Supplementary Information

Title: Thermal effects and ephaptic entrainment in Hodgkin-Huxley model.

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1 The variables $\alpha_x(V_m)$ and $\beta_x(V_m)$ $(x = n, m, h)$

$$\alpha_n(V_m) = 0.01 \frac{10 - V_m}{exp(\frac{10-V_m}{10}) - 1} \tag{1}$$

$$\beta_n(V_m) = 0.125 exp(-\frac{V_m}{80}) \tag{2}$$

$$\alpha_m(V) = 0.1 \frac{25 - V_m}{exp(\frac{25-V_m}{10}) - 1} \tag{3}$$

$$\beta_m(V_m) = 4 exp(-\frac{V_m}{18}) \tag{4}$$

$$\alpha_h(V_m) = 0.07 exp(-\frac{V_m}{20}) \tag{5}$$

$$\beta_h(V_m) = \frac{1}{exp(\frac{30-V_m}{10}) + 1} \tag{6}$$

2 Phase difference between the ephaptic signal I_{epha} and the membrane potential V_m

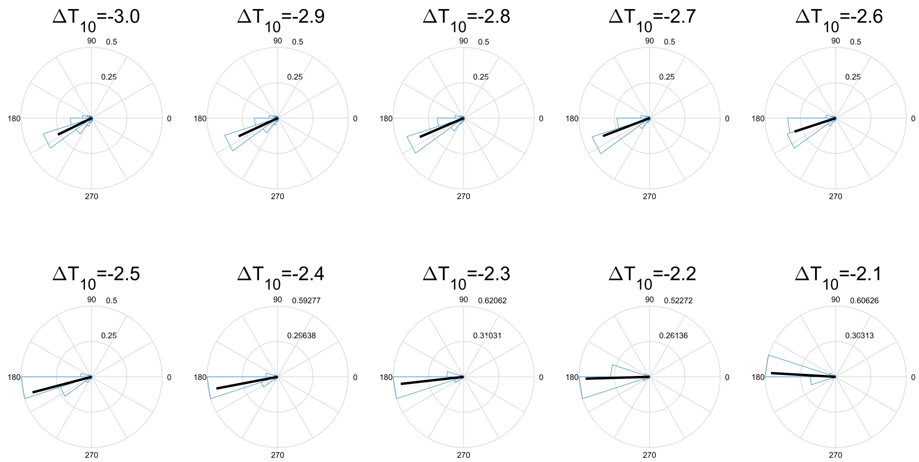

Figura 1: Subthreshold phase difference for different thermal factors values (between the range -3.0 to -2.1) and ephaptic signal frequency fixed at 8Hz.

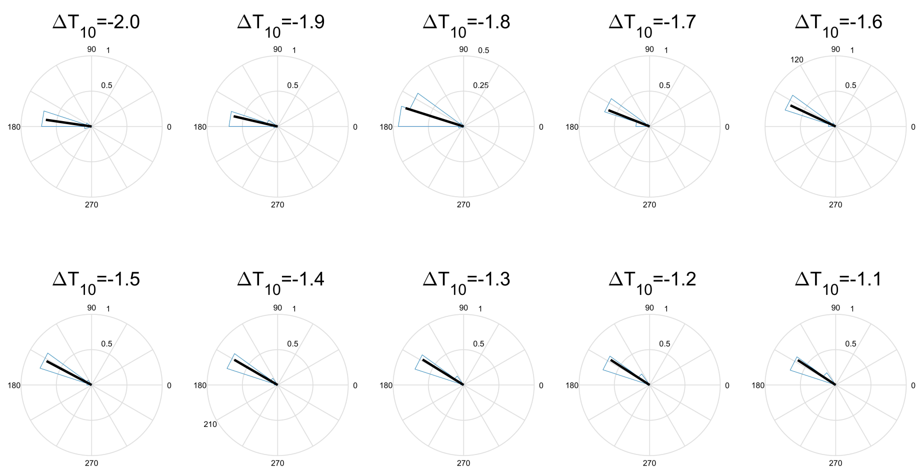

Figura 2: Subthreshold phase difference for different thermal factors values (between the range -2.0 to -1.1) and ephaptic signal frequency fixed at 8Hz.

3 HH-E code

```
% Hodgkin Huxley model adapted to ephaptic entrainment.
%Code developed by Matheus Phellipe Brasil de Sousa.
%Universidade Federal do Rio Grande do Norte (UFRN),
% Natal-RN. 2023


clear all

dt=0.001; % Time step
t=0:dt:10000; % Time simulation
T2 = 6; %Standart temperature

T = [10]; % Temperature range
I_0 = [12]; % Externa injected current
a = 3; %Q10 value
I_e = [0]*10^(-3); %Ephaptic currente nA
F = [0]*10^(-3); % Frequency of ephaptic current Hz

tic

sen = I_e*sin(2*pi*F*t);

%%%% variables %%%%%

V = zeros(1,length(t));
a_n= zeros(1,length(t));
a_m= zeros(1,length(t));
a_h= zeros(1,length(t));
b_n= zeros(1,length(t));
b_m= zeros(1,length(t));
b_h= zeros(1,length(t));
n = zeros(1,length(t));
m= zeros(1,length(t));
h= zeros(1,length(t));
GNa = zeros(1,length(t));
GK = zeros(1,length(t));

%%%%  constantes do modelo %%%%

g_na = 120; %sodium condutance mS/cm^2
g_k=36; %potassium condutance mS/cm^2
g_v=0.3; %leaking condutance mS/cm^2
Ena=115;  %sodium potential mV
Ek=-12; %potassium potencial mV
Ev=10.59; %leaking potential mV
V_rest = 0; % rest potential mV
C = 1; %membrane capacitance microF/cm^2

r = 50*10^(-3); %distance between neuron and source (micrometre)
rho = 3.5; % Extracelular resistivity Ohm^-1 . m^-1


Q = a^((T-T2)/10); %thermal factor

%%%% Initial conditions %%%
V(1) = V_rest;
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a_n(1) =Q*0.01*(10-V(1))/(exp((10-V(1))/10)-1);
a_m(1) =Q* 0.1*(25-V(1))/(exp((25-V(1))/10)-1);
a_h(1) =Q* 0.07*exp(-V(1)/20);
b_n(1) =Q* 0.125 *exp(-V(1)/80);
b_m(1) =Q*4*exp(-V(1)/18);
n(1) = a_n(1)/(a_n(1)+b_n(1));
m(1)=a_m(1)/(a_m(1)+b_m(1));
h(1)=a_h(1)/(a_h(1)+b_h(1));

tic

%%%%  Runge-Kutta 4th loop  %%%%
for i = 1:1:length(t)-1
    sen = I_e*sin(2*pi*F*t)

    a_n(i+1) = Q10*0.01*(10-V(i))/(exp((10-V(i))/10)-1);
    a_m(i+1) = Q10*0.1*(25-V(i))/(exp((25-V(i))/10)-1);
    a_h(i+1) =Q10* 0.07*exp(-V(i)/20);
    b_n(i+1) =Q10* 0.125 *exp(-V(i)/80);
    b_m(i+1) = Q10*4*exp(-V(i)/18);
    b_h(i+1) = Q10*1/(exp((30-V(i))/10)+1);

    k_1 = dt*(a_n(i)*(1-n(i))-b_n(i)*n(i));
    k_2 = dt*(a_n(i)*(1-(n(i)+k_1/2))-b_n(i)*(n(i)+k_1/2));
    k_3 = dt*(a_n(i)*(1-(n(i)+k_2/2))-b_n(i)*(n(i)+k_2/2));
    k_4 =  dt*(a_n(i)*(1-(n(i)+k_3))-b_n(i)*(n(i)+k_3));
    n(i+1) = n(i) + (k_1+2*k_2 + 2*k_3 + k_4)/6;

    k_1 = dt*(a_m(i)*(1-m(i))-b_m(i)*m(i));
    k_2 = dt*(a_m(i)*(1-(m(i)+k_1/2))-b_m(i)*(m(i)+k_1/2));
    k_3 = dt*(a_m(i)*(1-(m(i)+k_2/2))-b_m(i)*(m(i)+k_2/2));
    k_4 =  dt*(a_m(i)*(1-(m(i)+k_3))-b_m(i)*(m(i)+k_3));
    m(i+1) = m(i) + (k_1+2*k_2 + 2*k_3 + k_4)/6;

    k_1 = dt*(a_h(i)*(1-h(i))-b_h(i)*h(i));
    k_2 = dt*(a_h(i)*(1-(h(i)+k_1/2))-b_h(i)*(h(i)+k_1/2));
    k_3 = dt*(a_h(i)*(1-(h(i)+k_2/2))-b_h(i)*(h(i)+k_2/2));
    k_4 =  dt*(a_h(i)*(1-(h(i)+k_3))-b_h(i)*(h(i)+k_3));
    h(i+1) = h(i) + (k_1+2*k_2 + 2*k_3 + k_4)/6;

    I_epha = sen(i);

    k_1 = dt *(I_0 - (V(i)-Ena)* g_na*h(i)*m(i)^(3) - (V(i)-Ek)*g_k*n(i)^4 - g_v *(V(i)-Ev) -I_epha)/(C);
    k_2 = dt *(I_0 - ((V(i)+k_1/2)-Ena)* g_na*h(i)*m(i)^(3) - ((V(i)+k_1/2)-Ek)*g_k*n(i)^4 - g_v *((V(i)+k_1/2)-Ev) - I_epha)/(C);
    k_3 = dt *(I_0 - ((V(i)+k_2/2)-Ena)* g_na*h(i)*m(i)^(3) - ((V(i)+k_2/2)-Ek)*g_k*n(i)^4 - g_v *((V(i)+k_2/2)-Ev) - I_epha)/(C);
    k_4 =  dt *(I_0 - ((V(i)+k_3)-Ena)* g_na*h(i)*m(i)^(3) - ((V(i)+k_3)-Ek)*g_k*n(i)^4 - g_v *((V(i)+k_3)-Ev)- I_epha)/(C);
    V(i+1) = V(i) + (k_1+2*k_2 + 2*k_3 + k_4)/6;
end
toc
```