Extracellular synaptic and action potential signatures in the hippocampal formation: a modeling study

Amélie Aussel[1,2,3], Harry Tran[2,3], Laure Buhry[1,3], Steven Le Cam[2,3], Louis Maillard[2,4], Sophie Colnat-Coulbois[2,3,4], Valérie Louis-Dorr[2,3], and Radu Ranta[2,3]

[1]LORIA - UMR CNRS 7503 INRIA,[2]CRAN - UMR CNRS 7039,[3]Université de Lorraine,[4]Centre Hospitalier Universitaire de Nancy

Introduction

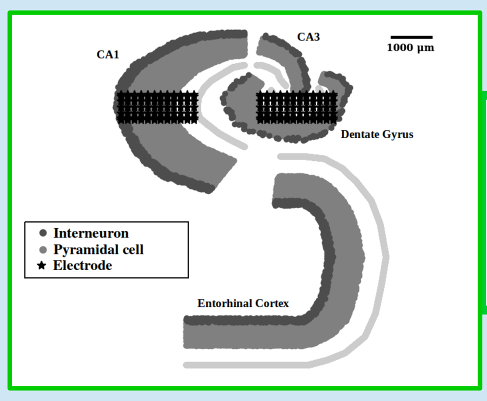
Local Field Potentials (LFPs) recorded with micro and/or macro-electrodes include a mixture of low frequency patterns, mainly attributed to the synaptic currents (SCs) and high-frequency components reflecting action potentials (APs) activity.

Simulating a realistic LFP is often based on detailed neural models and requires a high computational burden [1], but it is necessary to study phenomenons where the fast and slow components of neural activity are equally important, such as hippocampal oscillations [2].

In this work we propose a hybrid model to simulate large scale neural networks efficiently while computing a realistic approximation of the LFP signal including both SCs and APs signatures. We apply this method on a hippocampal network [3] and use it to infer their relative contributions on human intracranial measurements.

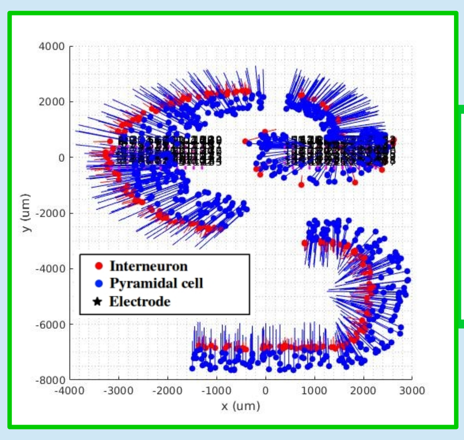
Methods

Simulation process :



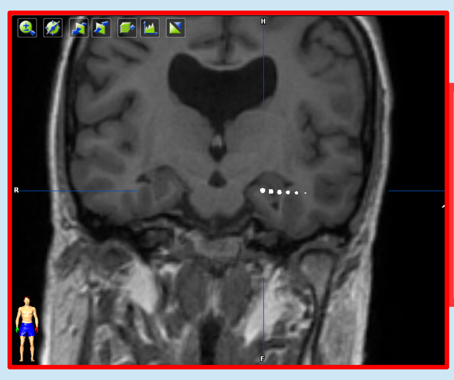
Computational model with simplified neuron morphology → LFP_SC

Raster plot



Extracellular Action Potentials model based on geometrical filtering and HH dynamics → LFP_AP

LFP_full=α LFP_AP+β LFP_SC



Comparison of the spectrums of the generated LFP and intracranial LFP measurement

More details on the computational model [3] :

- ≈30000 single compartment Hodgkin-Huxley neurons
- Realistic topology and connectivity of the hippocampus
- Able to reproduce sleep and wakefulness oscillatory patterns through cholinergic modulation

More details on the AP LFP model [4] :

- Mimicks multicompartmental neurons
- Extracellular action potentials obtained with a morphological filtering taking into account the neuron geometry and relative positions to the electrodes.
- Action potential signatures are convoluted with the raster plot obtained in the previous step

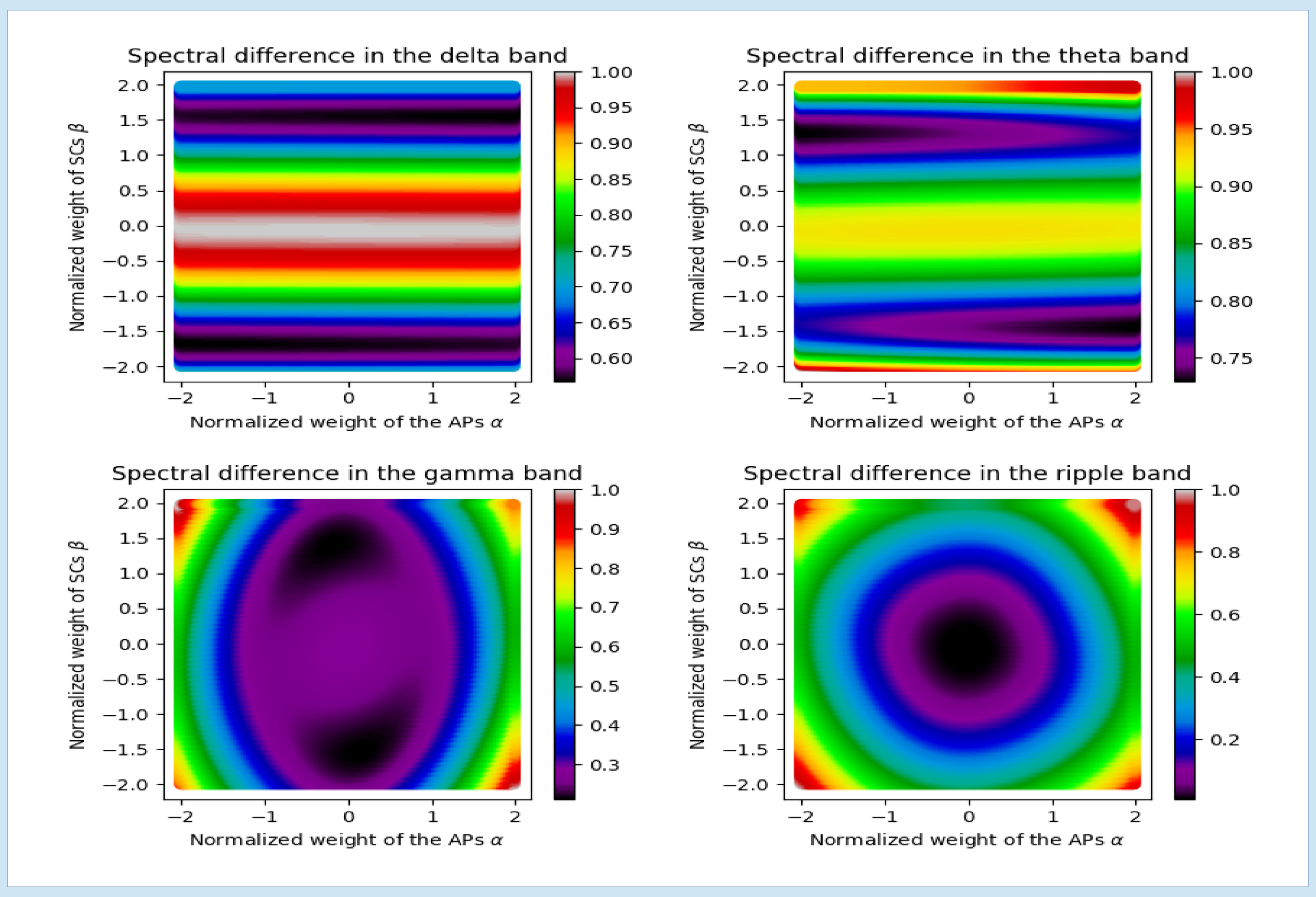
Final simulated LFP :

- Weighted average of SC and AP contributions over the surface of two sEEG electrodes
- Realistic intracranial recordings settings : 2 cylindrical contacts, 2mm-long, diameter 0.8mm, sampled with a regular grid

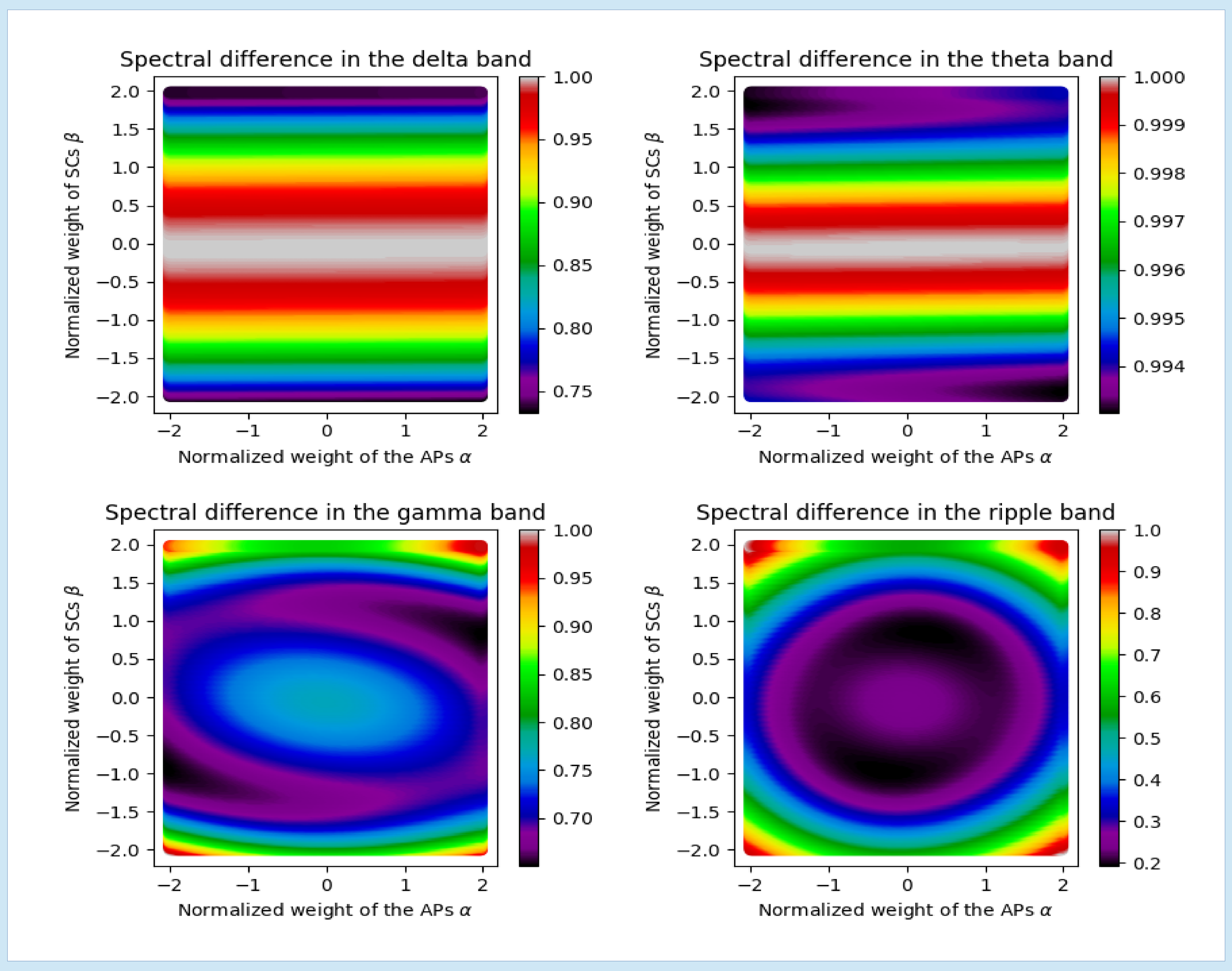
Results

We computed the difference between the spectrum of the real and simulated LFPs for different values of α and β in four frequency bands : delta (1-4Hz), theta (4-10Hz), gamma (30-100Hz) and ripple (120-250Hz)

During wakefulness : typical rhythms are theta and gamma. Theta oscillations are mostly due to SCs while gamma are mostly explained by APs.



During slow-wave sleep : typical rhythms are delta and ripples. Delta oscillations only depend on SCs but ripples involve both APs and SCs.



Conclusions

In this work, we present and analyze a computationally efficient way of calculating LFPs.

We show the importance of considering both action potentials and synaptic currents contributions to the LFP, even at rather low frequencies such as theta and gamma.

Our results suggest that, depending on the oscillatory pattern studied, these contributions could be balanced differently to better reproduce experimental findings.

References

[1] Einevoll GT, et al. Modelling and analysis of local field potentials for studying the function of cortical circuits. Nat. Rev. Neuroscience, 14(11), 770, 2013

[2]Schomburg EW, Anastassiou CA, Buzsáki G, Koch C. The spiking component of oscillatory extracellular potentials in the rat hippocampus. J Neurosci. 32(34):11798-811, 2012

[3] A. Aussel et al. A detailed anatomical and mathematical model of the hippocampal formation for the generation of sharp-wave ripples and theta-nested gamma oscillations. J Comput Neurosci 45: 207. https://doi.org/10.1007/s10827-018-0704-x, 2018

[4]H.Tran et al. Simulating extracellular signatures of actions potentials using single compartments neurons and geometrical filtering. In the 27th Computational Neuroscience Conf, Seattle, USA, 2018