Environmentally induced chaos and amplitude death in neuronal network activity

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Abstract. In this study, the role of common environment in emergence of chaos in network dynamics was examined. Different bifurcation scenarios for transition to irregular firing activity were shown. Role of the observed multistability with co-existent regular and chaotic regimes of neuronal activity was discussed.

Introduction

Communication of neurons performs detecting, processing and transmission of any information by the living organisms. For a lot of researchers dealing with biological experiments, mathematical modeling and neural network hardware design, the mechanisms involved into these processes are of particular interest. Due to significant development of the technical opportunities of experimental study of the real neuronal networks activity, new aspects for information processing in the brain are revealed, new influencers on this process are specified.

On one hand it is known that, astrocytes whose main function was believed to be a biochemical support for the neurons, can modify the neuronal response by the release of various gliotransmitters [1, 2]. In particular, the neuronal synchronization considered within the frame of tripartite synapse concept allowed to show glutamate and D-serine impacts on synaptic signal transmission leading to non-trivial changes in neuronal activity [3].

On other hand, the extracellular matrix components deposited in the space between neurons and astrocytes in the form of a net-like structure, also can regulate the neuronal excitability and synaptic connectivity. Scientific investigations in this direction provoked the development of the tetrapartite theory of synaptic signaling [4]. Recent results within the frame of this theory were presented in [5, 6]. It was shown that, the feedback between the neuronal firing activity and protease-dependent concentration of extracellular matrix (ECM) molecules may lead to different types of bistability that can play crucial role in brain homeostasis maintaining and memory function implementation.

Finally, a narrow gap separating the cells in the brain, besides perineuronal nets, ECM and other secreted molecules, also contains interstitial fluid. As shown recently, the properties of the latter (interstitial viscosity, steric hindrance, physical drag etc.) play significant role in brain health and disease, because it provides an environment for the well-being of neural network components [7].

Results and discussion

Recently, simple phenomenological model for the network with the coupling between the neuronal cells that takes into account the role of the interstitial viscosity, was introduced in [8]. For small-scale networks, the phenomenon of amplitude death was revealed, and analytical estimation for the threshold network scale providing the neuronal activity was obtained. It was shown that the results concerning the viscosity impact are qualitatively consistent with the experimental data.

In this study, the role of the common environment reflecting the possible change of interstitial viscosity in emergence of chaos in neuronal network dynamics was examined. It was shown that transition to irregular firing activity can occur via different bifurcation scenarios. Moreover, the range of parameters was obtained where the co-existence of both regular and chaotic regimes of neuronal activity is observed. These results of mathematical modeling demonstrate that the properties of interstitial fluid can contribute to a dual character of neuronal activity related with the development of hidden stages of some disease.

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