A BIOPHYSICAL MODEL OF PROJECTION NEURON IN MOTH PHEROMONE CENTRAL PROCESSING SYSTEM—MGC

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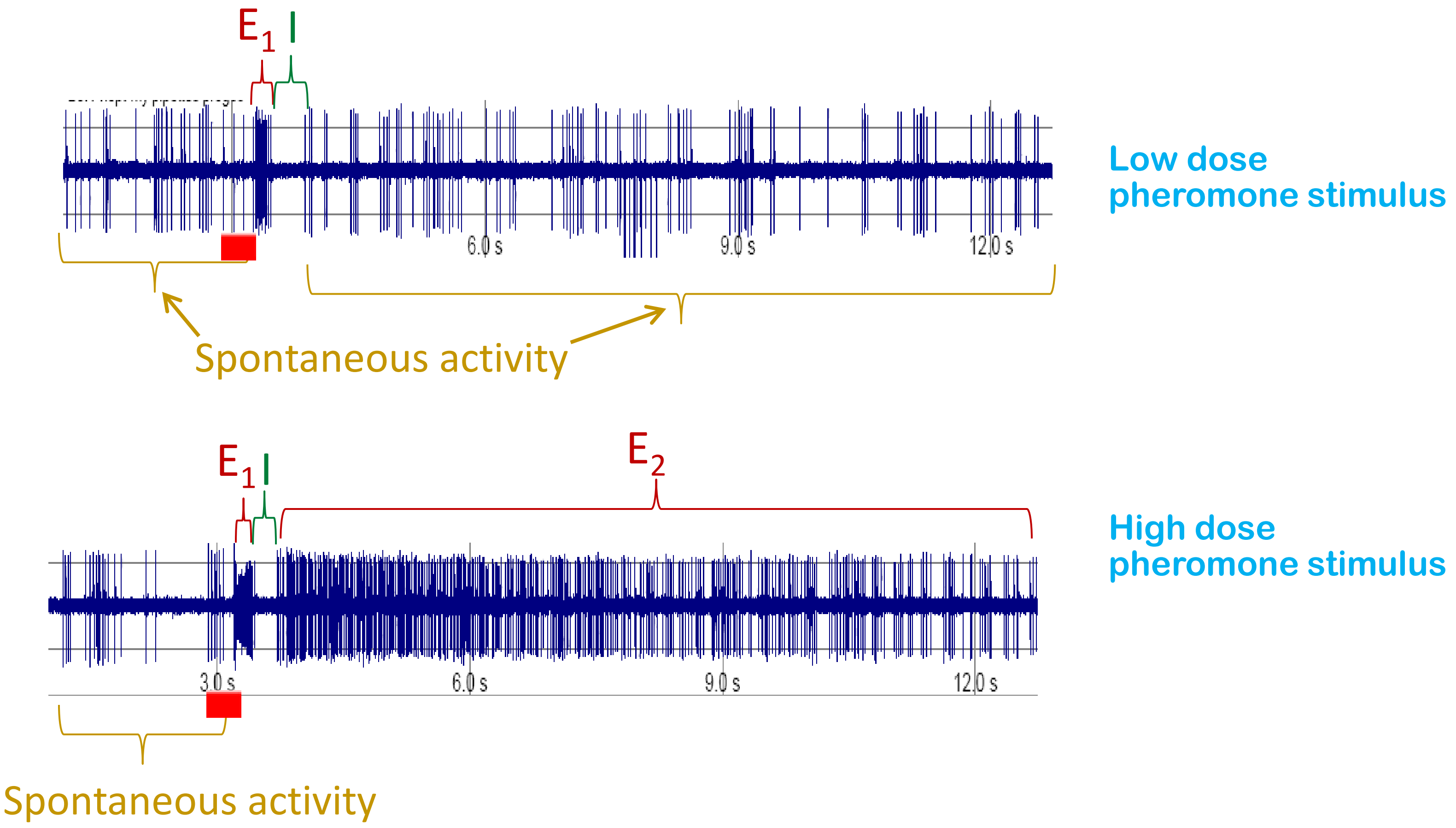
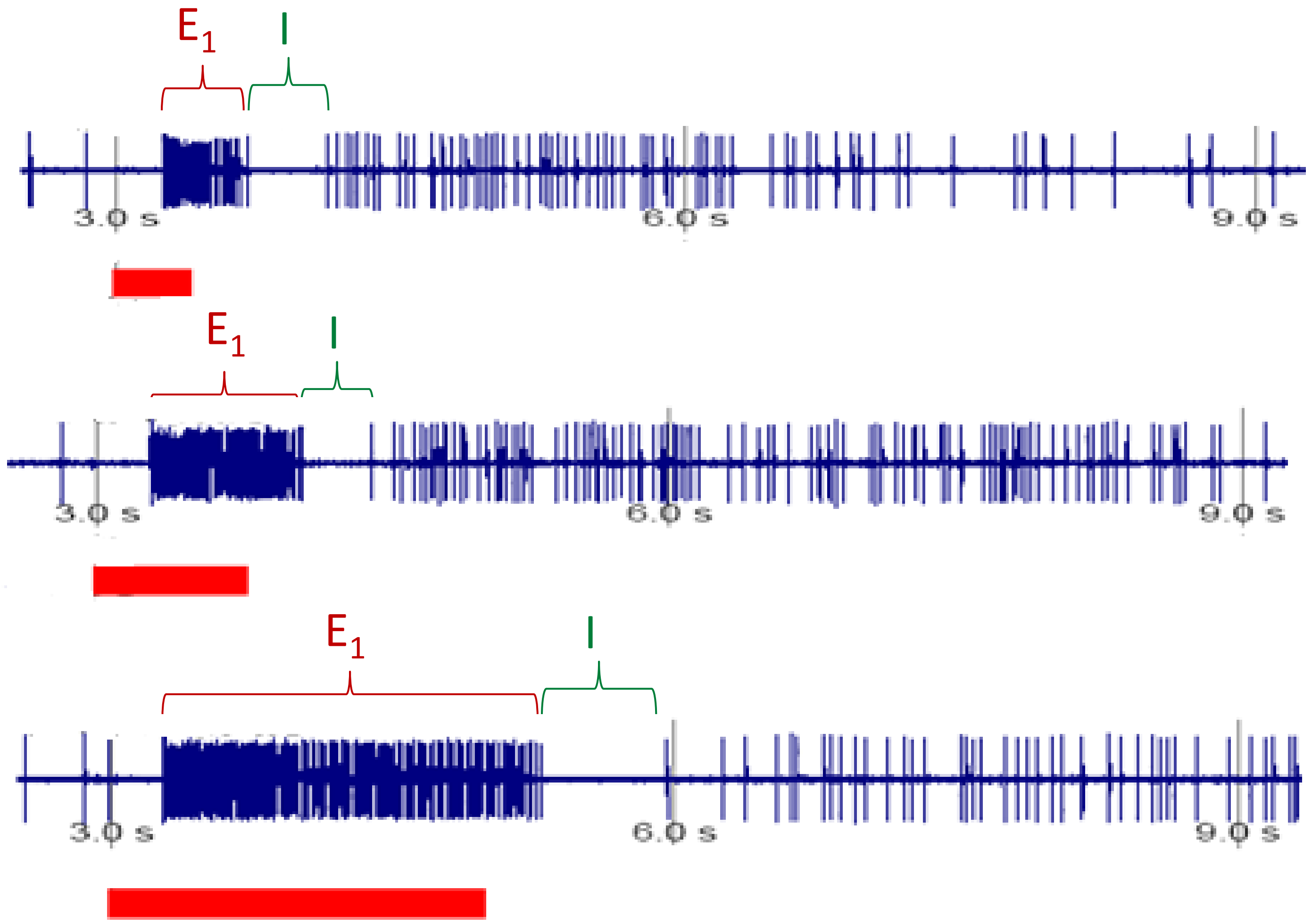
Experimental data from extra-, intracellular and patch-clamp recordings

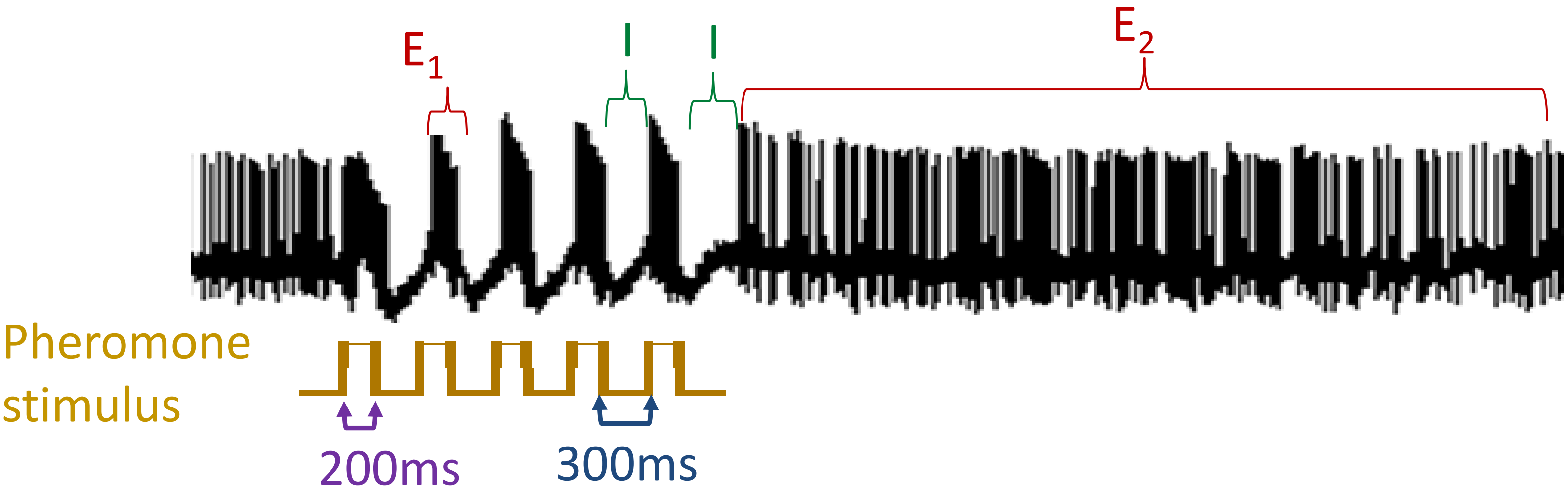
1. **Extracellular recorded response patterns of the moth pheromone sensitive projection neuron (PN) in MGC**

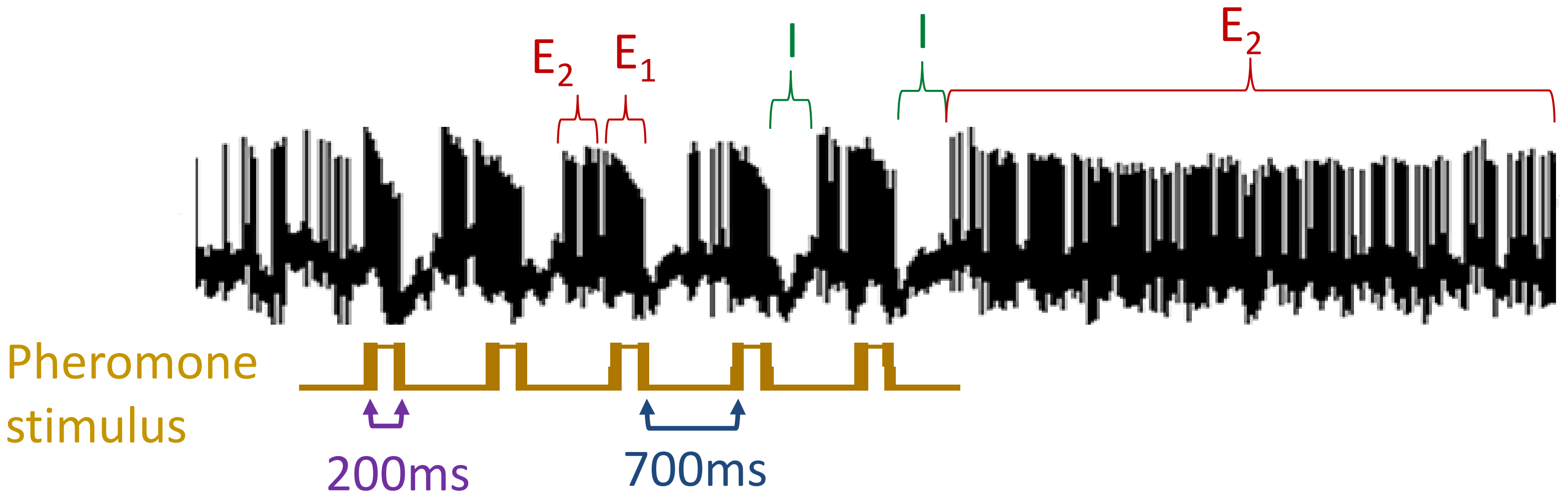


‘E_1’ period increases with stimulation period while ‘I’ period keeps almost constant



2. Intracellular recorded burst response activity of pheromone sensitive PN to repeated periodic phyromone pulse stimuli





3. Whole cell Patch-clamp data on the ionic channels on pheromone sensitive PN and on the other types of neurons in insects

Types of the intrinsic ionic currents on PN

Using whole cell patch-clamp technique on PNs in cockroach (Husch et al., 2009) and in moth (Mercer and Hildebrand, 2002) , five main components of the inward and outward currents were identified.

Two inward currents:

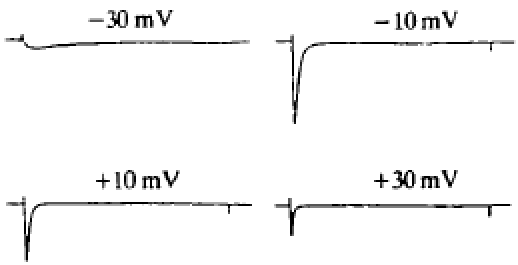
- A fast activating/inactivating Na^+ current (I_{Na})
- A smaller, slowly inactivating inward Ca^{2+} current (I_{Ca}).

Three outward currents:

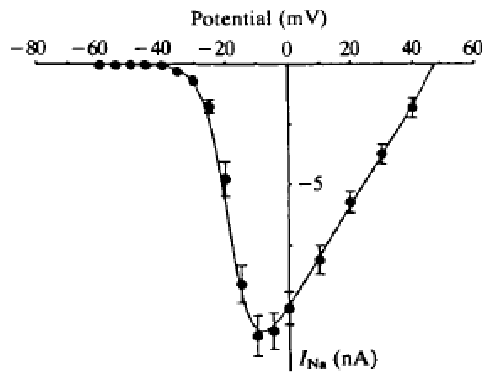
- A transient, voltage-dependent K^+ current (I_A);
- A sustained, voltage-dependent K^+ current ($I_{K(V)}$);
- A Ca^{2+}-dependent, outward current K^+ ($I_{K(Ca)}$).

The characteristics of the sodium Na^+ currents I_{Na}

The recorded Na^+ current Traces, that are transient.



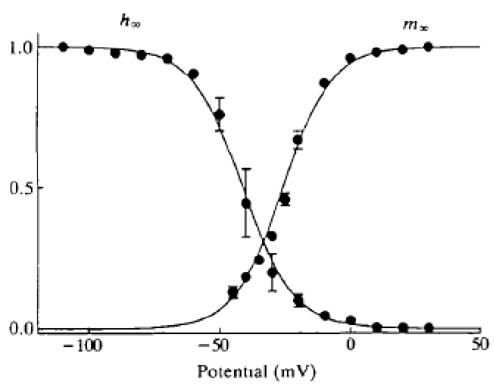
Current-voltage relationship



Lapied et al., 1990

Dorsal unpaired median (DUM) cells in cockroach *Periplaneta americana*

Voltage-dependence of steady-state inactivation and activation

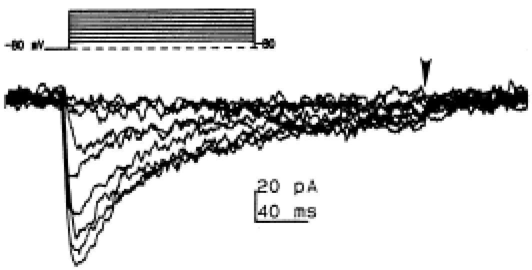


Time constants

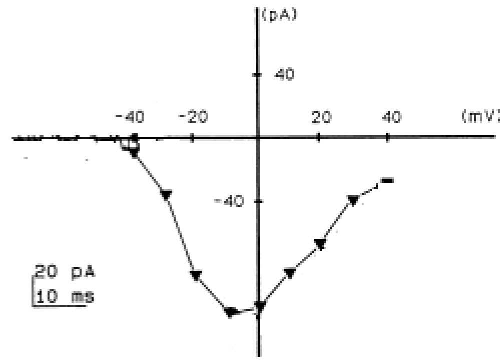
Potential (mV)	τ_m (ms)[a]	τ_h (ms)[b]
-25	2.24	6.22±0.89
-20	2.74	2.07±0.54
-15	1.59	1.10±0.09
-10	0.97	1.01±0.02
- 5	0.75	0.94±0.04
0	0.59	0.86±0.04
+5	0.52	0.77±0.04
+ 10	0.45	0.78±0.03

The characteristics of the calcium Ca^{2+} currents I_{Ca}

The recorded Ca^{2+} currents



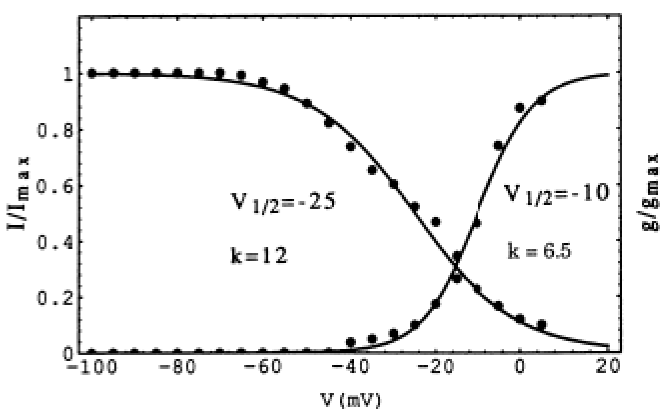
Current-voltage relationship



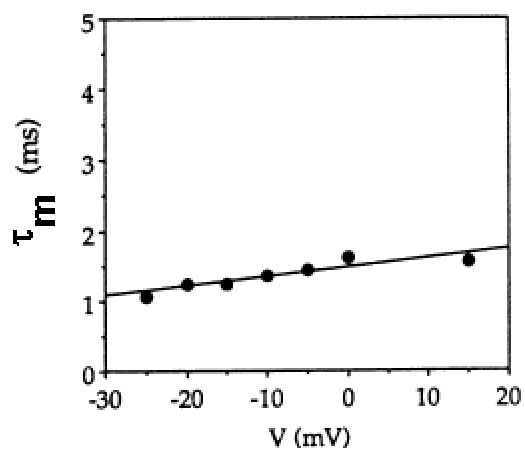
Laurent et al., 1993

Nonspiking LN in locust

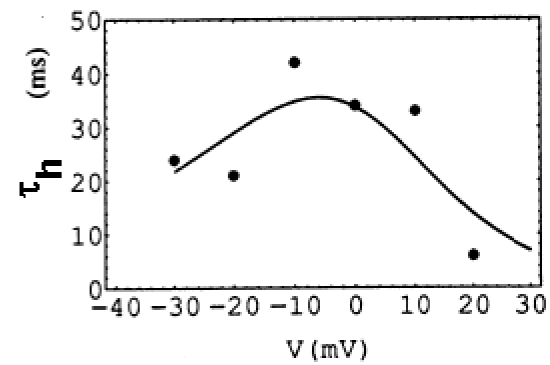
Voltage-dependence of steady-state inactivation and activation



Time constant of activation



Time constant of inactivation

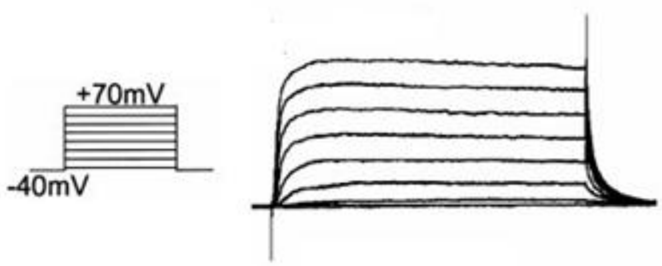


The characteristics of the voltage-activated sustained potassium K^+ *currents* $I_{K(V)}$

Kloppenburg et al., 1999, in MGC PN of moth *Manduca sexta*

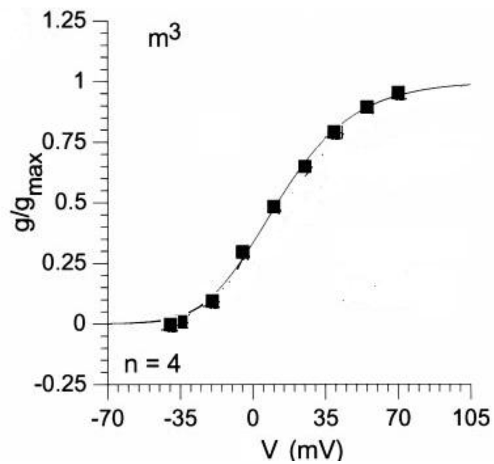
Mercer et al., 1995
In LN in moth
Manduca sexta

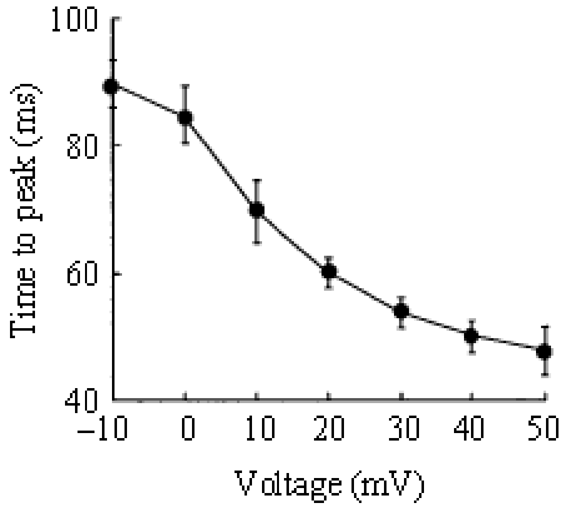
The recorded $I_{K(V)}$



Time to peak of activation

Voltage-dependence of steady-state activation



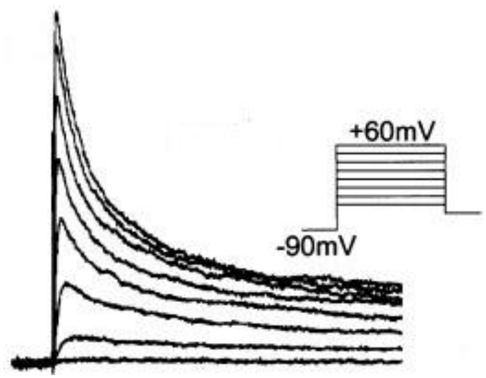


The characteristics of the transient, voltage-dependent potassium K^+ *currents* I_A

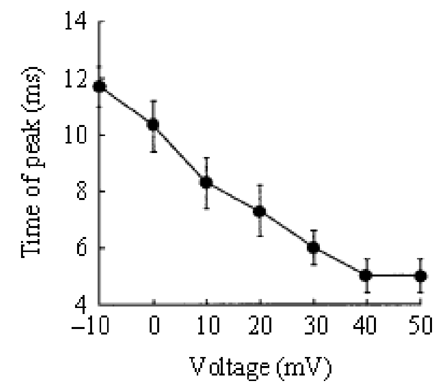
Kloppenburg et al., 1999, in PN of moth *Manduca sexta*

Mercer et al., 1995
In RR (LN) in moth
Manduca sexta

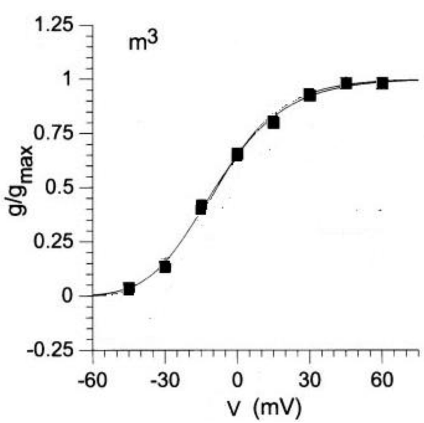
The recorded I_A



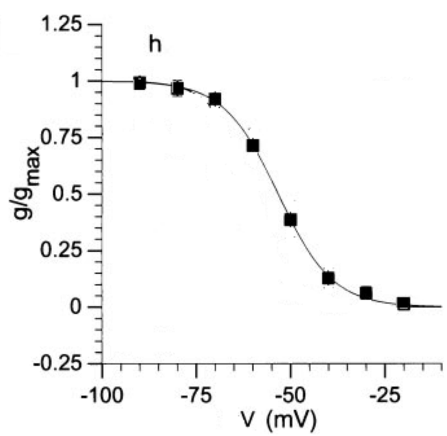
Time to peak of activation



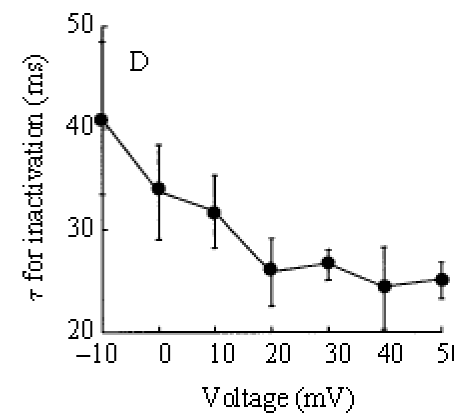
Voltage-dependence of steady-state activation



Voltage-dependence of steady-state inactivation



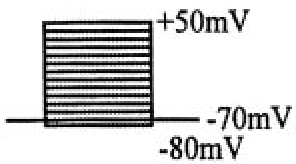
Time constant of inactivation

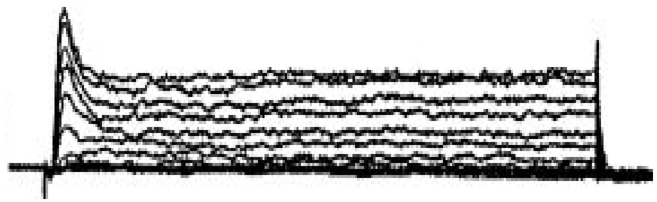


The characteristics of the Ca^{2+}-dependent, outward potassium K^+ *currents* $I_{K(Ca)}$

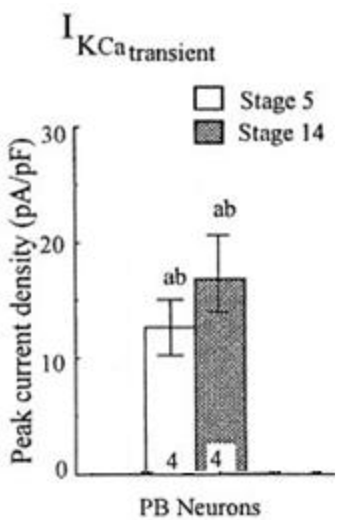
Mercer and Hildebrand., 2002 In PB (PN) in moth *Manduca sexta*

The recorded $I_{K(Ca)}$ In stage 5 PB (PN)

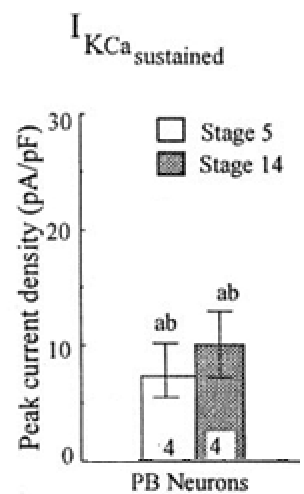




Comparison of mean current densities of $I_{K(Ca)transient}$ In early (stage 5) and late (stage 14) in PB (PN).



Comparison of mean current densities of $I_{K(Ca)sustained}$ In early (stage 5) and late (stage 14) in PB (PN).



The biophysical model of the projection neuron (PN)

The differential equation of the membrane potential of the PN

$$C_m \frac{dV}{dt} = -I_{Na} - I_{Ca} - I_{K(V)} - g_L(V - E_L) - I_A - I_{K(Ca)} + I_{inject}$$

C_m = 22.9 pF, g_L = 11.16 nS, E_L = -61.4 mV. (PN in cockroach, Husch et al., 2009)

$$I_j = \bar{g}_j m^M h^N (V - E_j)$$

The differential equations of the activation and inactivation variables

$$\dot{m} = (m_\infty - m)/\tau_m \qquad \dot{h} = (h_\infty - h)/\tau_h$$

The differential equation of the intracellular Ca^{2+} concentration

$$\frac{dCa}{dt} = -f_{Ca} I_{Ca} - (Ca - Ca_\infty)/\tau_{Ca}$$

Mathematical functions describing the voltage dependence of the steady state values and time constants of activation and inactivation variables

$$m_\infty = 1/\{1+\exp[(V_{0.5act} - V)/s_m]\} \qquad h_\infty = 1/\{1+\exp[(V - V_{0.5inact})/s_h]\}$$

$$\tau_m(V) = \frac{1}{a_{\tau m,up} e^{(V_{\tau m,0.5up} - V)/S_{\tau m,up}} + a_{\tau m,dn} e^{(V - V_{\tau m,0.5dn})/S_{\tau m,dn}}}$$

$$\tau_{mCa}(V) = 1 + (V + a)b$$

$$\tau_h(V) = \frac{1}{a_{\tau h,up} e^{(V_{\tau h,0.5up} - V)/S_{\tau h,up}} + a_{\tau h,dn} e^{(V - V_{\tau h,0.5dn})/S_{\tau h,dn}}}$$

Mathematical functions describing the Ca^{2+} dependence of the steady state value and time constant of Ca^{2+}-dependent K^+ currents

$$m_\infty = Ca/(Ca + a)$$

$$\tau_m = b/(Ca + c)$$

Preliminary qualitative simulation results

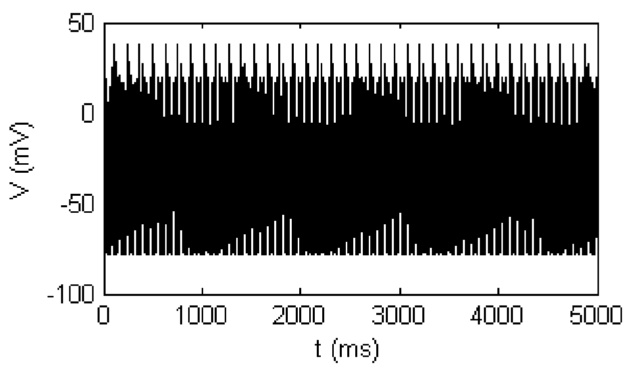
The intrinsic dynamical properties of the model

The model PN can be self-exited without any stimulation in certain range of some parameter values. Certain parameters have clear effects on the timing patterns of the action potential

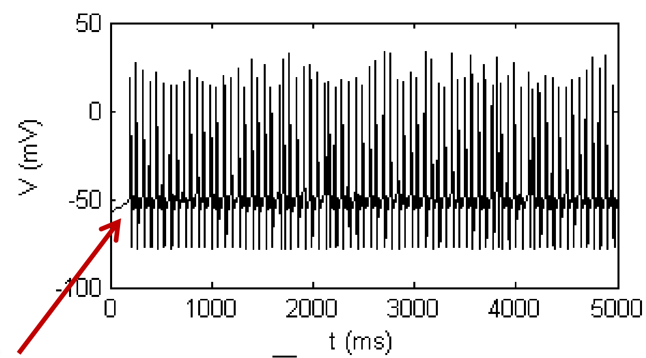
1. $\bar{g}_A$ of I_A current strongly affect the starting time and clearly affect firing frequency of the spiking activity

$\bar{g}_{Kd} = 2.5ns$ $\quad \bar{g}_{KCa} = 0ns$

$\bar{g}_A = 2.5ns$

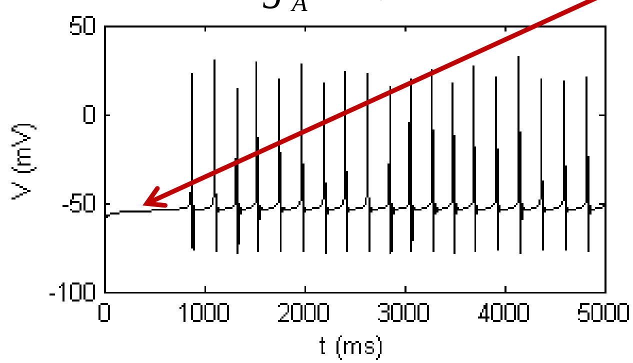


$\bar{g}_A = 3.0ns$

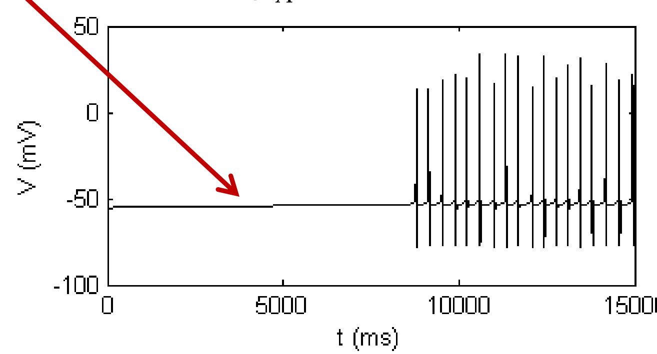


Latency

$\bar{g}_A = 3.08ns$



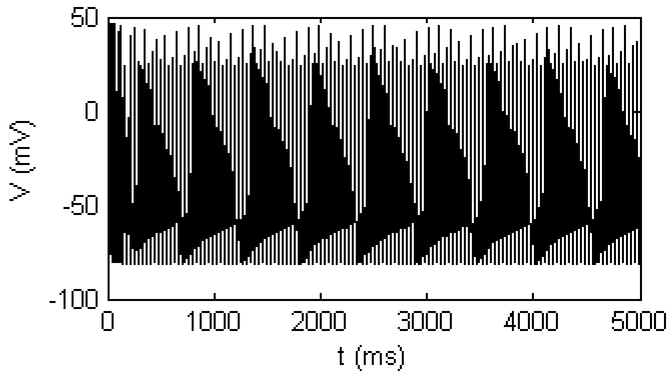
$\bar{g}_A = 3.0875ns$



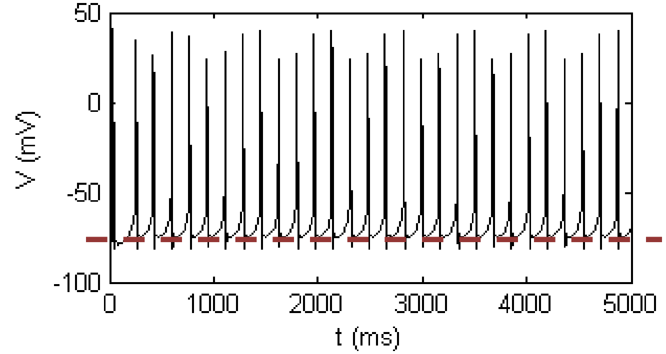
2. $\bar{g}_{KCa}$ of I_{KCa} current strongly affect the deepth of hyperpolarization and clearly affect the firing frequency of the firing pattern

$\bar{g}_{Kd} = 2.8ns$ $\bar{g}_{A} = 1ns$ $\tau_{Ca} = 100ms$

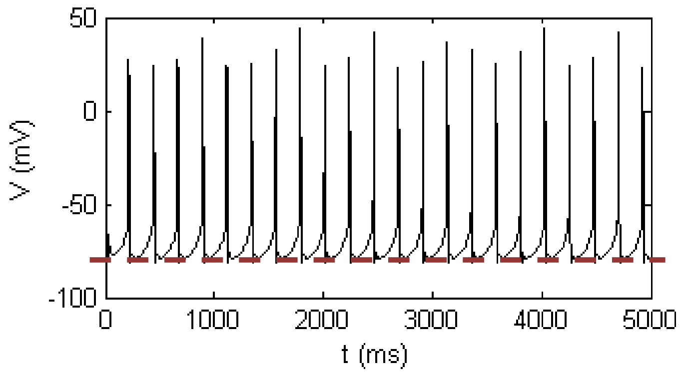
$\bar{g}_{KCa} = 0.1ns$



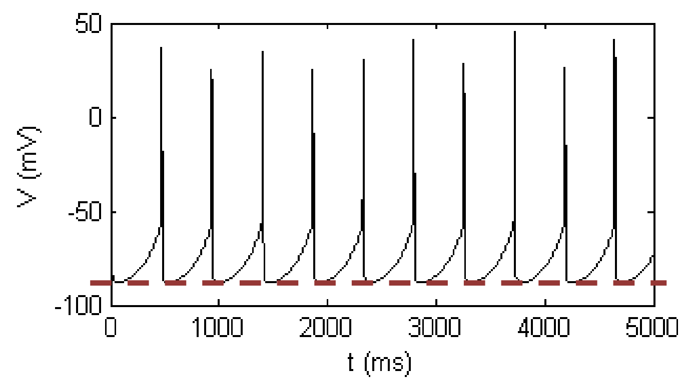
$\bar{g}_{KCa} = 0.6ns$



$\bar{g}_{KCa} = 1ns$



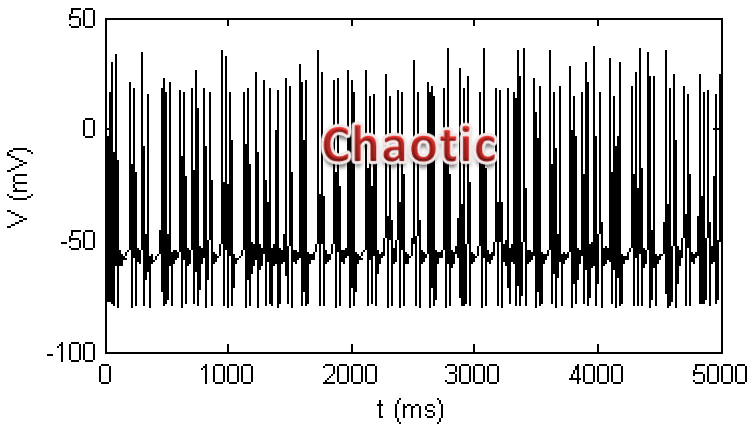
$\bar{g}_{KCa} = 5.63ns$



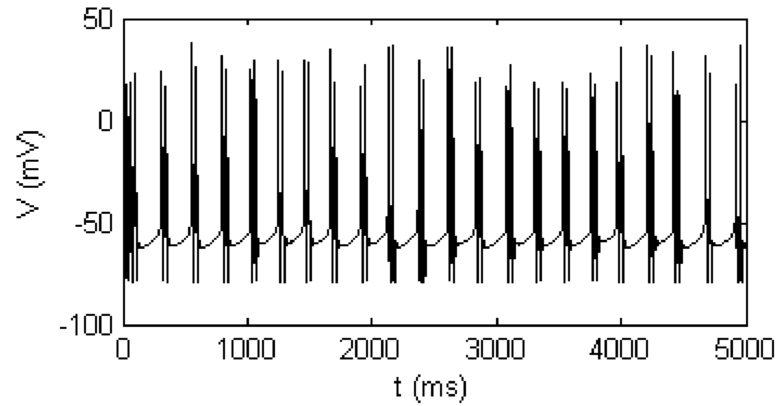
3. τ_{Ca} of Ca dynamics strongly affect firing frequency and clearly affect the regularity of the firing pattern

$\bar{g}_{Kd} = 2.8ns$ $\bar{g}_{A} = 2ns$ $\bar{g}_{KCa} = 0.1ns$

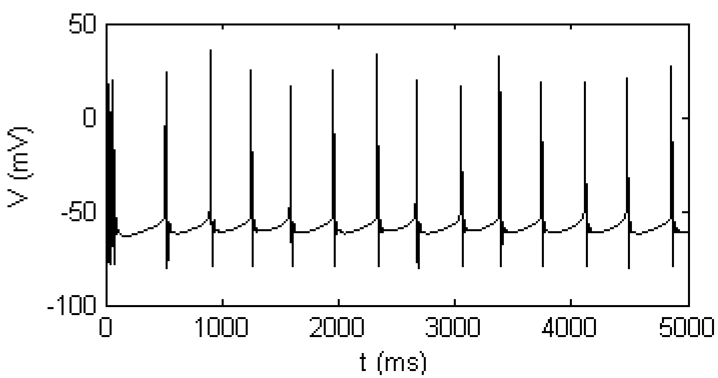
$\tau_{Ca} = 100ms$



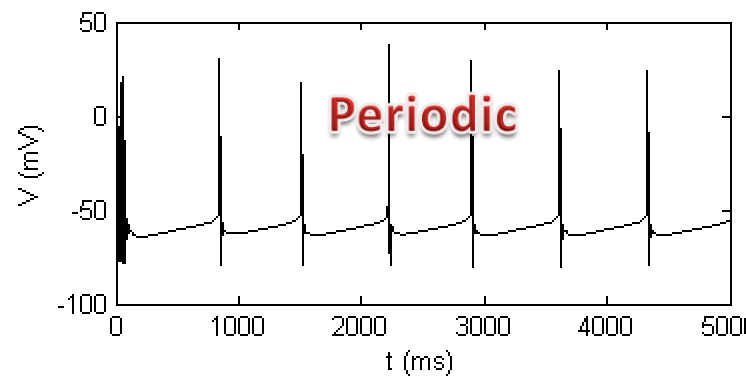
$\tau_{Ca} = 200ms$



$\tau_{Ca} = 500ms$

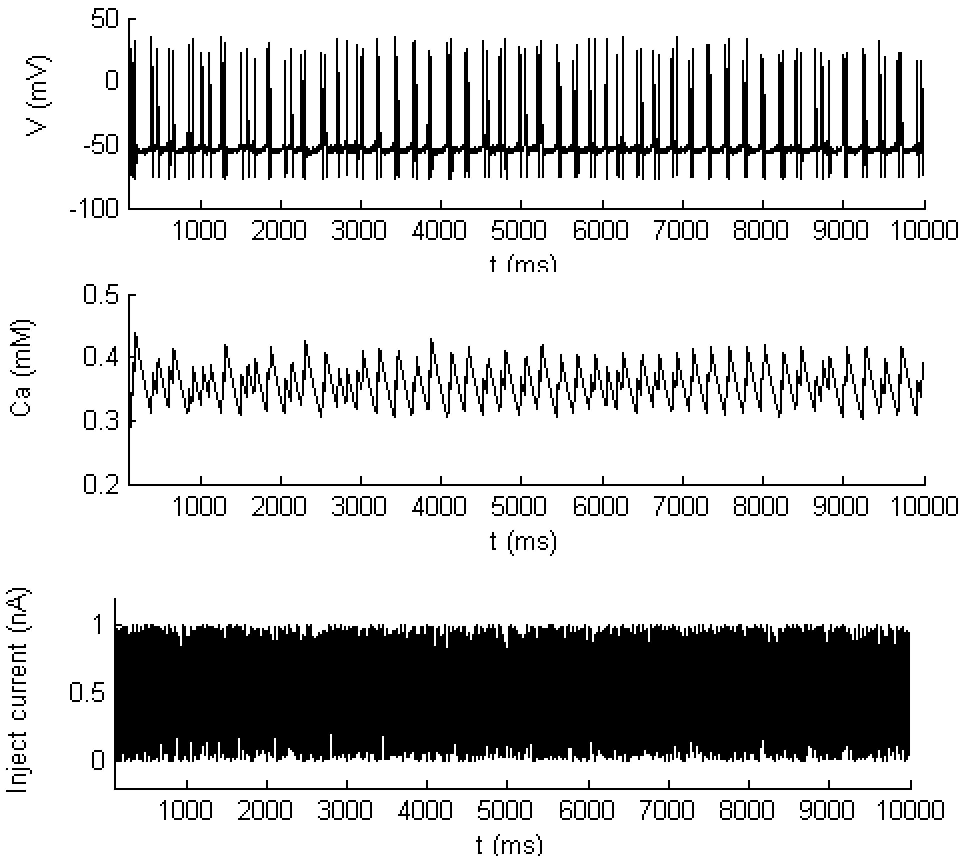


$\tau_{Ca} = 800ms$

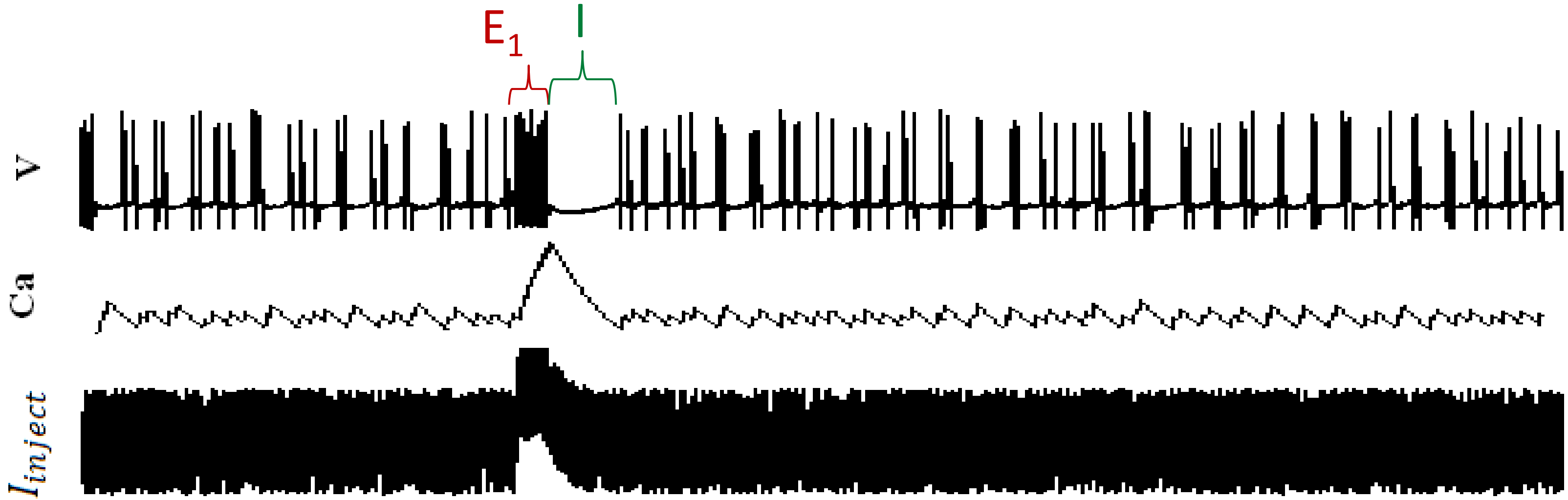


The generation of spontaneous activity

First, the values of the parameters were adjusted so that model PN cannot fire without any stimulation. Then a noisy current from 0 to 1 nA was applied as I_{inject}

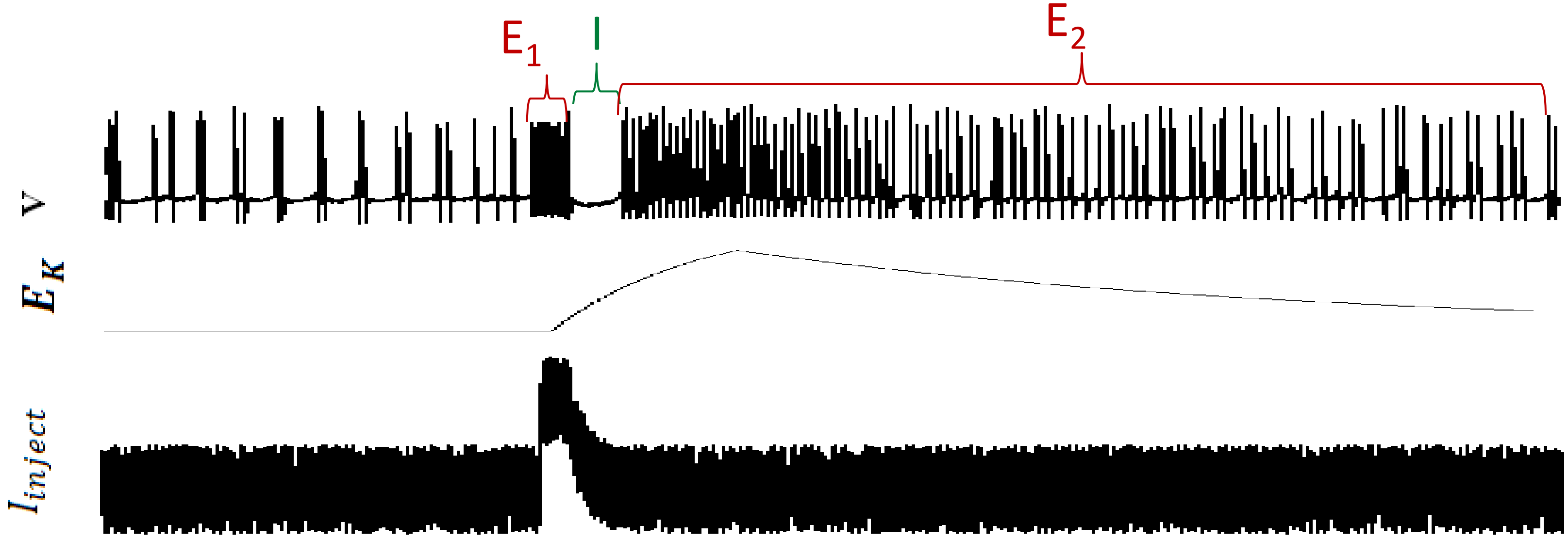


Reproducing E_1,I and E_2 as shown in the experimental data

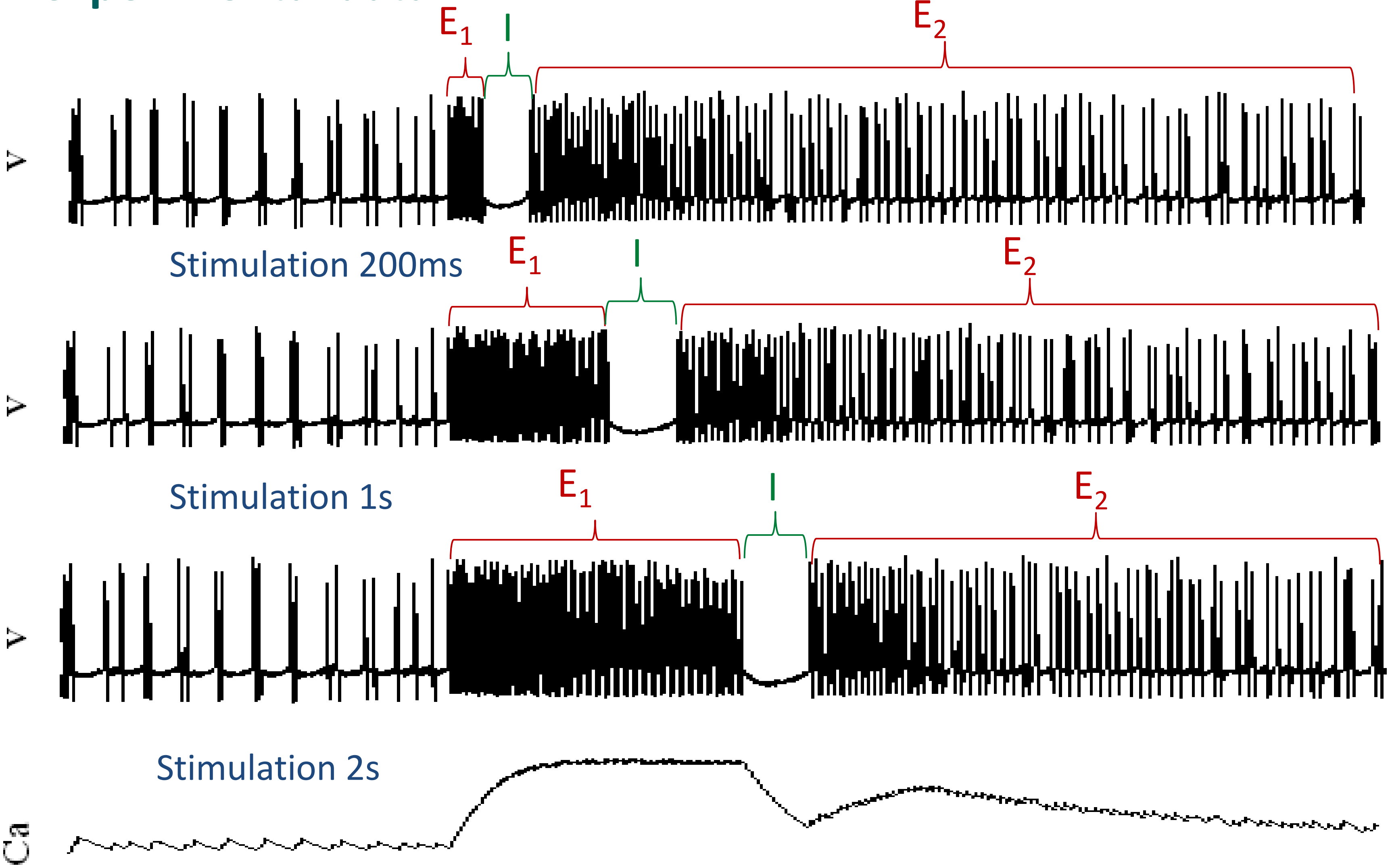


Goriely *et al.*,2002

Due to the increased dosage of stimuli, extracellular K^+ concentration in the glomerulus increases with the firing of ONR axons. This increases the reversal potential of K^+ currents E_K

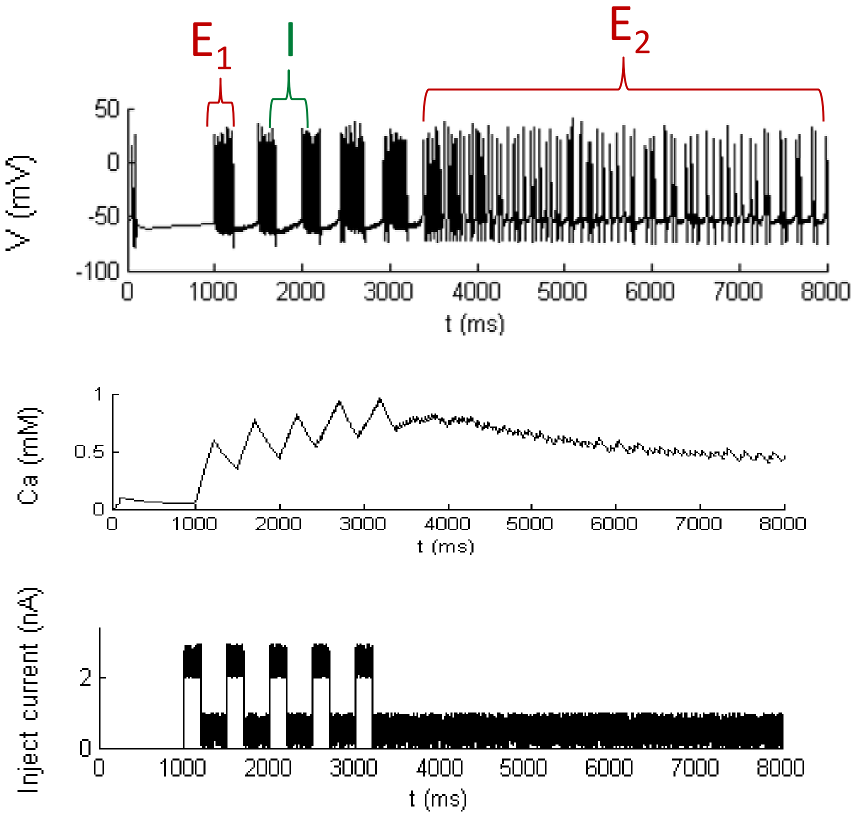


Reproducing that ‘E_1’ period increases with stimulation period while ‘I’ period keeps almost constant as shown in the experimental data

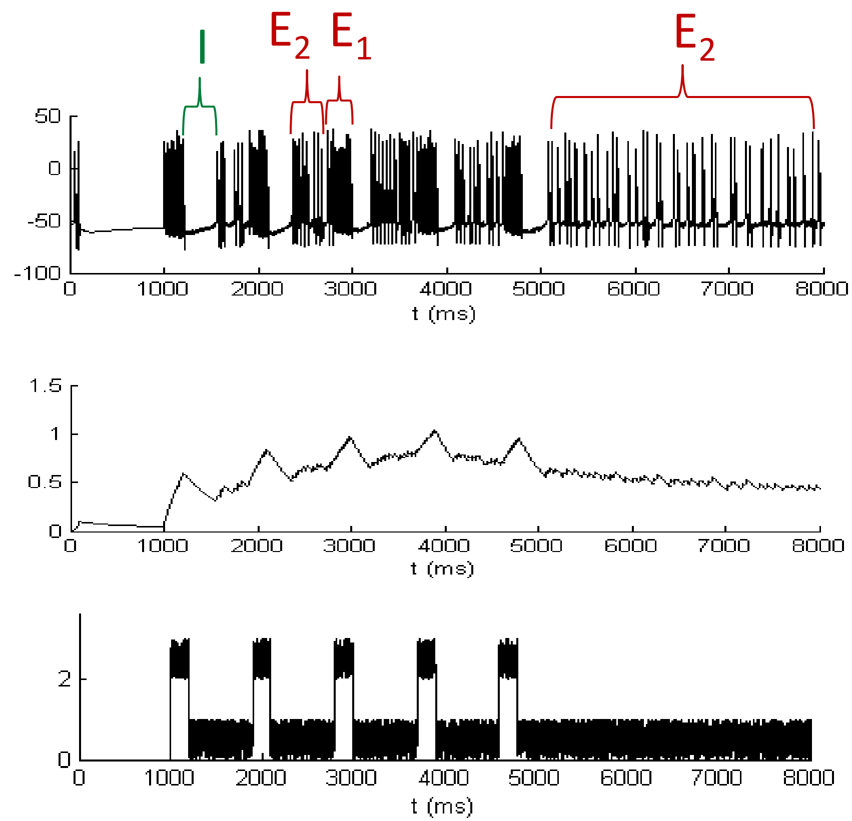


Reproducing the burst patterns in response to repeated periodic pheromone stimuli as shown in the experimental data

The duration of each pulse is 200ms
The duration between pulses is 300ms



The duration of each pulse is 200ms
The duration between pulses is 700ms



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Thank you for your attention !