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EXPERIMENT 5

JANSEN'S SINGLE COLUMN MODEL OF EEG GENERATION

Aim:

To simulate the generation of EEG signal using Jansen's single cortical column model for alpha and beta rhythm

Objective:

To generate the EEG signal based upon the neuron firing characteristics and synaptic potentials in the framework of single column model, and take into consideration the variation in the model parameters for different rhythms

Apparatus:

MATLAB

Theory:

A cortical column is a group of highly connected neurons that act as an elementary unit of organization in the cortex of the brain. It is a widely accepted hypothesis that the cortical processing of information can be effectively explained by the column arrangement of the cortical neurons. Based on this model assumption, the EEG signal can be defined as the vector sum of all the post-synaptic potentials (PSPs) in the cortical column at the electrode level. The action potentials are generally rapid in nature, lack synchronicity, and are not represented in the EEG, unlike the post-synaptic potentialll,ls.

For mathematical modeling of neurons, it is possible to model a neural network which will be computationally intensive. Another alternative approach is to develop a neuronal mass model when the population of neurons can be categorized and the average PSP represents that population. In Jansen's single column model, the neurons can be divided based on the direction of the PSP as the populations with Inhibitory PSP (IPSP) and with Exhibitory PSP (EPSP).

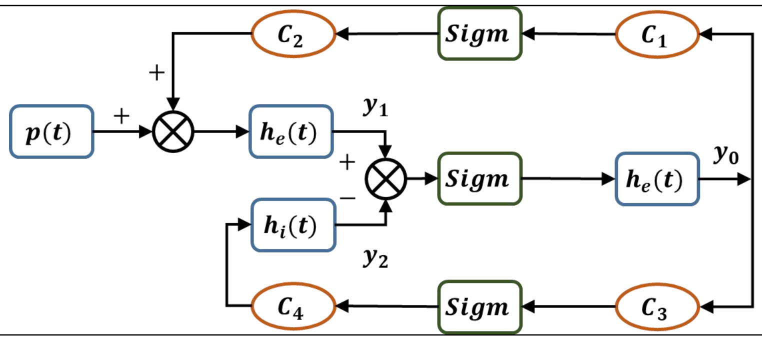

Figure 1. Jansen's Single Cortical Column Model

In the model shown in Figure 1, the upper half represent the EPSP (y_1) and the bottom half represent the IPSP (y_2), and they are summed to obtain the resultant EEG signal. To the EPSP, a component of afferent noise from the surrounding cortical columns is also added. This total PSP is fed back to both EPSP and IPSP populations.

Afferent Noise: $p(t)$ represents the input average pulse density from the neighboring as well as distal cortical columns. Pulse density implies the number of pulses received by the cortical column in each second. It can be considered the neuronal firing rate and can be modeled as a uniformly distributed random noise.

Sigmoid Blocks: The sigmoid blocks introduce the nonlinearity to the model. The purpose is to convert the average PSP into the pulse density similar to the pulse density similar to action potential that influences further neuronal firing:

$$Sigm(V) = \frac{2e_0}{1 + e^{r(V_0 - V)}}$$

where, V is the input PSP, r is a parameter that describes the steepness of the sigmoid, e_0 is the maximum firing rate of the neuronal population, V_0 is the PSP at which 50% firing rate is achieved. Thus, (e_0, V_0) is the point of inflection in the sigmoid function.

Connectivity Constants: C_i where $i = 1,2,3,4$ are the connectivity constants and they are proportional to the average number of synapses between the pyramidal cells and and feedback elements.

Postsynaptic Blocks: $h_e(t)$ and $h_i(t)$ are the impulse responses of the blocks that translate the pulse densities into the average EPSP and IPSP, respectively.

$$\begin{cases} h_e(t) = Aate^{-at}u(t) \\ h_i(t) = Bbte^{-bt}u(t) \end{cases}$$

A and B represent the maximum PSP for the ecitatory and inhibitory neuronal masses, and a and b represent the delay parameters.

The above system can be modeled based on the following system of 6 ODEs.

$$y_0'(t) = y_3(t)$$

$$y_3'(t) = A.a.Sigm\big(y_1(t) - y_2(t)\big) - 2.a.y_3(t) - a^2.y_0(t)$$

$$y_1'(t) = y_4(t)$$

$$y_4'(t) = A.a.\big[p(t) + C_2.Sigm\big(C_1 y_0(t)\big)\big] - 2.a.y_4(t) - a^2.y_1(t)$$

$$y_2'(t) = y_5(t)$$

$$y_5'(t) = B.b.\big[C_4.Sigm\big(C_3 y_0(t)\big)\big] - 2.b.y_5(t) - b^2.y_2(t)$$

For an appropriate choice of parameters, different rhytms of EEG signals such as alpha or beta can be generated.

Brain Rhythms	Model Parameters
Alpha	$C_1 = 135, C_2 = 108, C_3 = 34, C_4 = 34$ $A = 3.25\ mV, B = 22\ mV$ $a = 100, b = 50$ $e_0 = 2.5, r = 0.56, V_0 = 6\ mV$
Beta	$C_1 = 108, C_2 = 86.4, C_3 = 27, C_4 = 27$ $A = 3.25\ mV, B = 17.6\ mV$ $a = 100, b = 50$ $e_0 = 2.5, r = 0.56, V_0 = 6\ mV$

Table 1. Model parameters for different rhythms of EEG

Sample Code

```
%Initial values
y0 = zeros(6,1);
dt = 0.001; %step size in second
T = 10; %total duration
clock = 0:dt:T;
rng(10) %for reproducibility
p = 200*rand(size(clock))+120; %random firing of neuron
figure()
subplot(3,1,1)
plot(clock,p)
xlabel('Time (s)'); ylabel('Neuron Firing Count');
title('Neuron Firing Pattern')

%parameter definition
Params = struct('A',3.25,'B',17.6,'a',100,'b',50,'e0',2.5, ...
    'C',108,'r',0.56,'v0',6);
%solution
[t,y] = ode45(@(t,y) JansenSingleODEs(t,y,Params,p,clock),clock,y0);
subplot(3,1,2)
plot(t(2:end),y(2:end,2)-y(2:end,3),'LineWidth',0.8);
xlabel('Time (s)'); ylabel('Amplitude (mV)')
title('Synthetic EEG')

subplot(3,1,3)
periodogram(y(:,2)-y(:,3),[],[],1/dt)
xlim([0 50])

function ydot = JansenSingleODEs(t,y,Params,p,clock)
```

```
p = interp1(clock,p,t);
A = Params.A; a = Params.a; B = Params.B; b = Params.b;
C1 = Params.C; C2 = 0.8*C1; C3 = C1/4; C4 = C3;

ydot = zeros(size(y));
ydot(1) = y(4);
ydot(4) = A*a*Sigm(y(2)-y(3),Params) - 2*a*y(4) - a^2*y(1);
ydot(2) = y(5);
ydot(5) = A*a*(p + C2*Sigm(C1*y(1),Params)) - 2*a*y(5) - a^2*y(2);
ydot(3) = y(6);
ydot(6) = B*b*C4*Sigm(C3*y(1),Params) - 2*b*y(6) - b^2*y(3);

end

function out = Sigm(y,Params)
e0 = Params.e0;
v0 = Params.v0;
r = Params.r;
out = 2*e0/(1+exp(r*(v0-y)));
end
```

Results

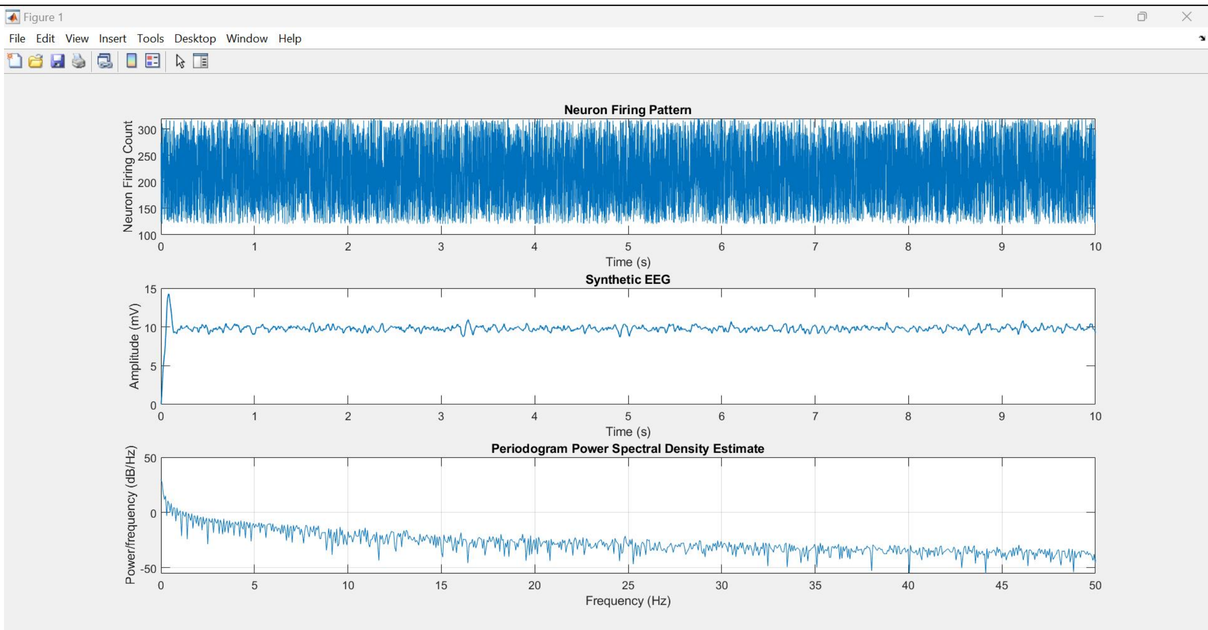

Figure 2. Sample synthetic EEG for beta rhythm and corresponding periodogram

Outcomes

For the variations in the input parameters, the frequency characteristics of simulated EEG signals are impacted. The bandwidths of the simulated signals also demonstrated to change with changing connectivity constants and inhibitory characteristics.

Conclusion

Using Jansen's single column model architecture, synthetic EEG signals can be generated. Different rhythms of EEG such as alpha and beta can be simulated by varying the model parameters which influences the spectral characteristics of the signal.