Model of the Generation of the Amygdala Theta Rhythm

Tyler Banks*, Tugce Tuna*, Pete Canfield, Gunes Unal, and Satish S. Nair, *Senior Member, IEEE*

Abstract— **Theta rhythms are seen in local field potential (LFP) recordings from the amygdala during fear learning, but it is unclear how the microstructure in the amygdala supports such a network oscillation. A biophysical computational model of the basolateral amygdala (BLA) suggests that both specific intrinsic connectivity and extrinsic afferents are important, with the former possibly being necessary**.

I. Introduction and Method

Guided by the findings in the hippocampal literature [1; 2], we hypothesized that GABAergic projection neurons from the ventral pallidum/substantia innominata (VP/SI) nuclei of the basal forebrain (BF) that selectively innervate inhibitory interneurons in the BLA [3] are responsible for the generation of local theta oscillations in this limbic structure. Building on previous work [4], we developed a biophysical computational BLA model to test the emergence of theta oscillations when both the *non-rhythmic cholinergic input* and the *rhythmic GABAergic input* of the VP/SI are present, in addition to the *constant excitatory thalamic/cortical input*. As observed for the hippocampal theta rhythm [5], removing the cholinergic or the GABAergic BF input alone should decrease theta power in BLA. Moreover, they should cease completely when the rhythmic GABAergic input is cut together with either the non-rhythmic cholinergic input or the thalamic/cortical input.

Single cell and network models. Following our previous models [4; 6], we developed a 1000-cell biophysical model of the BLA with four types of single cells (Fig. 1). Network model development details can be found in [4; 6].
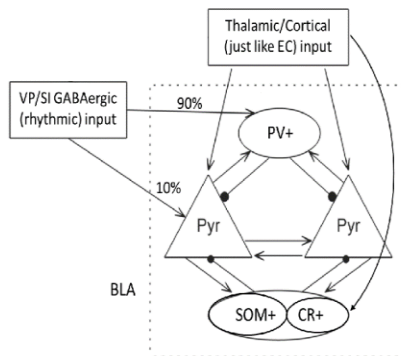

Figure 1. Computational network model of the BLA for analyzing mechanisms of its theta rhythm. Pyr: pyramidal neuron; PV+, SOM+, CR+: parvalbumin, somatostatin and calretinin-immunopositive interneurons.

II. Results and Discussion

After matching single cell responses to biological data, model cells were inserted into the network and synaptic weights were tuned to successfully reproduce baseline in vivo firing rates for all cell types except for SOM cells: 1.89Hz (± 1.03Hz), 8.66Hz (± 5.85Hz). and 21.33Hz (± 0.95Hz) for PN, PV+, SOM+/CR+ cell types [4]. With a higher firing rate of 21 Hz, a distinct bump in theta frequency range was noticed in the power spectral density (PSD) plot of the LFP, suggesting that the network has the capability for producing theta intrinsically. We then introduced extrinsic input with firing rates at 4-8Hz to represent theta rhythmic inputs from VP/SI. With SOM+ cells back to a baseline firing rate of 12.89Hz (± 5.85Hz) and an 8Hz rhythmic input, we found that theta remained consistently high (Fig. 2) at a power level as in experiments with higher levels of SOM+ activity. We show that GABAergic VP/SI input should strengthen the theta-range oscillatory power albeit sufficient network resonance arising from thalamic/cortical and BF cholinergic input. However, when these excitatory inputs fail to produce theta-genesis, GABAergic afferents may provide no additional effect.
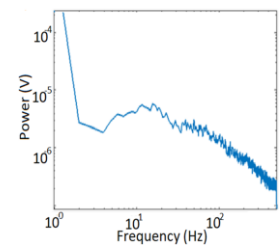

Figure 2. PSD of the LFP, showing theta using 8Hz rhythmic input from the VP/SI.

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*T. Banks and T. Tuna contributed equally. T. Banks, P. Canfield and S. S.Nair are with Electrical Engineering and Computer Science, University of Missouri, Columbia MO 65211 (corresponding author SSN phone: 573-882-2964; fax: 573-882-0397; e-mail: nairs@missouri.edu).

T. Tuna and G. Unal are with Department of Psychology, Bogazici University, Istanbul, Turkey.