Biophysics, Information Processing, and Biological Function of a Small Sensory System

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Evolution has led to acoustic communication behaviors of fascinating complexity which are made possible by sophisticated neural systems in both sender and receiver. Remarkably, even small insect auditory systems are capable of astounding computations. Some grasshoppers, for example, reliably detect gaps in conspecific songs as short as 1-2 ms, a performance level similar to that reached by birds and mammals.

These observations raise the question of how a minute insect auditory system processes auditory signals reliably and with high temporal precision. Important insight will come from studying the auditory periphery. It serves as a bottleneck between the external world and further neural processing stages; every computation and behavioral decision must be based on the primary stimulus representation on the level of auditory receptors.

Understanding the interplay between the dynamics and function of these neurons requires answers to a broad range of questions such as:

- Which physical sound attribute (e.g., sound pressure or energy) drives the receptor?
- What are the essential processing steps of auditory transduction and encoding?
- In which way do neural noise sources limit the system's performance?
- Is it possible to "read" the sensory input from the output of a single receptor?
- Are receptor neurons specifically tuned to behaviorally relevant features?

Grasshoppers of the species *Chorthippus biguttulus* provide a suitable model system to study these questions. Their calling songs possess an elaborate temporal structure, rhythmically arranged into distinct syllables. Individual songs from the same species differ in the frequency content of the carrier signal, syllable length, and the precise temporal pattern of amplitude modulations within a syllable. This variability may allow females to choose among different males and thus provide a basis for sexual selection. On the receiver side, the songs are encoded by a total of roughly one hundred auditory receptor cells into trains of action potentials. These can easily be recorded in the auditory nerve, thus allowing one to study the sound encoding process *in vivo* without damaging the animal's ear.

In this talk, I will summarize various aspects of the dynamics and signal-processing capabilities of a single type of neuron, the auditory receptor, using a variety of modern and partly novel experimental and theoretical techniques. The methods cover a wide range of disciplines – from biophysics to information theory – and demonstrate that a tight interplay of experiment, data-analysis, and theory can yield valuable new insights. All approaches have one feature in common: no neural parameter or variable, apart from the acoustic input and the final spike output, needs to be measured. The techniques may thus be of use for investigations of other systems that only allow axonal or extracellular recordings. To address a general audience, I will concentrate on the main underlying concepts and key results.

The talk is based on joint investigations with J.Benda, A.Franz, T.Gollisch, O.Kolesnikova, C.K.Machens, B.Ronacher, R.Schaette, H.Schütze, M.B.Stemmler and A. Wolf – all of whom I would like to thank for their great work and collaborative spirit. Apart from new, unpublished results about the biophysical origin of firing-rate saturation, details can be found in the following publications:

T. Gollisch, H. Schütze, J. Benda and A.V.M. Herz
Energy integration describes intensity coding in an insect auditory system.
Journal of Neuroscience, **22,** 10434-10448 (2002).

C.K. Machens, H. Schütze, A. Franz, O. Kolesnikova, M.B. Stemmler, B. Ronacher and A.V.M. Herz
Single auditory neurons rapidly discriminate conspecific communication signals.
Nature Neuroscience, **6**, 341-342 (2003).

J. Benda and A.V.M. Herz
A universal model for spike-frequency adaptation.
Neural Computation **15**, 2523-2564 (2004).

T. Gollisch and A.V.M. Herz
Input-driven components of spike-frequency adaptation can be unmasked *in vivo*.
Journal of Neuroscience **24**, 7435-7444 (2004).

T. Gollisch and A.V.M. Herz
Disentangling sub-millisecond processes within an auditory transduction chain.
Public Library of Science – Biology **3**, e8 (2005).

R. Schaette, T. Gollisch and A.V.M. Herz
Spike-train variability of auditory neurons *in vivo*: Dynamic responses follow predictions from constant stimuli.
Journal of Neurophysiology **93**, 3270-3281 (2005).

C.K. Machens, T. Gollisch, O. Kolesnikova and A.V.M. Herz
Testing the efficiency of sensory coding with optimal stimulus ensembles.
Neuron, to appear (2005).