International Congress Series 1301 (2007) 79 – 82

www.ics-elsevier.com

Synchronized spike selection in a hippocampal dentate gyrus network model in the theta frequency range

Katsumi Tateno *, Hatsuo Hayashi, Satoru Ishizuka

Department of Brain Science and Engineering, Kyushu Institute of Technology, Japan

Abstract. We propose a neural network model in which synchronized periodic synaptic inputs in the theta frequency range selectively pass. Random synaptic inputs contributed to the proposed signal filtering. When all granule cells received only synchronized periodic input, the network model worked as the low pass filter. When an adequate number of granule cells received synchronized periodic inputs and the rest of the granule cells received random inputs, the network model worked as the band-pass filter. The bandwidth was consistent with the frequency range of the theta rhythm. © 2007 Elsevier B.V. All rights reserved.

Keywords: Neural network model; Hippocampus; Dentate gyrus; Theta rhythm

1. Introduction

The hippocampal dentate gyrus receives synaptic input from the entorhinal cortex. The dentate gyrus may work as a filter for those synaptic inputs. The granule cell in the dentate gyrus responds well to the periodic stimuli at 4 Hz, while periodic stimuli at 10 Hz inhibit spikes of the granule cell [1]. Those results imply that spikes carried by the theta rhythm easily pass the dentate gyrus. We have proposed a model of the dentate gyrus in which periodic stimuli at a theta frequency selectively induce the 1:1 response of the granule cell [2]. Random synaptic input to mossy cells leads to the theta rhythm selection in the proposed model.

Neurons in layer II of the entorhinal cortex fire at a certain phase of each theta cycle [3]. It has been considered that synchronization of spikes may carry a part of the information. In

* Corresponding author. 2-4 Hibikino, Wakamatsu-ku, Kitakyushu, 808-0196, Japan. Tel.: +81 93 695 6090; fax: +81 93 695 6014.

E-mail address: tateno@brain.kyutech.ac.jp (K. Tateno).

doi:10.1016/j.ics.2006.12.027

the present study, we propose a network model of the dentate gyrus that shows dependence of theta rhythm selection on the degree of synchronization of synaptic inputs.

2. Hippocampal dentate gyrus network model

The present dentate gyrus network model consists of 9 granule cells (#1–#9), 9 inhibitory interneurons and 3 mossy cells. The granule cells are connected to the inhibitory interneurons and the mossy cells through excitatory synapses. The inhibitory interneurons are connected to the granule cells. Each mossy cell is connected to 6 granule cells and 6 inhibitory interneurons through excitatory synapses.

The present granule cell model has one somatic and 12 dendritic compartments. This model is based on Yuen and Durand's granule cell model [4]. The somatic compartment is formulated as follows:

$$C_m \frac{\mathrm{d}V}{\mathrm{d}t} = \bar{g}_{\mathrm{Na}} m^3 h (E_{\mathrm{Na}} - V) + \bar{g}_{\mathrm{K}} n^4 (E_{\mathrm{K}} - V) + \bar{g}_{\mathrm{Ca}} e^2 (E_{\mathrm{Ca}} - V) + \bar{g}_{\mathrm{K-AHP}} q^2 (E_{\mathrm{K}} - V) + \bar{g}_{\mathrm{Ls}} (E_{\mathrm{L}} - V)$$

The somatic compartment has the fast Na^+, the delayed rectifier K^+, the L-type Ca^{2+}, the Ca^{2+}-dependent K^+, and the leak currents. The dendritic compartments have only the leak current. The calcium concentration of the somatic compartment is formulated as follows:

$$\frac{\mathrm{d}[\mathrm{Ca}^{2+}]_i}{\mathrm{d}t} = -\frac{[\mathrm{Ca}^{2+}]_i - [\mathrm{Ca}^{2+}]_{i0}}{\tau} - \frac{I_{\mathrm{Ca}}}{wzF}$$

where $[Ca^{2+}]_i$ represents the calcium concentration, τ is the Ca^{2+} removal rate, w is the Ca^{2+} shell thickness, z is the valence of Ca^{2+}, and F is the Faraday constant.

We used a basket cell model developed by Traub et al. [5] as an inhibitory interneuron. The inhibitory interneuron model has one somatic compartment and two dendritic cylinders, which are connected to the soma. The somatic compartment of the basket cell model is formulated as follows:

$$C_m \frac{\mathrm{d}V}{\mathrm{d}t} = \bar{g}_{\mathrm{Na}} m^3 h (E_{\mathrm{Na}} - V) + \bar{g}_{\mathrm{K}} n^4 (E_{\mathrm{K}} - V) + \bar{g}_L (E_{\mathrm{L}} - V)$$

The somatic compartment has the fast Na^+ and the delayed rectifier K^+ currents. The dendritic compartment has only the leak current. The inhibitory interneuron is a silent neuron.

The mossy cell model is based on the hippocampal CA3 pyramidal cell model developed by Pinsky and Rinzel [6]. The mossy cell has one somatic and one dendritic compartment, and is formulated as follows:

$$C_m \frac{\mathrm{d}V_s}{\mathrm{d}t} = \bar{g}_{\mathrm{Na}} m^2 h (E_{\mathrm{Na}} - V_s) + \bar{g}_{\mathrm{K}} n (E_{\mathrm{K}} - V_s) + \bar{g}_h a (E_h - V_s) + \bar{g}_{\mathrm{Ls}} (E_{\mathrm{L}} - V_s)$$

$$C_m \frac{\mathrm{d}V_d}{\mathrm{d}t} = \bar{g}_{\mathrm{Ca}} s^2 (E_{\mathrm{Ca}} - V_d) + \bar{g}_{K-C} c \min(0.004 \cdot [\mathrm{Ca}^{2+}]_i, 1)(E_{\mathrm{K}} - V_d) + \bar{g}_{K-AHP} q (E_{\mathrm{K}} - V_d) + \bar{g}_{\mathrm{Ld}} (E_{\mathrm{L}} - V_d)$$

$$\frac{\mathrm{d}[\mathrm{Ca}^{2+}]_i}{\mathrm{d}t} = -\beta [\mathrm{Ca}^{2+}]_i - \phi \cdot I_{\mathrm{Ca}}$$