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Effects of potassium channel blockage on inverse stochastic resonance in Hodgkin-Huxley neural systems

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Research Background

Inverse stochastic resonance (ISR) is a phenomenon in which the firing activity of a neuron is inhibited at a certain noise level.

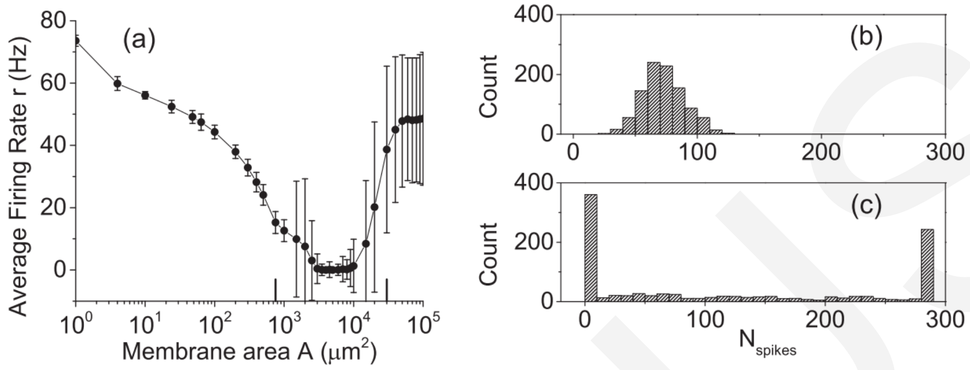

Fig. 1[1]. Inverse stochastic resonance in Hodgkin-Huxley neural.

Tetraethylammonium (TEA) can reduce the number of open potassium channels.

How does potassium channel blockage affect the ISR in neurons?

[1] Uzuntarla M, Cressman JR, Ozer M, et al., 2013. Dynamical structure underlying inverse stochastic resonance and its implications. Physical Review E, 88(4):042712.

ISR in single neurons with ion channel noise

Inverse stochastic resonance occurs in the bistable region of potassium channel blockage x_K

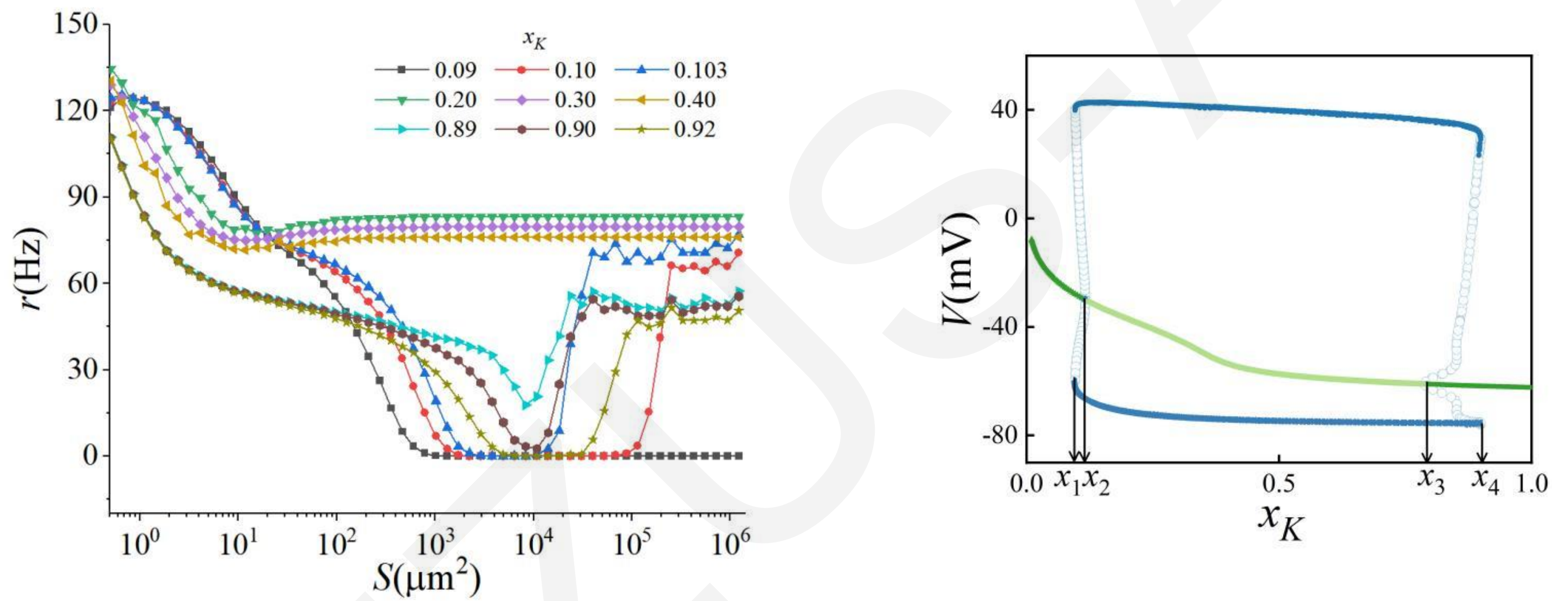

Fig. 2. Occurrence of ISR in HH neurons with different potassium channel blockages. The ISR effect appears only for specific values of x_K. Bifurcation plot of the Hodgkin-Huxley neuron model versus the ratio of potassium channel blockage x_K (from 0 to 1).

ISR in single neurons with ion channel noise

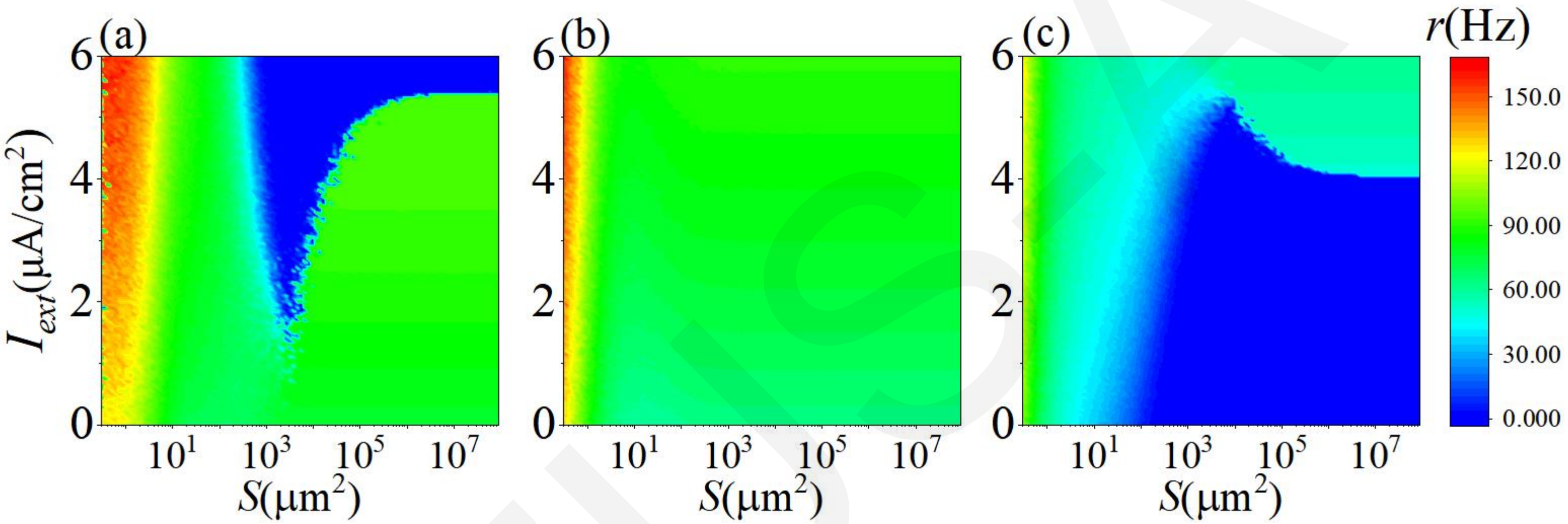

Fig. 3. Contour plots of the average firing rate r in the I_{ext} - S plane at different potassium channel blockage ratios x_K. (a) x_K=0.1, (b) x_K=0.4, (c) x_K=0.9. Note that x_K is negatively correlated with the degree of blockage.

ISR of small-world neuronal networks

***NBR*: the proportion of neurons in the network with blocked potassium channels to the total number of neurons in the network.**

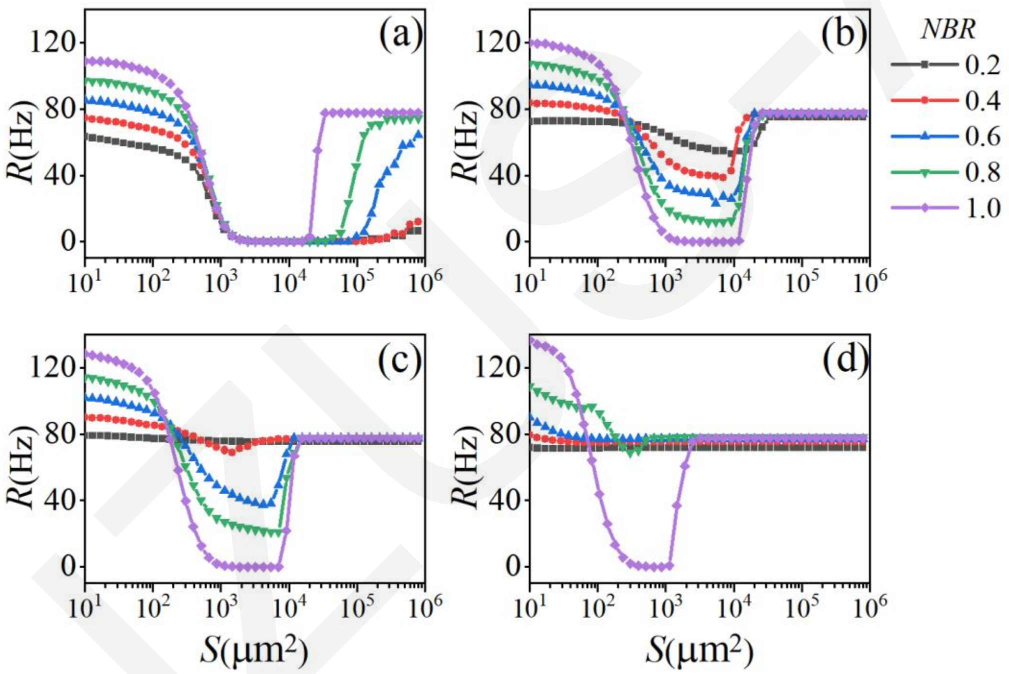

Fig. 4. ISR emergence in the small world network of electrically coupled neurons at different coupling strengths. The average firing rate as the function of membrane area for different coupling strengths g_e. (a) g_e=0.04 mS/cm^2, (b) g_e=0.10 mS/cm^2, (c) g_e=0.17 mS/cm^2, (d) g_e=0.60 mS/cm^2.

ISR of small-world neuronal networks

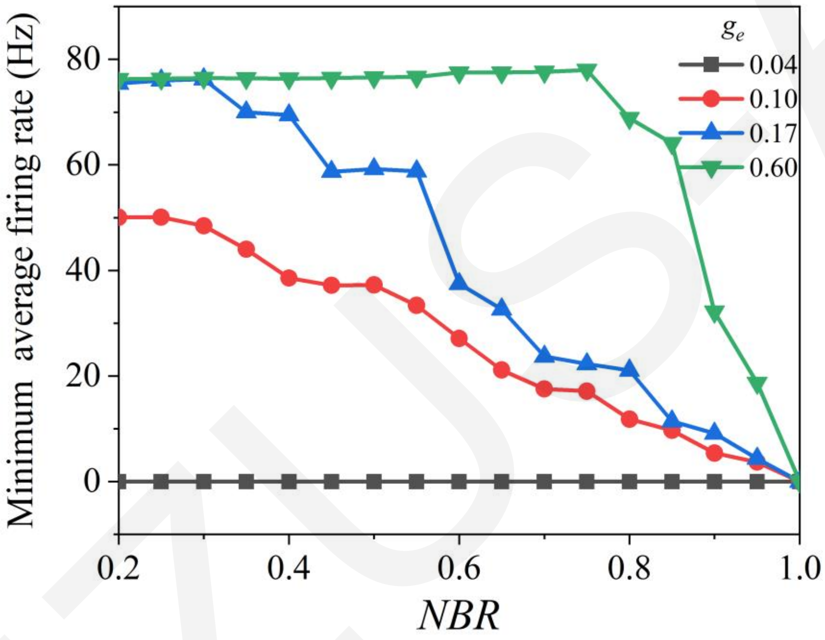

Fig. 5 Minimum value of the average firing rate relative to the network blockage ratios *NBR* in different electrically coupled neuronal networks. As g_e increases, the range of *NBR* that can occur with ISR decreases and the threshold for the minimum network blockage ratios that can occur with ISR increases.

Conclusions

- For single neurons, ion channel noise-induced ISR effects can occur only at a certain small range of potassium channel blockage ratios. The bifurcation analysis showed that within this small range is the bistable region, where stable fixed point and stable limit cycles coexist, and this range is regulated by the external bias current.

- For small-world networks, It is found that an increase in network blockage ratio at small coupling strengths results in shorter ISR duration. When the coupling strength is increased, the ISR is more significant in the case of a large network blockage ratio. The ISR phenomenon is determined by the network blockage ratio, the coupling strength, and the ion channel noise.