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Phase synchronization in a sparse network of randomly connected neurons under the effect of Poissonian spike inputs

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ABSTRACT

This article investigates the emergence of phase synchronization in a network of randomly connected neurons by chemical synapses. The study uses the classic Hodgkin–Huxley model to simulate the neuronal dynamics under the action of a train of Poissonian spikes. In such a scenario, we observed the emergence of irregular spikes for a specific range of conductances and also that the phase synchronization of the neurons is reached when the external current is strong enough to induce spiking activity but without overcoming the coupling current. Conversely, if the external current assumes very high values, then an opposite effect is observed, i.e., the prevention of the network synchronization. We explain such behaviors considering different mechanisms involved in the system, such as incoherence, minimization of currents, and stochastic effects from the Poissonian spikes. Furthermore, we present some numerical simulations where the stimulation of only a fraction of neurons, for instance, can induce phase synchronization in the non-stimulated fraction of the network, besides cases in which for larger coupling values, it is possible to propagate the spiking activity in the network when considering stimulation over only one neuron.

The cooperative behavior of neurons and neuronal areas associated with synchronization proves to be a fundamental neural mechanism and is relevant to many cognitive processes. The brain operates in a dynamic environment with spontaneous activity, generating unpredictable action potentials in neurons. In this scenario, neurons are submitted to a wide diversity of inputs that are provided, for example, from ion channel flux to coupling interactions and external perturbations. Hence, the effect of stimulation and perturbation protocols on the spiking activity is a key topic of relevance to neuroscience being the focus of several works in the last few decades. This research article aims to investigate the emergence of phase synchronization in a network of randomly connected neurons under the effect of a train of Poissonian spikes. The appearance of phase synchronization is explained by analyzing the competition between internal and external currents in the network, as well as considering the Poisson inputs only in a fraction of the neuronal network. The results shed light on the emergence mechanism behind synchronous and asynchronous activities in neuronal networks under stochastic stimuli.