Emergent Spatiotemporal Dynamics in Large-Scale Brain Networks with Next Generation Neural Mass Models

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Abstract

Macroscopic brain activity is characterized by prominent oscillatory phenomena that support a wide range of cognitive processes. Understanding how these collective dynamics arise from large-scale anatomical connectivity remains a central challenge in computational neuroscience. Here we study a whole-brain model comprising 90 anatomically connected regions, each represented by a next-generation neural mass model (NG-NMM) that explicitly accounts for interacting excitatory and inhibitory populations. We characterize homogeneous steady and oscillatory solutions of the network and examine their stability under both global and spatially structured perturbations. To address heterogeneous perturbations, we project them onto an appropriate eigenbasis of the connectivity and derive a dispersion relation, known as the Master Stability Function in the case of periodic orbits, linking network structure to perturbation growth rates. Analytical predictions are supported by numerical simulations and Lyapunov exponent calculations, which reveal that instabilities of homogeneous states give rise to complex spatiotemporal activity, including traveling waves and chaotic patterns. NG-NMMs exhibit a substantially rich dynamical landscape, both near homogeneous regimes and in symmetry-broken states. These results suggest that next-generation neural mass models offer a powerful and biologically grounded framework for investigating the emergence of complex dynamics in large-scale brain networks.