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Fractional differentiation in pyramidal neurons enable power-law adaptation to natural sensory stimuli

The understanding of how neural circuits perform key computations underlies the fundamental knowledge of how cellular machinery leads to neural network activity, which in turn determines perception/behavioral responses. Several studies have shown that neural coding strategies in many sensory systems are adapted to natural scene statistics to efficiently encode sensory stimuli as well as to maximize redundancy reduction in spatiotemporal correlations. Despite this, the molecular and/or computational mechanisms underlying such optimal adaptation remain elusive. Here we investigated how small conductance calcium-activated potassium (SK) channels contribute to optimizing neural coding and perception of natural second-order envelopes, which are found ubiquitously across sensory systems and carry important spatiotemporal information necessary for perception. In order to do so, we used the electrosensory system of the gymnotiform weakly-electric fish Apteronotus leptorhynchus as a model for its unique advantages for in vivo awake-behaving experiments. We recorded from sensory pyramidal neurons in the electrosensory lateral line lobe (ELL) in response to natural stimuli and demonstrated that these neurons perform fractional differentiation in order to give rise to power-law adaptation, leading to optimal encoding of a continuous range of envelope frequencies. Our results further reveal a novel function of SK channels in that they provide the fundamental bio-computational mechanism which enables optimal neural processing and behavioural perception to natural stimuli. The strong homology between SK channels and the weakly-electric fish to their mammalian counterparts suggest that it is very likely that our results will be generally applicable across systems and species.