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Spatio-temporal spike dynamics: localization of single cell currents based on extracellular potentials patterns

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Introduction

Traditional current source density calculation (CSD) method allows calculation of transmembrane current source distribution on neurons from the extracellular potential patterns, thus provides important information for neurophysiology. The traditional CSD method is based on strong physical foundations, but in most cases it is applied onto one dimensional data, so derivatives according to the orthogonal dimensions are neglected. This one-dimensional method uses the implicit assumption that current source density changes can be neglected in two dimensions on the spatial scale of the electrode. In other words, it assumes a laminar source distribution, with infinitely large, homogeneous laminar sources. Considering the laminar organization of the cortex, this can be a good approximation in case of large population activities such as epilepsy or evoked potentials, but certainly not valid in case of single cells. Thus traditional one-dimensional CSD method gives incorrect results for spatial potential patterns originated from a single neuron. To solve this problem, a new spike CSD (sCSD) method was designed, which fits more to the properties of individual cellular sources, making it able reconstruct the cellular transmembrane currents, based on extracellular potential measurements. This new method is based on the inverse solution of the Poisson-equation.

Results

The new method was tested on simulated data and its performance was compared to the traditional CSD method. It was shown, that the sCSD method was able to reconstruct the original source distribution with much higher accuracy than the traditional method and precisely determinate the cell-electrode distance as well. Our new method was applied to in vivo measured action potentials. These spikes were measured in cat primary auditory cortex with a sixteen-channel chronically implanted linear probe. Using our new method, many fine details of the spatio-temporal dynamics of spikes were uncovered. Dendritic back propagation was proven to be much more frequent than previously assumed; it was observable in every cell. The speed of back propagation was typically different in the apical and basal directions. In contrast to the literature, forward propagation preceding the spikes was also observable. In perspective, this new method raises the possibility of identifying synaptic inputs that cause a cell to fire.

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