Distinct mechanisms underlie electrical coupling resonance and membrane potential resonance

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Many neurons exhibit membrane potential resonance, a maximal subthreshold voltage amplitude response to oscillatory current input at a non-zero input frequency. In electrically coupled networks, an oscillatory current input to one neuron produces voltage oscillations in both pre- and post-junctional neurons. In recent studies, both the post-junctional neuronal response and the coupling coefficient (the ratio of post- and pre-junctional neuronal responses) have been shown to exhibit preferred frequency responses. However, the resonance properties of electrical coupling have been demonstrated in current clamp, but not in voltage clamp experiments. It is therefore unclear whether coupling resonance reflects the properties of the gap junctions, or it emerges from the interaction between the coupling current and membrane properties of the post-junctional neuron. To examine whether the gap junction conductance itself shows resonance, we performed dual voltage clamp recordings and quantified the frequency preference of the coupled neurons, the gap junction conductance, and the post-junctional neuronal response. We found that all three components exhibit frequency selectivity, but with distinct preferred frequencies. Furthermore, the resonance properties of the electrical coupling were subject to neuromodulation. To study the functional effect of the resonance of the gap junction conductance, we examine its role in synchronizing neuronal activities and influencing network frequency in electrically coupled model neurons, and how neuromodulation affects these effects. Together, our findings demonstrate the mechanisms underlying electrical coupling resonance and its functional effects at the network level. They also highlight the interaction between preferred frequency responses at different levels of organization in shaping the dynamics of oscillatory networks.