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The effect of rectifying gap junctions on phase-locking in neuronal networks

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Introduction

Gap junction mediated electrical coupling is ubiquitous in neuronal systems. Electrical coupling is almost always modeled as a linear ohmic resistance between cells, where the coupling current is proportional to the transjunctional potential. However, many gap junctions exhibit rectification with transjunctional voltage [1]. That is, the coupling conductance attenuates for increased voltage differences between cells. This rectification process can evolve at different time scales. Because gap junction rectification alters the strength of coupling between cells in a way that depends on the intrinsic states of the cells, it may affect the dynamics in neuronal networks. However, the effects of rectification on network dynamics are largely unstudied.

Methods

We explore the effects of gap junction rectification on phase-locking in model neuronal networks. Using an extension of the theory of weak coupling, phase plane arguments, and numerical simulations, we examine both fast and slow rectification and their effects on the dynamics of networks of spiking neurons and networks of bursting neurons.

Results

In the slow rectification case, we show that the rectification always promotes synchronous activity. Because it decreases the coupling strength only, slow rectification has no effect on the existence of phase-locked states in homogeneous, noiseless networks. However, it alters the robustness of these states. The synchronous state is relatively unaffected by the rectification, but the coupling strength can decrease substantially during asynchronous activity (especially anti-phase activity). Thus, the effective robustness of the synchronous state increases in the presence of noise and heterogeneity.

In the case of fast rectification, we find a wide variety of effects that depend on degree of rectification and the intrinsic dynamics of the cells. The effects include both stabilization and destabilization of the anti-phase state.

The effect of rectification is most prevalent in networks with bursting neurons, but it can also be of considerable magnitude in networks of spiking neurons.

Summary

Our theoretical and computational study shows that rectification of gap junctions can affect neuronal network dynamics in a significant and complex manner.

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