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Spatiotemporal structure of evoked gamma rhythms in a minimal multi-layer model of primary visual cortex

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The visually evoked activity of V1 neural populations displays a marked gamma-band component, which is modulated by stimulus orientation and contrast more than other frequency bands [1]. It has been proposed that synchronized oscillations in the gamma frequency range – affected by various local and global spatiotemporal aspects of the presented stimulus [2,3] – might contribute to the observed gamma-band spectral modulations. It remains however unclear whether gamma-band peaks are present for all stimulus conditions. Contrast-dependent power enhancements can indeed occur over a broad frequency plateau (> 30 Hz) [1] and narrow spectral peaks may not arise at all, in contrast with the harmonic spectra generated by most models of fast cortical oscillations [4].

We introduce here a minimal model of a striate cortex hypercolumn, which embeds a simplified description of the multi-layered structure of the cortical tissue. Two coupled ring networks are used to model the two main thalamo-recipient layers, layer IV and layer VI. The presentation of an elongated visual stimulus elicits a localized bump of activity whose position along the ring is correlated with the orientation of the input. Delayed mutual inhibition induces coherent local oscillations for small levels of noise. These synchronous oscillations display however a highly irregular spatio-temporal structure, which leads to their fast temporal decorrelation. We show that this behavior is due to interlayer interactions, as predictable by a recent theory [5]. For stronger levels of noise, synchrony is considerably weakened. Remarkably, in both the explored regimes – strong noise/weak synchrony and weak noise/strong synchrony – the stimulus properties modulate the power spectrum of the population response over a broad gamma frequency range and narrow spectral peaks are not produced.

We analyze how tuning and contrast response properties are affected by the interlayer coupling. Our simulations reproduce qualitatively several effects observed in single layer inactivation experiments, like broadening and skewing of tuning curves and firing-rate enhancement [6] and predict also potential alterations of the LFP spectra.

We finally study the dynamics of two hypercolumns associated to partly overlapping receptive fields and coupled via long-range intra-striate excitation [7]. We predict that their simultaneous activation by a sufficiently extended stimulus should boost their gamma response at high contrast, an effect reminiscent of [8]. An opposite effect is expected at lower contrast when the net effect of the long-range coupling switches from disynaptically inhibitory to excitatory.

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