Dynamics of multiple interacting excitatory and inhibitory populations with delays

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A network consisting of excitatory and inhibitory (EI) neurons is a canonical model for understanding local cortical network activity. In this study, we extended the local circuit model and investigated how its dynamical landscape can be enriched when it interacts with another excitatory (E) population with long transmission delays. Through analysis of a rate model and numerical simulations of a corresponding network of spiking neurons, we studied the transition from stationary to oscillatory states by analyzing the Hopf bifurcation structure in terms of two network parameters: (1) transmission delay between the EI subnetwork and the E population and (2) inhibitory couplings that induced oscillatory activity in the EI subnetwork. We found that the critical coupling strength can strongly modulate as a function of transmission delay, and consequently the stationary state can be interwoven intricately with the oscillatory state. Such a dynamical landscape gave rise to an isolated stationary state surrounded by multiple oscillatory states that generated different frequency modes, and cross-frequency coupling developed naturally at the bifurcation points. We identified the network motifs with short- and long- range inhibitory connections that underlie the emergence of oscillatory states with multiple frequencies. Thus, we provided a mechanistic explanation of how the transmission delay to and from the additional E population altered the dynamical landscape. In summary, our results demonstrated the potential role of long-range connections in shaping the network activity of local cortical circuits.

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