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Estimation of synaptic conductances

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Abstract

In order to identify and understand mechanistically the cortical circuitry of sensory information processing estimates are needed of synaptic input fields that drive neurons. From intracellular in vivo recordings one would like to estimate net synaptic conductance time courses for excitation and inhibition, $g_E(t)$ and $g_I(t)$, during time-varying stimulus presentations. However, the intrinsic conductance transients associated with neuronal spiking can confound such estimates, and thereby jeopardize functional interpretations. Here, using a conductance-based pyramidal neuron model we illustrate errors in estimates when the influence of spike-generating conductances are not reduced or avoided. A typical estimation procedure involves approximating the current–voltage relation at each time point during repeated stimuli. The repeated presentations are done in a few sets, each with a different steady bias current. From the trial-averaged smoothed membrane potential one estimates total membrane conductance and then dissects out estimates for $g_E(t)$ and $g_I(t)$. Simulations show that estimates obtained during phases without spikes are good but those obtained from phases with spiking should be viewed with skeptism. For the simulations, we consider two different synaptic input scenarios, each corresponding to computational network models of orientation tuning in visual cortex. One input scenario mimics a push–pull arrangement for $g_E(t)$ and $g_I(t)$ and idealized as specified smooth time courses. The other is taken directly from a large-scale network simulation of stochastically spiking neurons in a slab of cortex with recurrent excitation and inhibition. For both, we show that spike-generating conductances cause serious errors in the estimates of g_E and g_I. In some phases for the push–pull examples even the polarity of g_I is mis-estimated, indicating significant increase when g_I is actually decreased. Our primary message is to be cautious about forming interpretations based on estimates developed during spiking phases.

Keywords: Spiking neurons; Conductance-based models; Primary visual cortex; Estimation of conductances

1. Introduction

Primary goals of sensory neurophysiologists are to understand the dynamics of information processing and representation in various brain areas. What are the mechanisms (circuitry, synaptic and intrinsic cellular properties) that underlie sensory processing and that can account for the firing patterns of neurons? What are the relative contributions of feedforward and recurrent input, of the excitatory and inhibitory synaptic fields? What data are needed to develop and assess theories that can provide insights on mechanisms? We take a case-study approach here, the orientation tuning of visual cortex, and ask about the analysis of data that can give us reliable estimates of dynamic synaptic fields.

There are different theories about the wiring architecture of the primary visual cortex, mainly differing by the sensitivity to spatial phase in the coupling between cortical neurons. If we assume that the coupling is phase insensitive – see for instance the model studied in McLaughlin et al. (2001) and Wielaard et al. (2001) of a network of integrate-and-fire neurons in area 4 Cα of V1– and we present a drifting grating stimulus, then, after phase averaging, both the inhibitory and the excitatory cortico-cortical

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