Characterization of Triphasic Rhythms in Central Pattern Generators (I): Interspike Interval Analysis

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Abstract. Central Pattern generators (CPGs) neurons produce patterned signals to drive rhythmic behaviors in a robust and flexible manner. In this paper we use a well known CPG circuit and two different models of spiking-bursting neurons to analyze the presence of individual signatures in the behavior of the network. These signatures consist of characteristic interspike interval profiles in the activity of each cell. The signatures arise within the particular triphasic rhythm generated by the CPG network. We discuss the origin and role of this type of individuality observed in these circuits.

1 Introduction

Central Pattern Generators (CPGs) are assemblies of neurons that act cooperatively to produce regular signals to motor systems. CPGs are responsible for activities like chewing, walking and swimming [1]. The inner properties of every neuron in the CPG, together with the connection topology of the network and the modulatory inputs, determine the shape and phase relationship of the electrical activity. A single CPG (acting alone or together with other CPGs) can generate many different patterns of activity that control a variety of motor movements [2]. An essential property for these neural assemblies is the presence of robust and regular rhythms in the membrane potentials of their member neurons. Paradoxically, some of these cells can display highly irregular spiking-bursting activity when they are isolated from the other members of the CPG [3, 4] manifesting a rich individual dynamics.

Recently, the presence of characteristic interspike interval profiles in the activity of individual CPG neurons has been revealed using *in vitro* preparations of the pyloric CPG of the lobster [5,6]. These individual *signatures* of the CPG cells can have important implications for the understanding of the origin of the rhythms, their fast response to modulation and the signaling mechanisms to the muscles that the CPGs control. In this paper we want to study the origin of the individual neuron signatures. In particular, we want to determine their dependence on the network architecture and on the properties of the individual neural dynamics. For this goal, we will use two different types of spiking-bursting

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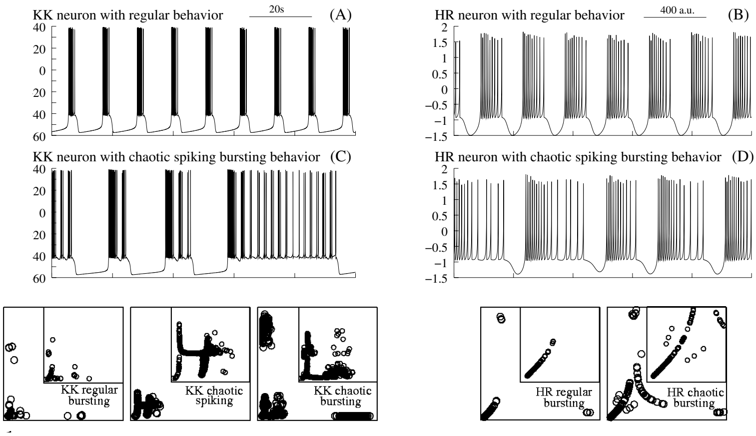

Fig. 1. Top panel: time series of the isolated model neurons (chaotic spiking in KK neurons not shown). Units are s and mV for KK neurons. Units are dimensionless for HR neurons. Bottom panel: ISI return maps of isolated KK and HR neurons. Axis length is 14s for KK neurons and 160 a.u. for HR neurons. Insets show a blowup of the region close to the origin (axis length is 4s for KK and 50 a.u. for HR) that will be compared with the ISIs obtained from the network activity.

neuron models: Komendantov-Kononenko [7] neurons (a Hodgkin-Huxley type model with eight dynamical variables), and Hindmarsh-Rose [8] neurons with three dynamical variables. These two models have in common a rich dynamical behavior with the ability to generate the characteristic chaotic spiking-bursting activity observed in isolated CPG cells.

2 Single Neuron Models

Komendantov-Kononenko (KK) type neurons [7] can have several patterns of activity as a function of the parameters used in the model. In this paper, we use three different behaviors: regular spiking-bursting, chaotic spiking and chaotic spiking-bursting activity (see Fig. 1). Each behavior is the result of a particular choice for the values of the maximum conductances of the ionic channels used in the model. The equations that describe the dynamics of the model and the parameters used to obtain each type of behavior can be found in [7]. The inter-spike interval (ISI) return maps (ISI_i vs. ISI_{i+1}) of the isolated KK neurons can be seen in Fig. 1 (left bottom panel) for the three different behaviors used in this paper. These return maps, which can be considered as signatures of the individual activity, constitute a useful tool to analyze the regularity of the spiking activity for each mode of behavior.

The Hindmarsh-Rose (HR) neurons [8] can also display a wide variety of behaviors. Right panels in Fig. 1 show two time series corresponding to the regular and chaotic spiking-bursting activity in this model, respectively. The equations of the HR model and the values of the parameters used in our simulations can