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Poster presentation

Determining the effect of the A-current on the activity phase of a follower neuron in an inhibitory network

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Background

The A-current is a transient outward potassium current that is present in most vertebrate and invertebrate neurons. When a neuron is subject to a strong inhibitory synapse, the activity time following the rebound from inhibition can be set by the conductance and kinetics of the A-current. As such, the A-current plays an important role determining the activity phase of neurons in rhythmic networks that involve inhibitory synapses. The precise influence of the A-current in setting the activity of neurons depends on its interaction with the inhibitory synaptic inputs and with other intrinsic properties of the neuron. We examine the role of the A-current in determining the phase of activity of a follower neuron in a rhythmic inhibitory network. Our modeling results are compared with the activity of the follower pyloric constrictor (PY) neurons in the rhythmically active crustacean pyloric network (Fig 1a). We examine the role of the A-current in a Morris-Lecar (ML) model plus an A-current with instantaneous activation kinetics, resulting in a 3D model with 2 variables (v and w) from the ML system and one variable h describing A-current inactivation. The response of the model to an inhibitory input from a square-wave presynaptic voltage is shown in Fig 1b.

Results

We examine the behavior of the model neuron in response to a periodic inhibitory input. After release from inhibition, the membrane potential moves to a "middle state" (light blue line in Fig 1b) where the A-current becomes activated. At this point, the trajectory encounters three possibilities: jumping to the active state, jumping back to the inactive state or staying in the middle state. Using phase plane analysis, we find that the outcome is determined by several factors: the shapes of the ML w-nullcline (w_∞) and the steady-state activation curve m_∞ of the A-current, the time constants τ_w and τ_h, and the inactive duration of the pacemaker. In the v-w phase plane (Fig 2), the v-nullcline has a quintic shape in the presence of the A-current and the middle branch represents the mid-

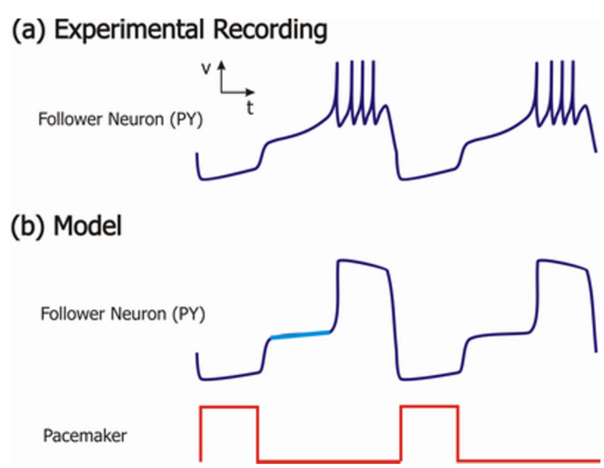

Figure 1
Delay to activity in the follower neuron following inhibition.

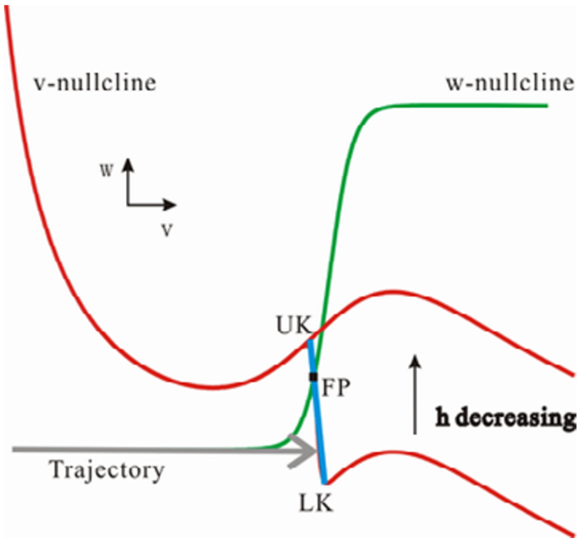

Figure 2
Fast-slow phase-plane dynamics demonstrating the effect of the A current inactivation.

dle state in Fig 1. When the trajectory reaches the middle branch, it moves toward the stable fixed point (FP) at a rate determined by the τ_w. Meanwhile, the lower knee (LK) of the middle branch moves up as the A-current inactivates (*h* decreases). If the trajectory encounters LK (resp. upper knee-UK), it jumps to the active (resp. inactive) state. If the trajectory does not reach LK or UK before the next inhibition phase, it will remain on the middle branch. In the case of Fig 2, FP is located below UK due to the steepness of the *w*-nullcline and therefore the trajectory can only jump to the right branch or remain in the middle branch. However, if FP is higher than UK (in the *w* direction), it is possible for the trajectory to jump to the left branch if it reaches UK. By following the trajectory in the slow manifold (w-h phase plane on the middle branch) we can determine its fate before the arrival of the next inhibition (Fig. 3). Our results show that, depending on the parameters mentioned, the effect of the A-current can be quite complex and non-intuitive. In particular, for large maximal conductance, the A-current may *prevent* the neuron from returning to its inactive state even when inhibited.

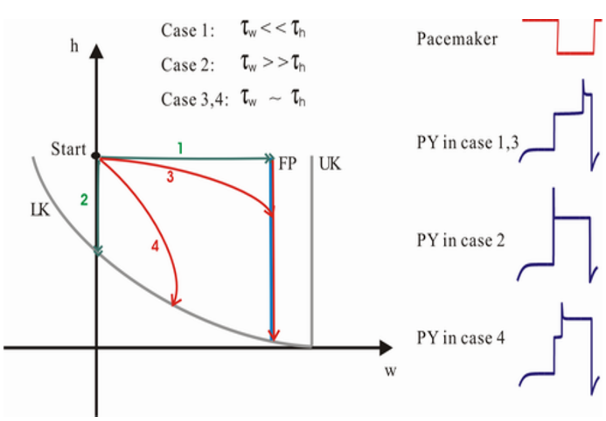

Figure 3
The trajectory in the slow phase space.

Conclusion

We are able to predict the effect of the A-current on setting the activity phase of an oscillatory neuron as a function of the shapes of w_∞ and m_∞, the values of τ_w and τ_h, and the inactive duration of the pacemaker.

Acknowledgements

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