MODELING AND ANALYSIS OF RHYTHM GENERATION MECHANISMS IN EXCITATORY NEURAL NETWORKS

Yaroslav I. Molkov[1], Patrick E. Jasinski[2], Natalia A. Shevtsova[2], Jeffrey C. Smith[3], Ilya A. Rybak[2]

[1]Dept of Mathematical Sciences, Indiana University – Purdue University Indianapolis, IN
[2]Dept of Neurobiology and Anatomy, Drexel University College of Medicine, Philadelphia, PA
[3]Cellular & Systems Neurobiology Section, NINDS, NIH, Bethesda, MD

The mechanisms generating neural oscillations in the brain stem (pre-Bötzinger Complex, pre-BötC) and spinal cord that persist after blockade of synaptic inhibition remain poorly understood. Experimental studies in thick medullary slices (~700 μm) from neonatal mice containing the pre-BötC identified two types of pacemakers and proposed two intrinsic neuronal bursting mechanisms that may contribute to rhythm generation in the pre-BötC: one with rhythmic bursting activity based on the persistent sodium current (INaP), and the other involving calcium (ICa) and calcium-activated, nonspecific cationic (ICAN) currents (Thoby-Brisson M, Ramirez JM. J Neurophysiol 2001, 86:104-112). Interestingly, only the INaP-dependent bursting mechanism has been found in the pre-BötC within thin (~350 μm) slices from neonatal rats (Koizumi H, Smith JC. J Neurosci 2008, 28:1773-1785). Both these mechanisms were also suggested to contribute to the generation of rhythmic activity in the isolated spinal cord. However, an involvement and relative roles of these mechanisms in the operation of rhythmogenic excitatory networks within the brain stem respiratory and spinal cord locomotor central patter generators are still under debate. Studies of the effects of pharmacological blockers of INaP and/or ICAN on the network busting activity and its characteristics (burst frequency, amplitude, and duration) have shown inconsistent results. Therefore, in this theoretical/modeling study we have investigated rhythmogenic mechanisms in a population of excitatory neurons with INaP, ICa and ICAN conductances randomly distributed within the population. In addition, we incorporated in the model and investigated the possible roles of Na+/K+ pump, IP3-dependent intracellular calcium release, and mutually excitatory synaptic interactions within the population in generation of population busting activity. We also elaborated the reduced low-dimensional model of such a population adapting activity-based approach (Rubin et al. J Comp. Neurosci 2011, 30(3):607-32) for large excitatory neural populations. By combining computer simulations of the full model and fast-slow decomposition and bifurcation analysis of the reduced model we have demonstrated that such population can operate in several regimes of oscillatory bursting activity, which can be dependent on INaP and/or ICAN, or **independent of both**. The particular oscillatory regime also depends on several external and internal parameters, such as those defining general neuronal excitability, mutual neuronal interactions including the number of neurons involved, which may vary for example with the size of the slices studied experimentally. The existence of multiple oscillatory regimes and the transitions between them may provide explanations for the different rhythmogenic mechanisms inferred to operate under various experimental conditions *in vitro*. The modeling approach elaborated and the results obtained in this study may be relevant to a wide range of excitatory neural populations exhibiting self-sustained rhythmic activity.