Predicting response variability in the primary visual cortex

Timothy J Blanche, Kilian Koepsell, Nicholas Swindale, Bruno A Olshausen

The Poisson-like spiking of visual cortex neurons driven by drifting gratings or noise stimuli has led to the general conclusion that cortical neurons are noisy and temporally imprecise. In recent work, however, we found that naturalistic stimuli evoke spike trains that are remarkably reliable (fano factors as low as 0.1), precise (temporal jitter on the order of a few milliseconds), and sparse (lifetime sparsity ~0.85) [1]. What is it about natural stimuli that produce such highly reliable, sparse responses? Conversely, why are the responses to 'traditional' stimuli so variable?

One clue comes from looking at the larger scale response variability as measured by the local field potential (LFP), and the coupling between the LFP and single-unit spike timing. High-density silicon electrode arrays (polytrodes) were used to make simultaneous recordings of 100+ neurons spanning all cortical layers in anesthetized cat primary visual cortex [2]. Brief 5s white noise and natural scene movie segments [3] were presented 25-75 times (50Hz frame rate, 200Hz refresh). The complex analytic signal was used to obtain an instantaneous measure of LFP phase in frequency bands from 1-150Hz. LFP inter-trial phase coherence (ITC) was also calculated. LFP modulation of spike timing was quantified by fitting a von Mises distribution (circular Gaussian) to the histograms of spike phase relative to the LFP oscillation.

The LFP exhibited stimulus-locked phase alignment across trials at several frequencies. ITC was dramatic (~1.0) and sustained in response to natural stimuli, whereas to repeated white noise the ITC was weak and transient. The activity of individual neurons showed varying degrees of phase locking to the LFP with predominant peaks in all the classically defined EEG bands. Neurons often had multiple peaks.

Spike event reliability and temporal precision were correlated with the broadband trial-averaged LFP amplitude, however ITC was an even better predictor of spike response variability. For individual neurons, the spike count reliability of stimulus-evoked events (as quantified by the fano factor) was correlated with ITC in several distinct frequency bands. Periods of high ITC in the beta & gamma bands were predictive of not only spike count reliability but also coincided with spike events that showed the highest temporal precision (onset spike time jitter with $\sigma \sim 3$ms).

We have demonstrated that neurons in the primary visual cortex are capable of high spike timing precision comparable to that reported in the lateral geniculate and retina, but this is apparent only when the larger scale activity is also coherent. When ongoing stimulus-independent cortical dynamics dominate, as is the case with white noise stimuli, response variability is high. Understanding the complex interplay between the stimulus and neuronal and network level dynamics is necessary not only for estimating the limits of spike timing reliability and precision, but is also a pre-requisite for revealing the true nature of spatiotemporal activity patterns in neural populations that may underlie cortical processing.

[1] Blanche TJ & Koepsell K. (2007) Spike timing precision and the influence of cortical dynamics. COSYNE, Salt Lake City, Utah.
[2] Blanche TJ, Spacek MA, Hetke JF, Swindale, NV. (2005) Polytrodes: high-density silicon electrode arrays for large-scale multiunit recording. J NPhys. 93(5):2987-3000.
[3] Kayser C, Salazar RF, Konig P. (2003) Responses to natural scenes in cat V1. J NPhys. 90(3):1910-20.