Noise-Induced Synchronization of Fast Oscillations In A Random Network

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Noise induced synchronization of limit-cycle oscillators has been established in theory and demonstrated in numerical simulations and experiments. Here we report on an extension of this phenomenon to a system of pulse-coupled inhibitory neurons in a random network. We investigate whether common noise shared between uncoupled networks is able to synchronize the average activity of the networks.

I. INTRODUCTION

Synchronization appears to play an important role in various cognitive functions inside the brain. Synchronization is thought to play a role in attention, selecting attended signals from a large pool of signals[1, 2]. It is also thought to be important in binding together sensory fragments from disparate regions of the brain[3]. The brain needs some mechanism in which synchronization can be turned on and off as needed. This cannot be achieved effectively through coupling of disparate networks, as a coupling is a fairly permanent structural change. Also, it would be desirable for the network to show reasonably invariant spiking characteristics at the neuron level when comparing its normal and synchronized states.

It is well known that uncoupled limit-cycle oscillators may synchronize with each other when a common random input is applied to them[5–7]. Neurons also show increased spike-timing reproducibility with common, fluctuating current[4]. The mechanism therefore seems to be general for oscillatory systems. With this in mind, we consider networks that show oscillatory activity[8]. Would it be possible to synchronize the oscillatory activity of networks using common random inputs?

Here we investigate this possibility using a network of inhibitory neurons enervated by independent excitatory Poissonian inputs, and use as the synchronizing signal common excitatory Poissonian inputs. We take as a measure for the network activity the local field potential (LFP), taken to be the number of neurons in the network that fire in a given time bin. The network we will consider exhibits collective oscillations that are many times faster than the average firing rate of the constituent neurons, indicating sparse participation of individual neurons in the overall activity.

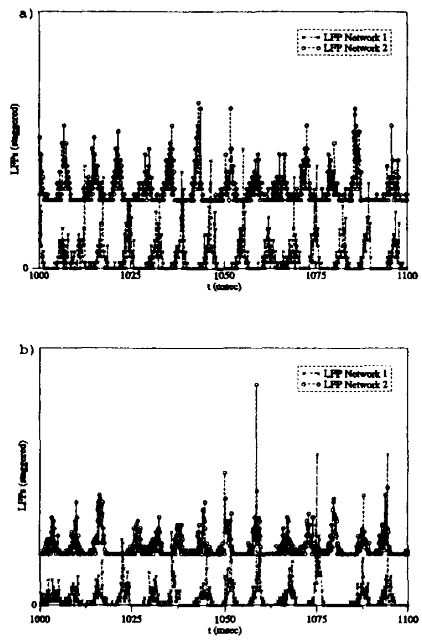

FIG. 1: a) LFP of two networks that receive no common noise. The peaks of the LFPs of the networks rarely coincide. b) With the addition of common noise, the peaks of the LFP are seen to be coincident to a far greater degree than without common noise.

II. RESULTS

We construct random networks of leaky integrate and fire neurons ($N = 5000$) with synaptic delay that are either identical or statistically identical (ie. the same connection probabilities, 0.2). Each random network is driven by 10,000 independent excitatory Poissonian spike generators with connection probability 0.1 to a given network neuron. By varying the spike rate and synaptic weight of the external to internal connection, we can vary the amount of fluctuation of the enervating Poisson current. The fluctuation relative to the average becomes a bifurcation parameter, bringing the network from a stationary to an oscillatory state[8]. The common noise is provided by 10 excitatory Poissonian spike generators whose connection probability to a given network neuron is 0.9. Synaptic weights are 5 times larger than the synaptic weight of the enervating Poissonian spike generators, and the firing rate is 3 times lower.

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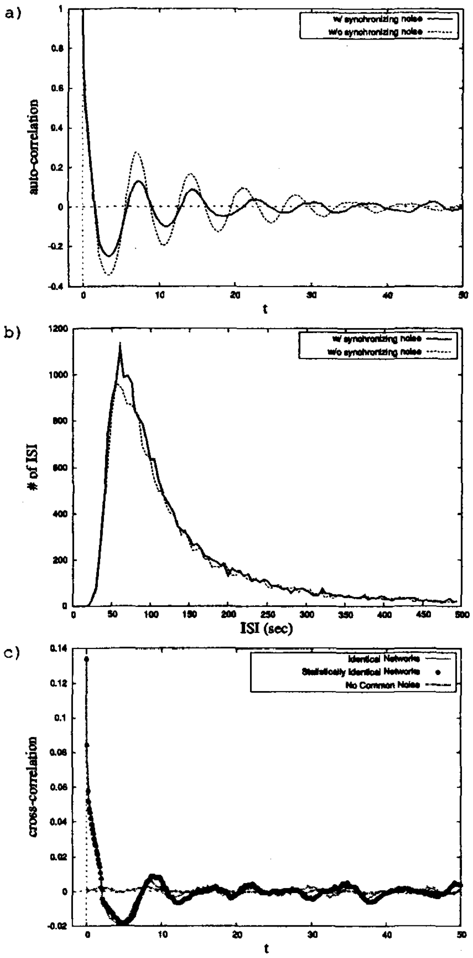

FIG. 2: a) The autocorrelation of the LFPs in networks with and without common noise. The common noise is seen to degrade the rhythmicity of the network somewhat. b) The ISI distribution with and without common noise. c) The cross-correlation between the LFPs of networks with and without common noise. The cross-correlation increases remarkably with the addition of common noise.

One can subjectively see in Fig.1 the matching peaks of the LFP in the presence of common noise. In the presence of such noise, the spiking characteristics of the network do not change very much, as shown by Fig.2a and 2b. The ISI distribution is quite similar, although the autocorrelation of the LFP does decrease, indicating a slightly less stable oscillatory state. The cross-correlation between two networks receiving common noise increases quite dramatically, Fig.2c. Furthermore, it is interesting that the increase in cross-correlation exists and is nearly the same whether the networks are identical or merely statistically identical.

III. CONCLUSION

We have shown the generality of the noise-induced synchronization phenomenon to oscillatory systems that are not strict limit-cycle oscillators. The LFP of the network exhibits significant synchronization even when the common noise is small compared with the driving currents, which keeps the network spiking characteristics relatively invariant with the addition of noise. With these properties, noise-induced synchronization may be an ideal mechanism for bringing about synchronization on demand in the brain.

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