An Important Role of Spike Timing Dependent Synaptic Plasticity in the Formation of Synchronized Neural Ensembles

Valentin P. Zhigulin[1,2] and Mikhail I. Rabinovich[2]

[1]*Department of Physics, MC 103-33,*
California Institute of Technology, Pasadena, CA 91125
[2]*Institute for Nonlinear Science, University of California,*
San Diego, La Jolla, CA 92093-0402

Abstract

Synchronous neural activity plays an important role in the functioning of the brain. Here we study the entrainment of heterogeneous network of electrically coupled neurons by periodic external stimulation. We demonstrate by computer simulations that input synapses with STDP greatly enhance the coherence of activity in the network as compared to the case of input with constant strength. We also study how the observed phenomenon is influenced by the number of stimulated neurons, strength of electrical coupling and the degree of heterogeneity. A possible role that such a mechanism could play in synchronizing the activity of hippocampal network is discussed.

I. SUMMARY

Synchronous neural activity plays an important role in the functioning of the brain. It is a robust phenomenon, frequently observed across populations of neurons with diverse membrane properties and intrinsic frequencies. In the light of such diversity it remains unclear how can precise synchronization be achieved in heterogeneous network. Several mechanism were suggested and many of them require unreasonably high degree of network homogeneity or very strong connectivity to achieve coherent neural activity. Recently we demonstrated that in simulations of a network of two synaptically coupled neurons spike timing dependent plasticity (STDP) of the synapse leads to the dynamic self-adaptation of its conductance to the value that is optimal for the entrainment of postsynaptic neuron with given mismatch of intrinsic frequency [1, 2]. Here we study the entrainment of heterogeneous network of electrically coupled neurons by periodic external stimulation. Only small fraction of the neurons in the network receive stimulation. We show by computer simulations that such network oscillates with much higher degree of coherence when it is subject to the stimulation that is mediated by STDP synapses as compared to the case of stimulation through static synapses. We also study how the observed phenomenon is influenced by the number of stimulated neurons, strength of electrical coupling and the degree of heterogeneity.

Such an effective entrainment of the network by the stimulation trough STDP synapses has the following explanation. Due to heterogeneity of the network stimulation of different strength is needed at different sites of the network to bring it into synchronized state. We demonstrate that STDP leads to such specificity of stimulation by dynamically adjusting the strength of each synapse to the value that is appropriate for entrainment given initial mismatch of pre- and post-synaptic frequencies. On the other hand, stimulation through static synapses is, in general, not site specific and can not provide adaptive level of stimulation.

Recent experiments with connexin36 knock out mice [3, 4] and modelling studies [5] suggest that electrical coupling between hippocampal pyramidal cells is responsible for the formation of synchronized γ-band activity in hippocampus, while gap junctions between interneurons exert modulatory effect. Taking into account the fact that processes that synapse onto pyramidal cells exhibit STDP, we suggest that the described above mechanism can play a role in effective entrainment of this hippocampal network by the input from

upstream areas of the brain.

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