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The effects of realistic conductivity distribution and slice geometry on simulations of local field potentials and in Current Source Density analysis

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Abstract:
Multielectrode recordings of local field potentials (LFP) from brain slices are a standard research technique. To test different methods of LFP analysis we need to have realistic ground truth data which demands plausible models of neural activity and taking into account physical properties of the setup, tissue, and the electrodes. To decorrelate the electrode signals it is often useful to reconstruct the Current Source Density from the measured potentials (CSD). In CSD analysis one often assumes field propagation in isotropic and homogeneous tissue, which is not true in slice recordings.
We studied the effect of realistic conductivity profiles and the slice geometry on i) computation of LFP generated by cell populations embedded in slice, as would be measured on MEA, and ii) CSD reconstruction in the slice from such potentials.
First, we investigated how the use of increasingly detailed physical models of slice tissue affects the resulting model LFPs. We simulated Traub's model of thalamo-cortical loop (Traub et al. (2005)) in NEURON and the extracellular potentials in uniform, homogeneous medium were computed post-hoc from tracked trans-membrane currents. To verify the need for inclusion of experimental setup context we modeled the field in the tissue and saline using finite-element approach (FEM). The slice was placed in a saline solution, the cortical column was put inside the slice, and we computed the extracellular potentials it generated at the electrode plane underneath.
We saw that the inclusion of slice setup noticeably modifies the observed activity as both the amplitude and shape of the potential profile were changed. However, inclusion of inhomogeneity and anisotropy in the computations does not lead to substantial changes of the profile and amplitude. Indeed, inaccurate estimation of conductivity will in general introduce bigger errors than assuming homogeneous and isotropic tissue.
We also obtained an approximation to the potential computed at the electrode grid from the slice using the method of images (MOI). In computation of the LFP for the cases studied, the MOI approximation gives results very close to FEM model while being much more efficient computationally. To improve CSD estimation in the slice we included MOI model in the kernel CSD method. Testing the new kCSD variant on FEM model data we found that i) the reconstructed error is smaller when the correct slice thickness and the difference in conductivities (slice/saline) are taken into account, but the improvement is relatively minor, ii) the first two extra terms from the method of images are enough.

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