Visual alpha generators in a spiking thalamocortical microcircuit model

Renan O Shimoura[1,2], Antonio C Roque[1], Markus Diesmann[2], Sacha J van Albada[2]

[1] University of São Paulo, Department of Physics, Ribeirão Preto, Brazil
[2] Institute of Neuroscience and Medicine (INM-6) and Institute for Advanced Simulation (IAS-6) and JARA-Institut Brain Structure-Function Relationships (INM-10), Jülich Research Centre, Jülich, Germany

Contact: renanshimoura@usp.br

Introduction

One of the most prominent features observed in waking electroencephalograms of a variety of mammals, mainly at eyes-closed rest, is the alpha rhythm around 10 Hz. Although alpha is strongly associated with reduced visual attention, it is also related to other functions such as the regulation of the timing and temporal resolution of perception, and transmission facilitation of predictions to visual cortex [1].

Motivation and goal

Understanding how and where this rhythm is generated can elucidate its functions. In this regard, two possible alpha generators were studied:

1) Pyramidal cortical neurons of layer 5 (L5) producing rhythmic bursts (IB, intrinsically bursting) close to 10 Hz after stimulation by a short current pulse [2] were introduced in a full-scale layered network of adaptive exponential integrate-and-fire neurons.

2) A thalamocortical loop delay around 100 ms previously proposed in mean-field models [3] was evaluated for different combinations of thalamocortical and corticothalamic delays.

Methods

The cortical network model was composed of ~80,000 neurons simulated using the AdEx model. Neurons were connected by current-based synapses with instantaneous rise and exponential decay. Network connections were constructed based on the connectivity map given in Potjans & Diesmann (2014).
All simulations were performed using the neural network simulator NEST.

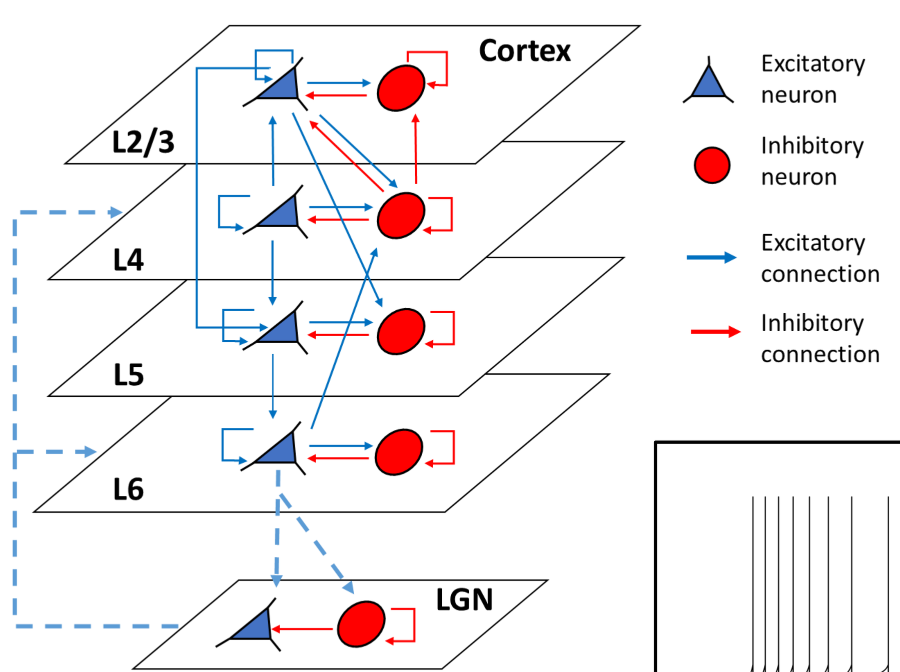
Neurons (AdEx model)

$$C_m \frac{dV}{dt} = -g_L(V - E_L) + g_L \Delta_T \exp\left[\frac{V - V_T}{\Delta}\right] - u + I_{ext} + I_{syn}$$

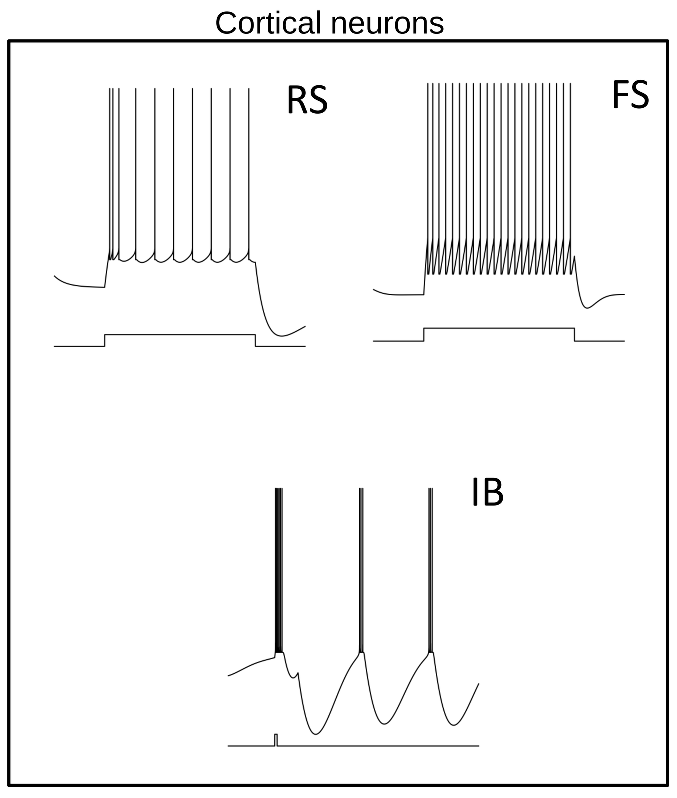
$$\tau_u \frac{du}{dt} = a(V - E_L) - u \qquad \text{If } V > V_{cut}, \text{then} \begin{cases} V = V_{reset} \\ u = u + b \end{cases}$$

Thalamocortical network

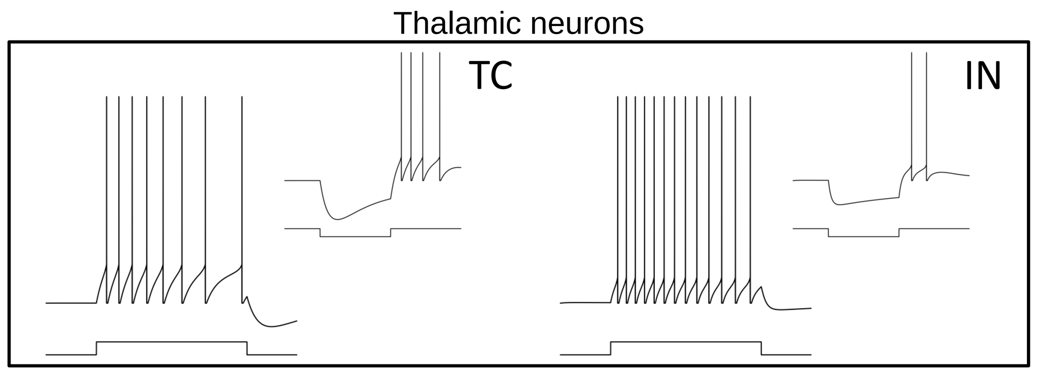
The thalamic network was composed of 902 thalamocortical (TC) and 301 inhibitory neurons (IN). Cortical neurons in layers 4 (L4) and 6 (L6) received thalamocortical connections. In turn, L6 neurons sent feedback to thalamus. Moreover, the number of thalamocortical connections onto L4 neurons was modified to be two times as high as usually described, matching recent observations [4].



Cortical neurons



Thalamic neurons

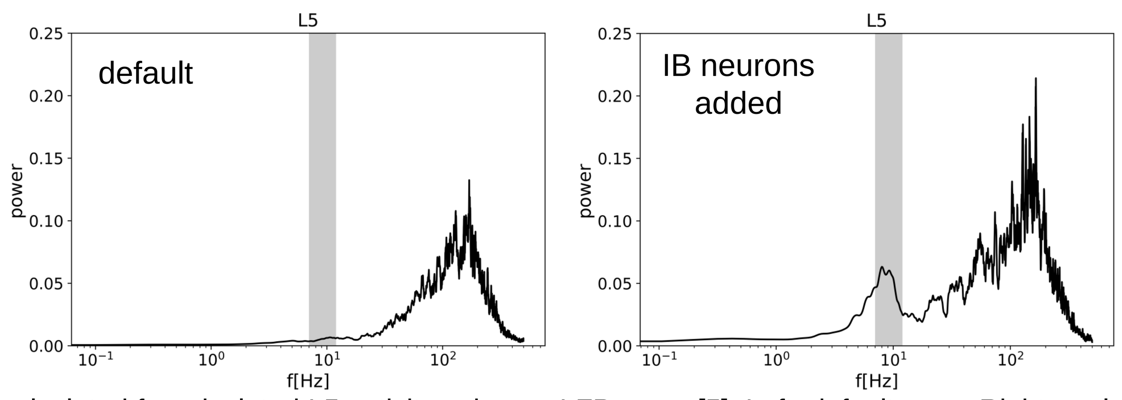


Results

L5 rhythmic burst neurons

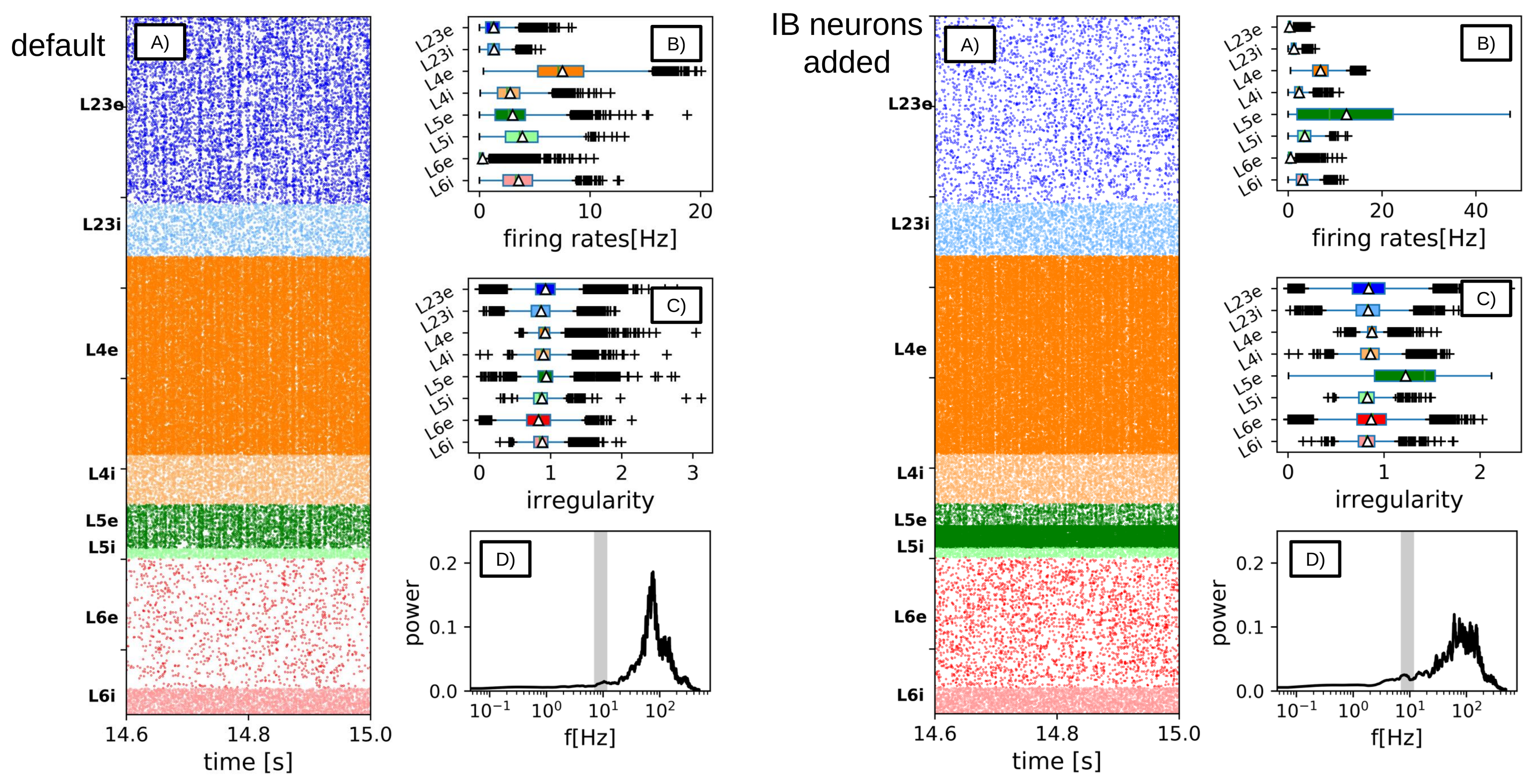
50% of L5 excitatory neurons were replaced by rhythmic burst neurons

▪Isolated L5:



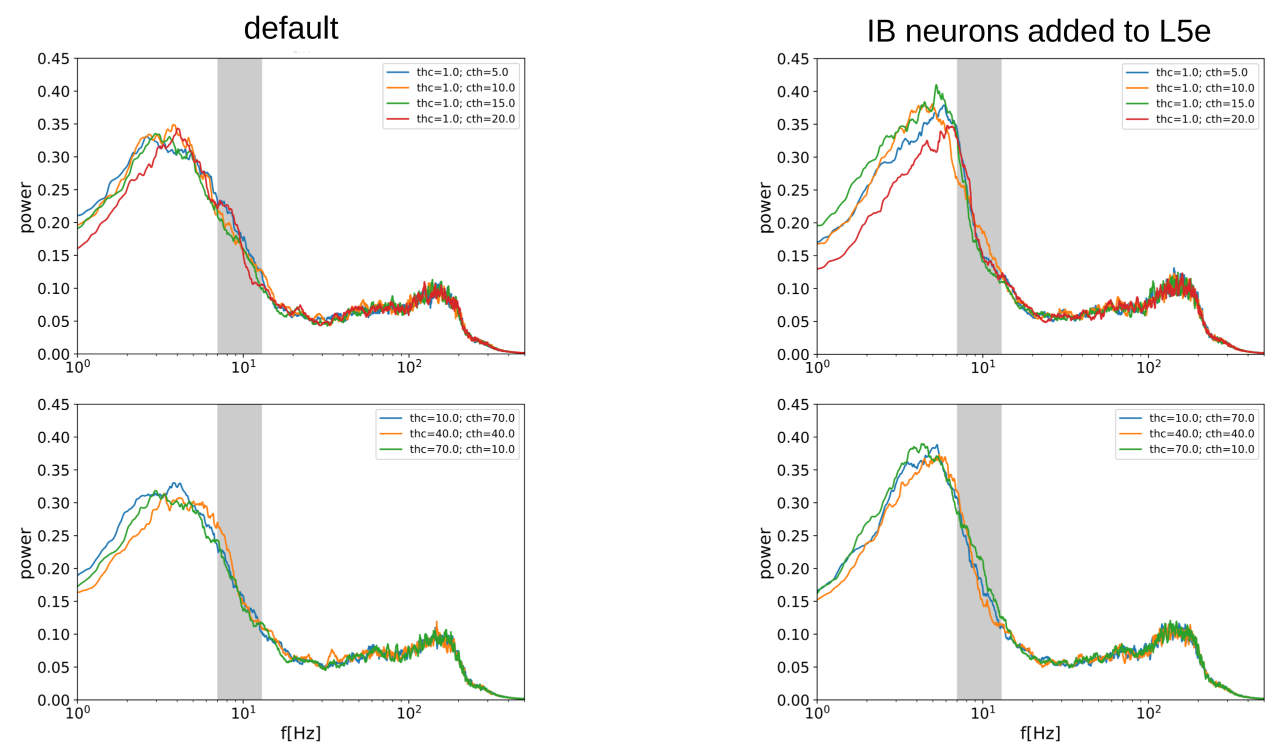
Power spectra calculated from isolated L5 activity using an LFP proxy [5]. Left: default case. Right: replacement of 50% of excitatory neurons by IB cells. Grey areas represent alpha range.

▪Activity of the full cortical microcircuit:



Full cortical microcircuit (left) and the same network but replacing 50% of excitatory neurons by IB cells (right). For both panels: A) raster plot; B) mean firing rates; C) mean coefficient of variation of the interspike intervals; and D) power spectrum calculated from network activity. Each color represents a different population.

Thalamocortical loop delay



Power spectra calculated from cortical activity using an LFP proxy [5] for different combinations of thalamocortical (thc) and corticothalamic (cth) delays (in ms). Left: default case. Right: replacement of 50% of L5 excitatory neurons by IB cells. Grey areas represent the alpha range. For both cases, the thc and cth delays follow a normal distribution with relative standard deviation of 1% of the average value.

Conclusion

- Intrinsically bursting neurons in isolated L5 are able to generate slow network oscillations close to 10 Hz;
- Oscillations supported solely by IB neurons are not evident in the full network;
- The thalamocortical interactions create a prominent low-frequency peak for which the mechanism is so far unclear;
- Thalamocortical loop mechanism combined with the addition of IB cortical neurons moves the frequency peaks closer to alpha range depending on the combination of thalamocortical and corticothalamic delays.

References

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