Processing Sensory Input with Bursts and Isolated Spikes

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Abstract

Although burst firing is commonly observed, a direct relationship between burst dynamics and sensory information transfer has not been established. We employ *in vivo*, *in vitro* and modeling approaches to investigate electrosensory pyramidal cell responses to mimics of behaviorally relevant sensory input. We find that, within a given spike train, backpropagation-dependent bursts signal low frequency events while isolated spikes simultaneously code for high frequency components. In addition, burst dynamics are essential for feature detection but are not required for stimulus estimation. Thus, burst and spike dynamics segregate a single spike train into two parallel and complementary streams for information transfer.

Summary

A number of ionic burst mechanisms have been identified in a variety of brain regions (*1*) and theoretical studies suggest the potential existence of many more (*2*). In the electrosensory lateral line lobe (ELL), *in vitro* studies have established that the biophysical basis of the burst mechanism of pyramidal cells is dependent on the active dendritic backpropagation of somatic spikes (*3, 4*). *In vivo,* pyramidal cell bursts have been shown to extract stimulus features better than single spikes (*5, 6*). However, the mechanism underlying burst production was not addressed in this study. Nonetheless, these prior results, combined with well-understood behaviorally relevant patterns of sensory input, make the electrosensory system an ideal preparation in which to elucidate the role of a biophysically and dynamically characterized burst mechanism in sensory coding.

In response to broadband stimuli, both *in vivo* and *in vitro* ELL pyramidal cells generate spike trains that consist of bursts and isolated spikes. These spike trains can be divided for analysis into two component trains comprised of solely of bursts or isolated spikes. Spectral analysis of these spike trains revealed that bursts are selectively coherent with low frequency stimulus components while isolated spikes were found to be broadband and in some cases high frequency coherent. Thus, ELL pyramidal cells generate a single spike train that consists of two parallel streams for information transfer; burst events code for low frequency signals whereas isolated spikes for high frequencies.

We further verified and investigated these results in a reduced two-compartment model of ELL pyramidal cell bursting known as the ghostburster (Doiron et al., 2002). The ghostburster system is a conductance based description of ELL pyramidal cell burst dynamics that is rooted in active dendritic backpropagation. A full mathematical characterization of this model has been the focus of several previous studies (*7-10*). A key feature of the model is that burst dynamics can be selectively blocked by the removal of dendritic Na^+ conductance, rendering the dendrite passive. In doing this we found that the low frequency coherence of pyramidal cell responses was not dependent on burst dynamics, a prediction that was verified by the dendritic application of TTX *in vitro.*

This intriguing result led us to further quantify the selectivity of bursting neurons. Although isolated spikes are generated by a non-bursting pyramidal cell remain coherent with low frequency input, the application of a previously described feature extraction technique (*5, 6*) revealed that bursts *in vivo* and *in vitro* are substantially better detectors of these signals. We compared the feature extraction by the model neuron with and without burst dynamics intact and found that true bursts were superior feature detectors even when compared to similar high frequency spike events produced by the non-bursting model neuron. We therefore propose that pyramidal cells use high frequency bursts to selectively detect and efficiently code for the low frequency components of stimuli.

In conclusion, during electrosensory processing, pyramidal cell burst and spike dynamics code broadband sensory inputs via two parallel but complementary streams for information transfer. Interestingly, these animals routinely code both low frequency prey-like inputs and high frequency communication-like inputs (*12*). Thus, we speculate that these streams ultimately correspond to the behaviorally relevant stimulus features that can be selectively decoded by the filtering properties of higher brain centers.

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