Natural background noise and the detection of weak signals in the electrosensory system

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Introduction

In natural environments, sensory systems are faced with the task of extracting weak signals embedded in background noise. Neural mechanisms of signal extraction involve both spatial and temporal integration of sensory information. These mechanisms are presumably tuned to a particular set of naturally occurring signal and noise characteristics. Therefore, an accurate description of these environmental stimuli is prerequisite to a systems level study of neural filtering.

Sensory Processing in Weakly Electric Fish

The electrosensory system of weakly electric fish is a model for studying neural filtering of weak signals. These fish detect prey-induced perturbations in a dipole-like electric field surrounding their body that is generated by continuous high-frequency electric organ discharges. Electroreceptors in the skin encode electric field amplitude by measuring the potential difference across the skin of the fish. This transdermal potential is typically in the range of a few millivolts (Bastian, 1981; own observations). The perturbations induced by prey are several orders of magnitude lower than this baseline amplitude of the electric field (Nelson and MacIver, 1999; MacIver *et al*., 2001).

Electrosensory Environment Characterization

We developed techniques to record the transdermal potential in immobilized and freely swimming fish. This enables us to measure the contributions of signal and noise sources in the fish's natural environment. Transdermal potential perturbations induced by nearby objects are characterized by systematically modifying the size, conductance, and distance of objects. Additionally, we quantified global shifts in transdermal potential due to tail bending, presence of large non-conducting boundaries (e.g., substrate, water surface, tank walls), changes in water impedance, and proximity of conspecifics. Initial data suggests that the amplitude of background noise can be at least an order of magnitude larger than perturbations caused by prey at the time of their detection, and that the spectral characteristics of noise and prey signals strongly overlap.

Electrosensory Modeling and Freely Swimming Fish

A previous model of electrosensory image formation described the properties of small spherical objects in the electric field (Rasnow 1996). We developed an extended model that allows us to compute perturbations associated with tail-bending movements and the effects of non-conducting boundaries in the environment. Comparisons between model and experimental results show strong correlation in both relative changes in transdermal potential when modifying object size and distance and in absolute transdermal potentials. The complete model is a predictive tool to study naturalistic environmental characteristics that can be compared directly with recordings in freely swimming fish.

At the behavioral level, many sensory systems have shown to be sensitive to small changes in input signal. The same principles apply to electrosensory prey detection. The spatio-temporal property characterizations of the naturalistic background noise in electrosensation enables us to investigate the neuronal mechanisms for the detection of weak signals employed by the electrosensory system. In complementary work we study theoretically optimal strategies for object detection using algorithms derived from signal detection theory and constrained by known spatio-temporal filtering properties of electrosensory neurons in the hindbrain of weakly electric fish (see contribution by Ludtke and Nelson). The confluence of theoretical and experimental approaches gives us a more complete appreciation of how the nervous system has adapted to environmental constraints on detection of weak signals.

References

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