Spatiotemporal behavior in networks of Ca3 region in the hippocampus

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The interaction of a network of coupled neural oscillators is studied. The motivation for this work is to understand the role of coupling in promoting the synchronization of activity observed in the CA3 region in the hippocampus. This region can be source of epileptic seizures. In this way, the comprehension of the synchronization in this area can help us to understand the epileptic mechanism. Various types of spatiotemporal behavior are described for networks of excitatory and inhibitory neurons. We described how the network behaves as several structural parameters are varied, such as the connectivity and the values of synaptic weights.

Synchronization is a common fact between living organisms. Synchronization with prevalence of the gamma frequency range is well known to occur in the olfactory bulb and entorhinal cortex of various species, where these phenomena have been related to the integration of odor information [1]. Similar evidence is available for the motor system where neural synchronization has been discovered in monkeys and in humans [3]. However, this phenomenon not always benefits them. An example is epileptic seizures where abnormal firing patterns exhibited by focal region spread throughout surrounding normal brain tissue synchronizing all neurons to the same stationary or periodic behaviors. In this case, it is interesting to speculate with the possibility of controlling the synchronizing mechanism that allows the spreading of seizure- like activity, desynchronizing the periodic behavior typical of epileptic seizures and perhaps it suppresses the seizure generation [2]. We analyze the interaction of a network of coupled neural oscillators. The motivation for this work is to understand the role of coupling in promoting the synchronization of activity observed in the CA3 region in the hippocampus. This region is an important epileptic focus. In this way, the

comprehension of the synchronization in this area could help us to find a tool able to control the generation of the epileptic seizure. Various types of spatiotemporal behavior are described for networks of excitatory and inhibitory neurons depending on the strength coupling. We described how the network behaves as several structural parameters are varied, such as the connectivity and the values of synaptic weights.

To characterize the individual cells or oscillators of the network, we use the recently introduced Morris-Lecar three-variable ordinary differential model [4]. The variables in this model correspond to membrane potentials for prototypical pyramidal cells (or excitatory cells) and inhibitory interneurons because in the CA3 region of the hippocampus is considered the existence of a subnetwork constituted by excitatory and inhibitory cells with a synaptic connectivity between them [4,7].

The next set of coupled differential equations simulates the oscillator or subnetwork considered

$$\begin{aligned} \frac{dV_i}{dt} &= -g_{Ca} m_\infty (V_i - V^{Ca}) - g_K W_i (V_i - V_i^K) - g_L (V_i - V^L) + I - \alpha_{inh} Z_i; \\ \frac{dW_i}{dt} &= \frac{\phi (w_\infty - W_i)}{\tau_w}; \\ \frac{dZ_i}{dt} &= b(cI + \alpha_{exc} V_i), \end{aligned} \tag{1}$$

with $m_\infty, w_\infty, \alpha_{exc}, \alpha_{inh}, \tau_w$ given in [4,5]. V_i and Z_i are the membrane potentials of the pyramidal and inhibitory cells, respectively, while W_i is a relaxation factor which is essentially the fraction of open potassium channels in the population of pyramidal cells, for the node $i = 1, \ldots, N$ (N number of cells). The third equation corresponds to the effect of inhibitory neurons, while the first two equations, without the last term in the first equation, correspond to the Morris-Lecar model [6]. The parameters g_{Ca}, g_K and g_L are the conductances for Ca, K and leakage channels, respectively. V_i^K is the Nernst potential for potassium in node i. V_L is a leak potential, V_{Ca} is the Nernst potential for calcium ($V_{Ca} = 1$), τ_w is a voltage dependent time constant for W_i, I is the applied current, and ϕ and b are temperature scaling factors. The parameter c modifies the current input to the inhibitory neuron. The functions w_∞ and m_∞ correspond to the voltage-regulated Ca^{2+} channels in the cell membrane. The functions α_{exc} and α_{inh} are dimensionless parameters, describing the synaptic, either excitatory or inhibitory,

strengths[1].

With this individual oscillators we have built a two-dimensional network coupled where we have implemented both a coupling with time delay and diffusive coupling. The network was numerically integrated using an explicit Euler method with a time step of 0.05 time units (t.u.) per iteration, and considering both periodic boundaries and reflective boundaries.

The dynamical behavior of the network described above was found to be essentially dependent on the number of neurons, the connectivity pattern and the values of the synaptic weights, varying the synchronization patterns of the network and the behavior of the individual cells.

References

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[1] A more detailed description of all the parameters concerning the Morris-Lecar model, Eqs. (1), can be found in [4].