Talk 302

Optimality of sensory receptor array

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An implicit hypothesis underlying a lot of recent research in neuroscience and neuroethology is that sensory systems have evolved, through natural selection, toward optimal functional performance and/or energetic efficiency. However, it has proven extremely difficult to derive precise definitions for functional optimality and efficiency, and even more difficult to determine the nature and relative importance of different factors that might be constraining this process of optimization. Our multidisciplinary group of researchers is developing a theoretical framework for defining and assessing optimality of one specific sensory system, as well as carrying out experiments to assess its optimality and efficiency.

The system we are studying is the cercal sensory system of the cricket. This system functions as a low-frequency, near-field extension of the animal's auditory system, and mediates the detection, localization and identification of signals generated by predators, mates and competitors. The sense organ for this system consists of a pair of antenna-like 'cerci' at the rear of the cricket's body, each of which is covered with approximately 1000 mechanosensory hairs. Each of these hairs is attached to a single nerve cell. The working hypothesis is that the biomechanical and neurophysiological characteristics of these receptor organs are optimized for the sensory processing operations they mediate.

During the past year we have developed a modeling framework that allows us to calculate the movement of hairs due to air currents, and to investigate the fluid-dynamical interaction between different hairs. Each hair is modeled as an inverted pendulum, and the hair's interaction with the fluid is computed using Stokes equations. We are systematically calculating the amplitude and phase of mechanosensory hair movements as a function of the amplitude, frequency and direction of air current stimuli, the length of the hair, and the local density and characteristics of surrounding hairs.

To set model parameters and verify our calculations, we have designed and calibrated an experimental device that enables us to observe the motion of individual hairs in response to arbitrary air current stimuli stimuli. This device uses a sophisticated optical position sensor and image intensifier mounted on an inverted microscope. The stimulus-response properties of individual hairs are being measured, before and after surrounding hairs are removed.

We have also begun a systematic characterization of the distribution of mechanosensory hairs on the cerci, as a basis for an evaluation of the extent to which that distribution might have become optimized for signal reception and processing.

Finally, we have investigated the extent to which the physical distribution of receptor hairs out along the length of the cerci leads to a dispersion of the receptors' spike trains upon entry into the terminal abdominal ganglion. Surprisingly, the measurements show that the dispersion is much less than would be expected from the standard assumption of uniform conduction velocities.

Project (or PI) Website

http://cns.montana.edu/cercal-system-optimality

Publications

1. Cummins, B., T. Gedeon, I. Klapper and R. Cortez. Interaction between insect filiform mechanosensory hairs in a fluid environment. In preparation.

2. Mulder-Rossi, S., G.I. Cummins and J.P. Miller. Action Potential Conduction Velocities of Cercal Afferent Receptors: is the Cercus a Delay Line? In preparation