < \theta(t)$

$$\tau \frac{dV}{dt} = V_b - V + k e^{\frac{V - V_T}{k}} - R g_K (V - E_K) + R I_{ext} + \frac{\sigma}{2} \tau\, \eta(t)$$

$$\tau_1 \frac{d\theta}{dt} = V_0 + s\, f\big(R_\theta (I_{ext} - I_0)\big) - \theta$$

$$\tau_\theta \frac{d\theta_s}{dt} = -\theta_s$$

$$\tau_K \frac{dg_K}{dt} = -g_K$$

$$f(V) = \frac{V}{1 + |V|}$$

If $V(t) = \theta(t) + \theta_s(t)$

$$V(t + dt) = V_b + \alpha_R (V(t) - V_b) - \delta$$

$$\theta_s(t + dt) = \theta_s(t) + \frac{\theta_m - \theta_s(t)}{\theta_m} \Delta\theta$$

$$g_K(t + dt) = g_K(t) + \Delta g_K$$

Membrane parameters:
I_{ext} → applied current
$\tau = 38$ ms → membrane time constant
$V_b = -67$ mV → resting (or baseline) potential
$R \approx 150$ MΩ → membrane resistance
$\alpha_R = 0.8$ → reset voltage slope

$\delta = 2$ mV → reset voltage drop
$k = 10$ mV → voltage rise slope
$V_T = -45$ mV → voltage rise threshold
$E_K = -70$ mV → K inversion potential
$\tau_K = 40$ ms → K decay time

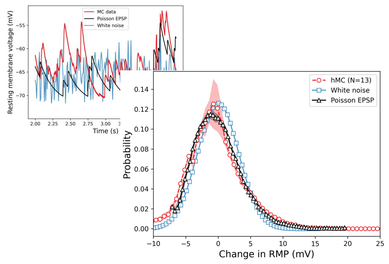
Threshold parameters:
$\tau_1 \leq 20$ ms → threshold-input coupling time
$V_0 = -46.67$ mV → threshold baseline
$s = 13.44$ mV → sigmoid scaling
$R_\theta = 13.43$ MΩ → threshold decay time

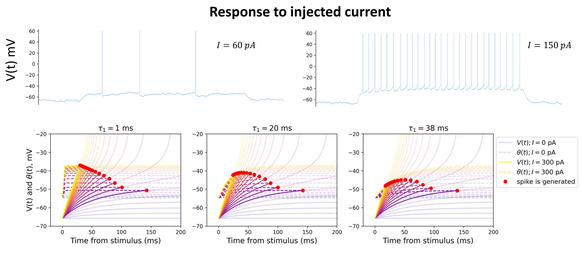
$I_0 = 110$ pA → threshold baseline current
$\tau_\theta = 540$ ms → threshold decay time
$\theta_m = -20$ mV → max threshold
$\Delta\theta = 3$ mV → threshold increment

All parameters fitted to experimental data

Model spontaneous activity

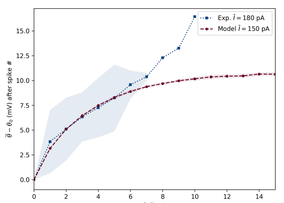
1) The double exponential EPSP model reproduces well the distribution of resting membrane voltages; white noise is worse.

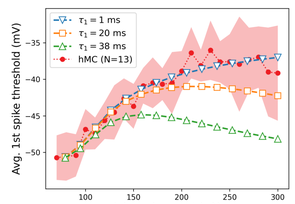


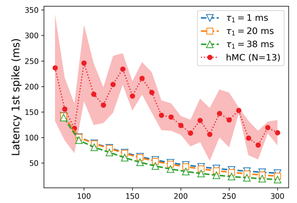


Model threshold dynamics

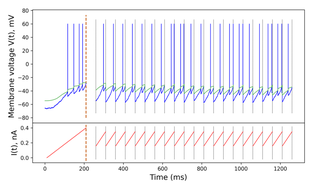
2,3,4) The spike-dependent and input-dependent threshold dynamics perfectly fit the data; the 1st spike latency presents only qualitative fit

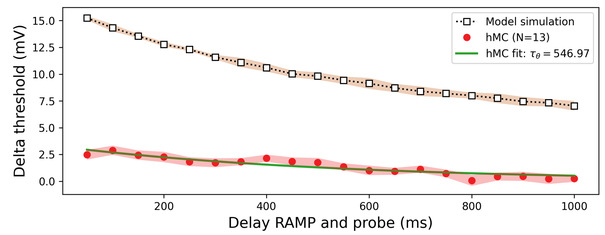






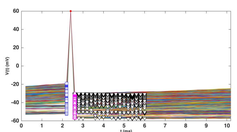
5) The threshold decay is systematically shifted from the experimental data by about 10-15 mV. We are working on fixing this gap!

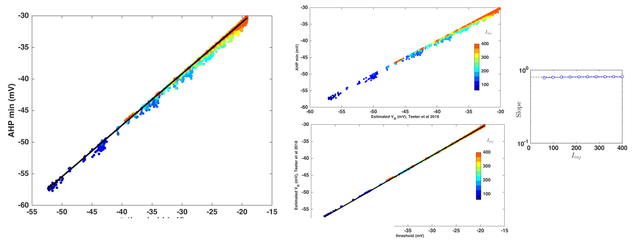




Model AHP dynamics

6,7) The AHP dynamics (reset potential) fits the model for small currents. However, in MC experiments, the AHP vs. threshold changes slope as the injected current increases.





Model computational properties

8) The f-I curve highlights a continuous underlying bifurcation, as expected for IF models with dynamic threshold. The experimental f-I curve is very noise and is not clear whether it is continuous or not (more cells are needed for a better average). This is because the step injections were not designed to probe for the f-I curve, but to look for the cells' intrinsic properties.

