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Cost of linearization for different time constants

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Persistent sodium and A-type potassium conductances serve as linearizing mechanisms over limited and different voltage ranges. This research investigates the relationship between time constants and the metabolic cost (here total potassium current I_K) of such linearization. This metabolic cost is a window into explaining the 40% energy use by postsynaptic elements of the brain [1].

We consider neurons under constant synaptic bombardment spending much of their time in a range of -62 to -58 mV with threshold around -55 to -52 mV. For this subthreshold voltage range, the A-type potassium (g_A) [2] and the persistent sodium (g_{NaP}) [3,4] are the most relevant linearizing conductances. Here 'linear' means that, within a certain voltage range, each additional active synapse makes the same depolarizing contribution, in contrast to the sublinear contributions occurring in purely passive dendrites.

Steady-state voltages and currents are evaluated for a single-compartment dendritic model under synaptic bombardment. There are three conductances in each analysis: the resting dendritic conductance g_d with a reversal potential of -72 mV; the synaptic conductance g_s with a reversal potential of 0 mV; and a voltage-dependent conductance, either g_{NaP} or g_A, with reversal potentials of +55 mV and -95 mV respectively. The assumed capacitance of this collapsed dendritic field is 1 nF.

Table 1 shows that, in the presence of an appropriate amount of active conductance (g_A or g_{NaP}), there is 1) a constant voltage range of linearization across time con-

Table 1: Sample results

g_d	g_s	g_{NaP}	Voltage range	g_{total}	Time constant	Total I_K
6.25 nS	0.68 ± 0.5 nS	0.16 ± 0.15 nS	-61.8 ± 7.2 mV	7.09 ± 0.6 nS	141 ± 1.4 ms	0.14 ± 0.04 nA
12.5 nS	1.37 ± 1.1 nS	0.33 ± 0.31 nS	-61.8 ± 7.2 mV	14.18 ± 1.4 nS	70.5 ± 7.2 ms	0.29 ± 0.07 nA
25.0 nS	2.75 ± 2.2 nS	0.66 ± 0.63 nS	-61.8 ± 7.2 mV	28.36 ± 2.8 nS	35.2 ± 3.6 ms	0.58 ± 0.14 nA
50.0 nS	5.5 ± 4.5 nS	1.32 ± 1.26 nS	-61.8 ± 7.2 mV	56.72 ± 5.7 nS	17.6 ± 1.8 ms	1.16 ± 0.29 nA
g_d	g_s	g_A	Voltage range	g_{total}	Time constant	Total I_K
6.25 nS	4.7 ± 1.2 nS	3.54 ± 0.35 nS	-51.1 ± 5.2 mV	14.5 ± 1.5 nS	68.0 ± 7.6 ms	0.44 ± 0.05 nA
12.5 nS	9.4 ± 2.5 nS	7.09 ± 0.70 nS	-51.1 ± 5.2 mV	29.0 ± 3.2 nS	34.0 ± 3.8 ms	0.88 ± 0.10 nA
25.0 nS	18.8 ± 5.1 nS	14.18 ± 1.40 nS	-51.1 ± 5.2 mV	58.0 ± 6.4 nS	17.2 ± 1.9 ms	1.76 ± 0.21 nA
50.0 nS	37.7 ± 10 nS	28.36 ± 2.81 nS	-51.1 ± 5.2 mV	116.0 ± 12.8 nS	8.6 ± 0.9 ms	3.5 ± 0.42 nA

stants and 2) there exists a direct relationship between time constant and total cost. Indeed as the time constant speeds up, the metabolic cost in terms of coulombs/sec increases as dictated by higher total conductance. To conclude: 1) faster computing is linearly increasing in metabolic cost; 2) changing inhibitory tone appears to require dynamic control of the available linearizing conductance if threshold is unchanged.

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