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Stimulus-dependent suppression of intrinsic variability in recurrent neural networks

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Trial-to-trial variability is an essential feature of neural responses and is likely to arise from a complex interaction between stimulus-evoked activity and ongoing spontaneous neural activity in the central nervous system. Response variability is often treated as random noise generated either by an external source like another brain area, or by stochastic processes within the circuit. A considerable amount of variability can also arise from the same circuitry and intrinsic network dynamics that generate responses to a stimulus. Indeed ongoing neural activity in the central nervous system is comparable in magnitude and complexity to activity evoked by sensory stimuli [1,2].

How can we distinguish between external and internal sources of neuronal variability? We ask whether internal and external sources of variability depend on stimulus features in different ways, giving them distinct experimental signatures and functional interpretations. How are stimulus-evoked responses faithfully extracted from complex background activity to identify real features of the external world?

We use a neural network model that generates highly irregular and chaotic patterns of activity in the absence of stochastic input. On the basis of numerical simulations and mean-field calculations [1], we find a phase transition between two basic dynamic behaviors: a periodic state where the network is locked in phase and frequency to the external stimulus, and a chaotic state where neurons behave as noisy oscillators with only partial entrainment to the stimulus (Figure 1). We construct phase diagrams showing how these dynamics depend on the strength and frequency of the external input, the strength of the connectivity, and the residual imbalance between excitation and inhibition. We argue that sensory-evoked responses can actively suppress ongoing intrinsically generated fluctuations. This provides a theoretical basis and potential mechanism for the experimental observation that intrinsic neuronal variability is reduced by the presence of a stimulus [1-3].

We also show that the nonlinear interaction between the relatively slow intrinsic fluctuations and external stimulus results in a non-monotonic frequency dependence of this suppression. Consequently, measures of trial-to-trial variability of neural responses can be more

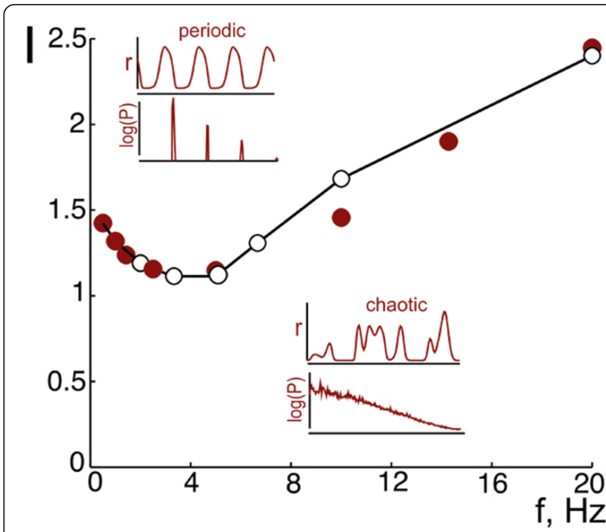

Figure 1 A phase transition curve showing critical input amplitudes that divide regions of periodic and chaotic activity as a function of input frequency, computed by mean-field theory (open circles) and by simulating a 10,000-neuron network (red circles). There is a resonant frequency at which it is possible for a periodic input to entrain the network by suppressing intrinsic chaos even though there are no resonant features apparent in the spontaneous activity. Inset traces show representative firing rates for the regions indicated along with the logarithm of the power spectrum of the activity across the network.

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sensitive to the amplitude and frequency of the stimulus, compared to the mean responses that are typically the focus of electrophysiological studies.

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1. Please find detailed methodology as well as relevant references in the supplement to this abstract.. .
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