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The role of burst duration in inhibitory synchronization

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Synchronized neuronal firing has been suggested as particularly relevant for neuronal signal transmission and coding. While its involvement in cortical processing remains unclear, the presence of synchronization has been shown in various areas including the olfactory system, the hippocampal region, and central pattern generators (CPGs) controlling various rhythmic motions. The emergence of synchronous rhythms in a neuronal network is closely tied to the properties of the individual bursting neurons, type of synaptic coupling, and network topology.

For example, synchronization in an inhibitory network of two bursting neurons, interconnected via direct fast synapses is typically unstable. Here, desynchronizing inhibition triggers asynchronous or antisynchronous behavior. This carries over to larger interconnected inhibitory networks. At the same time, common fast inhibition of a neuronal network received from one or several pacemaker neurons has been demonstrated to favor synchronization. CPGs and other neural circuits are often composed of pairs of mutually inhibiting cells, driven by a common bursting inhibitor. Understanding the emergence of different anti-phase and synchronous rhythms in such networks requires knowledge of the interplay among mutual internal inhibition, common external driving, and temporal characteristics of neurons composing the network.

We show that the burst duration of neurons composing a network with fast chemical synapses is the critical characteristic, explicitly determining synchronization properties of the network. In particular, we demonstrate that a bursting network with strong desynchronizing connections can be synchronized by a weak common inhibitory input from an external pacemaker neuron whose burst duration sufficiently exceeds the interburst interval. In strongly heterogeneous networks, the ratio of the burst durations becomes the imperative order parameter that controls the dynamics of the network and designates its pacemaker by the intrinsic properties, or by the network structure. Thus, the pacemaker, being the longest bursting cell, makes other strongly uncorrelated neurons synchronized and determines the network's paces and rhythms. We analyze different topologies and synaptic configurations of subnetworks (motifs) composing CPGs and describe universal burst-duration based mechanisms of induced synchronization. We also discuss the multistability of synchronous rhythms and causes for intertransitions.

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