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Joint modeling of voltage-sensitive imaging data and laminar microelectrode recordings

AUTHOR BLOCK: *H. LINDÉN[1], K. H. PETTERSEN[1], A. DEVOR[2,3,4], P. TIAN[2], I. C. TENG[2], A. M. DALE[2,3], G. T. EINEVOLL[1];

[1]Mathematical Sci. and Technol., Norwegian Univ. of Life Sci., Aas, Norway; [2]Dept. of Neurosciences, [3]Dept. of Radiology, UCSD, La Jolla, CA; [4]Mgh, Harvard Med. Sch., Boston, MA

Abstract: Voltage-Sensitive Dyes (VSD) imaging provides a unique tool for visualizing real-time neuronal activity. This method allows high temporal resolution imaging of neuronal transmembrane potential changes across the cortical surface, but lacks depth resolution. The signal at every pixel represents a weighted sum of the transmembrane potential, with sensitivity decreasing exponentially with depth. The Local Field Potential (LFP), on the other hand, reflects the extracellular potential, which is directly related to the transmembrane currents, and can be sampled throughout the cortical depth. Both VSD signals and LFP recordings are dominated by synaptic, rather than spiking, activity. Thus, LFP and VSD data may provide complementary constraints on models of cortical circuit behavior, incorporating biophysical information at the level of laminar or cell-type specific neuronal populations.
In this study, we simulated LFP and VSD profiles from transmembrane currents and the corresponding potentials under different scenarios of synaptic inputs. All simulations were done using reconstructed pyramidal cells in NEURON, assuming only passive conductances. LFP was calculated using forward modeling as described in [1]. The VSD was modeled as a weighted sum of membrane potential where the weight factor depends on distance from the top of cortex and membrane area. Specifically, we assumed a simple model in which $VSD(t) = \sum area_i * f(z_i) * V_i(t)$, where $area_i$ is the total surface area of the neuronal segment i, f is a weight function that describes the contribution to the VSD signal at different depths z_i, and $V_i(t)$ is the transmembrane potential in segment i at time t.
Using this approach, we calculate the contribution of synaptic currents at different depths, to the predicted VSD signals, for different cell types, based on cellular reconstructions. Our results imply that the contribution of L5 pyramidal neurons to the VSD is dominated by the apical dendrites, while both basal and apical compartments of L2/3 pyramidal cells are predicted to contribute. We further compare model results for different assumed synaptic connection patterns with stimulus-evoked VSD and LFP data recorded from the rat somatosensory system.
The cell-specific VSD signatures can be combined with the corresponding LFP/CSD profiles, to provide complementary constraints for modeling of combined VSD imaging and laminar recordings in vivo, extending the previously described Laminar Population Analysis method [2].

[1] Pettersen KH et al, J Comp Neurosci 24, 291 (2008)

[2] Einevoll, GT et al, J Neurophysiol 97, 2174 (2007). Blomquist P et al, PLoS Comp Biol 5, e1000272 (2009)

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