Bistable firing patterns: one way to understand how epileptic seizures are triggered

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Abstract

• Excessively high, neural synchronisation has been associated with epileptic seizures.
• Epileptic and normal neuronal activity are support by the same physiological structure.
• How neuronal systems transit between these regimes?
• We verify that the decrease in the influence of inhibition can generate synchronisation originating from a pattern of desynchronised spikes.

In the transition from desynchronous spikes to synchronous bursts of activity, emerges a bistability where a square current pulse can:
I - trigger abnormal synchronisation (epileptic seizures);
II - suppress abnormal synchronisation by applying on less than 10% of the neurons.

Introduction

Epileptic seizures are associated with excessively high synchronous activities of neocortex regions or other neuronal populations [1]. In experiments and simulations, the reduction of excitatory and the increase of inhibitory influence have been effective in suppressing and preventing synchronized behaviorns. Traub and Wong [2] showed that synchronized bursts that appear in epileptic seizures depend on neural dynamics. Recurrent seizures can kill neurons and lead to chronic epilepsy. Evidence that supports this further is provided by abnormal anatomical alterations, such as dendritic reconfigurations, synaptogenesis, and neurogenesis. In fact, such alterations change the balance between inhibition and excitation. Several studies showed that epileptiform activities are related not only with unbalanced neural networks, but also with highly synchronous networks. In this work, we build a random network with neural dynamics to study synchronization induced in a bistable state which is related to epileptic seizures.

Neural Network

We consider a network composed of $N=1000$ (80% excitatory) adaptive exponential integrate-and-fire (AEIF) neurons coupled by means of inhibitory and excitatory synapses. Borges et al. [3,4] verified that depending on the excitatory synaptic strength and connection probability, a network of coupled AEIF neurons can exhibit transitions between desynchronized spikes and synchronized bursts. The dynamics of each neuron in the network is given by the set of equations

$$C_m \frac{dV_i}{dt} = -g_l(V_i - E_l) + g_l \Delta \gamma \exp{\left(-V_i - V_T \Delta \gamma\right)} + I_i - w_i + \sum_{j}^{N} (V_{i+1} - V_i) M_{ij} + \Gamma,$$

$$\tau_w \frac{dw_i}{dt} = a_i (V_i - E_l) - w_i$$

The membrane potential $V_i$ and adaptation current $w_i$ represent the state of each neuron $i$. The synchrony behavior in the network can be identified by means of the complex phase order parameter $R$ (=1 for fully synchronized patterns). Using the mean value of ISI (inter-spike interval), and its standard deviation, we calculate the coefficient of variation CV (spike when $CV<0.5$ and burst fire patterns when $CV\geq 0.5$) [3,4].

Bistable Regime

We analyse synchronization in function of $g$ and $g_{exc}$ (excitatory synaptic conductance). The transition from desynchronous spikes to synchronous bursts of activity, induced by varying the synaptic coupling, emerges in a hysteresis loop due to bistability where abnormal (excessively high synchronous) regimes exist.

External Square Current Pulse

We verify that a square current pulse can trigger excessively high (abnormal) synchronization.

References