Chapter 97
WLC Analysis of Lamprey Neural System

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Abstract The paper simulates membrane potential of Lamprey neural circuit based on WLC model. The influences parameter of RS and SR neuron stimulation are numerically analyzed. The results show that left or right motoneuron will appear alternately spike in circumstance of external stimulation. In alternate-current stimulation the ISI sequences of motoneuron will have periodical increase. Also it shows transforming of motoneuron frequent from left to right motoneuron. These results explain the experiment phenomena when lamprey was influenced by electrical stimulation.

Keywords Lamprey · ISI · motoneuron · stretch receptor neuron

Introduction

The Vertebrate neural system of mammals is very complex. Its structure contains numerous neurons form different central pattern generators. There are many specialists doing research in lamprey experiment, especially on the rhythm caused by central pattern generator [1]. The experiments study the influence of synaptic strength and lamprey pattern activity by modulating dopamine concentrations and reveal essential properties.

In order to analyze the rhythm of neuron in the lamprey system, we not only use the motoneuron rhythm to analyze the locomotor behavior, but also study the lamprey locomotor influenced by external stretching. For example, we can compute the ISI (interspike interval) sequence of neuron spike, and then analyze the relationship between external stimulation and locomotor frequency. As the lamprey system is inhibited neural network the WLC model is used to describe the inhibition of the system, which is composed of brain part and 1-segment neurons. We analyze the influence of motoneuron inputted by external stimulation and discuss the changes

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of the neuron ISI sequence. The simulation results here explain the experiment phenomena when we vary the external stimulation.

The Lamprey Network

Based on Sten Grillner's experiment results [2], the lamprey network contains four parts: brainstem neuron, stretch receptor neuron, CPG and motoneuron. There are two kinds of stretch receptor neurons: SR-E neuron is excitatory stretch receptor neuron, while SR-I neuron is inhibitory stretch receptor neuron. CPG is composed of E, I, L neuron. These three neurons can generate motor rhythm. In CPG, E is an excitatory interneuron, while L and I are two kinds of inhibitory interneurons. L neuron can inhibit I neuron in the ipsilateral side. I neuron can inhibit spinal cord cell in the contra lateral side. M is included in every segment.

The lamprey network's synaptic connection is mainly inhibitory synaptic. So we can use WLC model to simulate the head of lamprey neural system [3]. While the excitatory synaptic in the lamprey network can be considered as the perturbation to neuron. The WLC model including excitatory synaptic is described as followed:

$$\begin{aligned}\frac{dx_i(t)}{dt} =& \frac{1}{\tau_1}\left\{x_i(t) - \frac{1}{3}x_i^3(t) - y_i(t) - z_i(t)[x_i(t) - v] + 0.35 + S_i\right\} \\ &+ \sum_{j\neq i} E_{ji}x_j(t) \end{aligned} \tag{97.1}$$

$$\frac{dy_i(t)}{dt} = x_i(t) - by_i(t) + a \quad i = 1, 2, \cdots, 14 \tag{97.2}$$

$$\frac{dz_i(t)}{dt} = \frac{1}{\tau_2}\left\{\sum_j g_{ji}G[x_j(t)] - z_i(t)\right\} \tag{97.3}$$

Where E_{ji} is the strength of excitatory synaptic, which describes as jth neuron excite ith. The parameters of WLC model can be seen references [3].

The Lamprey Model Analysis

Motoneurons Influenced by the Constant Stimulation to SR or RS Neurons

1. The ISI sequence of motoneuron is analyzed when we give a constant external stimulation $S_i = I_i$ to SR neuron or RS neuron. If we choose a set of parameters of the model the alternating spike from neuron RS, L, E, I rhythms appear in Fig. 97.2. These results conform to the experiment phenomena of lamprey [2]. We add constant stimulation to neuron SR-E or SR-I on the left or right side of

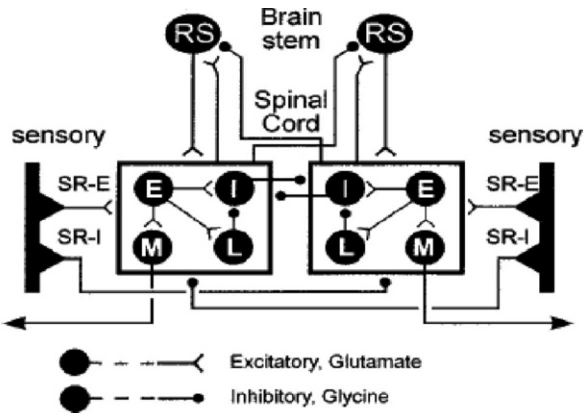

Fig. 97.1 The head network of lamprey

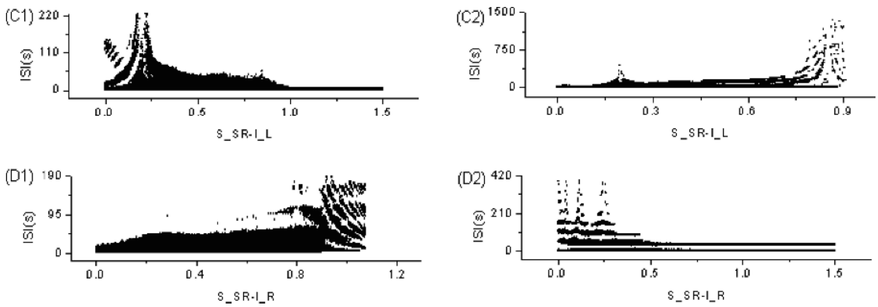

Fig. 97.2 ISI sequence of M neuron by constant stimulation of left SR-I

lamprey network and compute the ISI sequence. Figure 97.2 show, when left SR-I is given an increasing constant stimulation, the rhythm frequency of left M will become slow first and then become fast. While we increase constant stimulation to right SR-I, the rhythm frequency of left M will become fast first and then become slow. These results conform to the experiment phenomenon mentioned in reference [4].

2. When RS neuron is given constant stimulation, lamprey also shows alternate property on two sides of neurons. In Fig. 97.3, it is apparent to see that RS neurons have more information in increasing period phenomena. These results show the head of lamprey controls the body movement. The general rule of controlling movements can be studied by more segments in lamprey network.

The reference [5] shows, when the two sides of spinal cord are given a 100–200 μA pulse or 20 Hz alternate stimulation, the symmetric rhythm phenomena would appear in the neurons in lamprey's dorsal. These results can be explained by model results here.

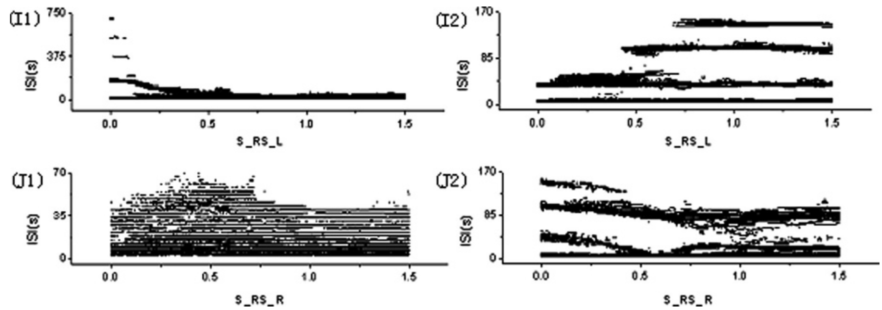

Fig. 97.3 ISI sequence of M neuron by constant stimulation of left RS

Motoneurons Influenced by the Alternate Stimulation of SR or RS Neurons

1. We will study the influences of motoneurons when stretch receptor neuron or RS neuron is given by alternate stimulation, $S_i = I_i \cdot \cos(wt)$. The ISI results can be seen in the following, Fig. 97.4.
2. From Fig. 97.4, we can apparently see that ISI sequence of single motoneuron occur symmetric phenomena. These phenomena can be described as alternate

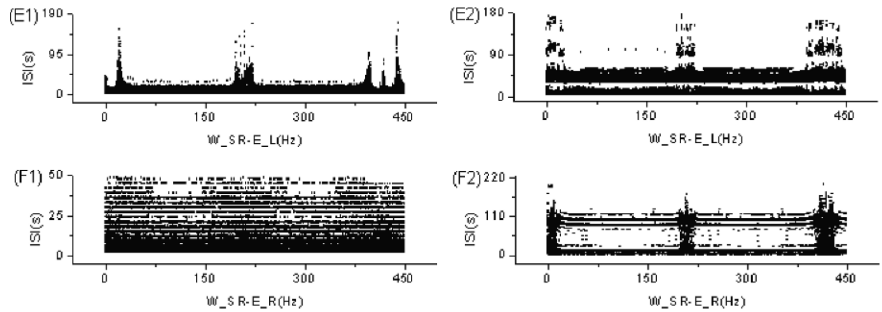

Fig. 97.4 ISI sequence of M neuron by alternate stimulation of SR-E

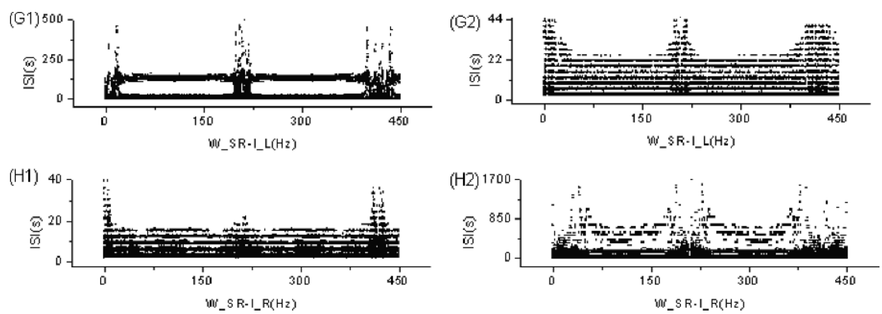

Fig. 97.5 ISI sequence of M neuron by alternate stimulation of SR-I

activity of lamprey. From Figs. 97.4-E1 and 97.4-F2, one can see the alternate stimulation frequency of left or right SR-E increases, the general motor frequency has no difference. In the same way, we can analyze the ISI sequence of single motoneuron when left or right SR-I is given alternate stimulation. These results can be seen in Fig. 97.5.

Discussion

In lamprey spinal cord, our numerical analysis shows the rhythm activity of the two sides motoneuron. The result here shows, WLC model can describe the alternate rhythm of neuron in two sides of lamprey system very well. We also use constant or alternate stimulation of two sides SR neurons to analyze the influence of lamprey rhythm. When single SR neurons are inputted by constant stimulation, the motor frequency of two sides motoneuron will occur alternate phenomena. So that two sides of muscles will transform from the contracting status to the relaxing status or the inverse. This transformation can explain the forward swim or turning of lamprey. When a single SR neuron is inputted by alternate stimulation, the general motor frequency of one side motoneuron will be fast, while the general motor frequency of the other side motoneuron will be slow. So the lamprey will bend from one side to the other side. The ISI results here can explain lamprey's spinal cord has stable ability of controlling movements. This result shows that lamprey's system has high efficiency of information transmission. Using lamprey's system to control robot's movement is also the hot spot of many specialist researches.

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