Plausible and phenomenological models of multifunctional central pattern generators

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Rhythmic motor behaviors, such as heartbeat, respiration, and locomotion on land and in water are produced by neural microcircuits called Central Pattern Generators (CPGs). Synergetic interactions of networked cells within a CPG can autonomously generate an array of bursting patterns of activity that determine these and other vital motor behaviors. Modeling studies have proved to provide insights into operational principles of CPGs. It still remains unclear how the CPGs achieve the level of robustness and stability observed in nature. It is not clear either what mechanisms a single motor system uses to generate multiple rhythms, i.e., whether CPGs use dedicated circuitry for each function, or whether the same circuitry is multifunctional and can govern several behaviors. A systematic way to explore this is to create such mathematical models that use biologically key components and classify the possible varieties of rhythmic patters. Switching between multi-stable rhythms can be attributed to input-dependent switching between attractors of the CPG, where each attractor is associated with a specific rhythm. Our goal has been to characterize how observed multi-stable states arise from the coupling, and also to suggest how real circuits may take advantage of the multistability to dynamically switch between the corresponding polyrhythmic outputs. Our greater goal is to gain insight into the rules governing pattern formation in complex networks of cells, for which we believe one should first investigate the rules underlying the emergence of cooperative rhythms in smaller network motifs. There is a growing consensus in the community of neurophysiologists and computational researchers that same basic structural and functional elements are likely shared by CPGs of both invertebrate and vertebrate animals. The ultimate aim of developing effective tools and approaches to understanding CPGs in identified neural circuits is to make them applicable to studying the governing principles of neurological phenomena in mammals. This will eventually assist in treating neurological disorders, which are perturbations of normal mechanisms.

In this research, we address the fundamental question of how circuit architectures infer and contribute to the dynamics of neural activity. Understanding generic mechanisms of the evolution of neural connectivity and transitions between different patterns of neural activity and modeling these processes are the fundamental challenges for applied mathematics. This research is genuinely cross-disciplinary research bridging applied mathematics with experimental neuroscience. It extends and generalizes our understanding of dynamical principles in neural systems. Our findings have provided a systematic basis for comprehension of plausible biophysical mechanisms for the origination and regulation of rhythmic patterns generated by other CPGs. The insights of this study allow us to predict both quantitative and qualitative transformations of the observed patterns as the network configurations are altered or the network states are perturbed dynamically. The nature of these transformations provides a set of novel hypotheses for biophysical mechanisms about the control and modulation of rhythmic activity. Our findings can be employed for identifying or implementing the conditions for normal and pathological functioning of basic CPGs of animals.

References

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