BMC Neuroscience

BioMed Central

Poster presentation

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The effect of global context on the encoding of natural scenes

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from Eighteenth Annual Computational Neuroscience Meeting: CNS*2009
Berlin, Germany. 18–23 July 2009

Published: 13 July 2009

BMC Neuroscience 2009, **10**(Suppl 1):P306 doi:10.1186/1471-2202-10-S1-P306

This abstract is available from: http://www.biomedcentral.com/1471-2202/10/S1/P306

The complexity of natural stimuli has made it difficult to understand how cortical neurons encode and process information about them. Even in V1, where neurons have well characterized receptive field properties, efforts to deduce which features of a natural scene stimulus a neuron responds to, have generally been unable to fully account for most of the neurons' spiking statistics. It has been proposed that this is at least partly due to activity of the network in which the neuron is embedded. Such activity depends on the stimulus in the whole visual field, not only that in the neuron's receptive field.

We set out to quantify the extent to which neuronal activity in V1 of the behaving macaque monkey is modulated by visual stimuli outside a neuron's classical receptive field, and by extension by network activity. We simultaneously recorded neuronal spiking activity and local field potential (LFP) from the regions of central and peripheral representation of the visual field (4 and 10 degrees of eccentricity). After mapping the receptive fields (using moving bars), we presented natural scene movies (trees, flowing water, a busy street, etc.) under two conditions. In the un-masked condition we displayed the unobscured movie. In the masked condition we displayed the same movie but with only the portion corresponding to the neuron's receptive field visible, the remainder of the frame was obscured by an opaque Gaussian mask. To rigorously quantify differences in spike statistics between these two conditions we fitted Generalized Linear Models (GLMs) of the history dependent spike probability to the spiking responses. The GLM included a PSTH-like term accounting for the stimulus and a second renewal process-type term accounting for the neuron's previous spiking history. For almost all neurons, we obtained excellent goodness of fit as quantified by Kolmogovov Smirnov tests. Notably, we found that for many neurons (9 of 15 to date) the spiking responses were substantially different between the unmasked and masked conditions, indicating the strong influence of stimuli outside the neuron's receptive field.

We then attempted to determine what proportion of the difference in spiking response could be accounted for by the LFP, a population-averaged network activity measure. We decomposed the LFP into different time scales using a Daubechies wavelet multi-resolution analysis, and included a non-linear autoregressive model of each LFP scale in the GLM. For many neurons (6 of 9 to date) we found that much of the difference between the un-masked and masked conditions could be explained through LFP variations. Our goal is to determine which LFP time scales and features most inform the differences between masked and unmasked conditions by recasting the AR coefficients as non-linear filters and studying their frequency and phase response properties.

Our study suggests that analysis of receptive field properties is not sufficient to account for spiking responses to complex stimuli such as natural scenes. The global context of the stimulus, possibly mediated by network activity, remains an essential component.

Acknowledgements

Supported by NIH grants K25 NS052422-02, DP1 OD003646-01, MH59733-07 and the Max Planck Society.