Adaptation reduces sensitivity to save energy
without information loss in the fly visual system
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Signal processing in neurons is constrained by internal noise and energy consumption. Neural systems often invest energy in amplifying signals to protect them against internal noise. There is no general expression for the trade-off between energy and information, because it is strongly dependent on the properties of signal, noise and underlying mechanism.

We present the first analysis of this energy-information trade-off in a specific system, the R1-6 photoreceptors of the blowfly, Calliphora vicina. These photoreceptors adapt to light level by adjusting their transduction gain (number of light-gated channels opened per photon) and potassium conductance. By combining experimental measures of photoreceptor impedances, transfer functions and signal quality in a basic membrane model we discovered that photoreceptors do not adapt to maximise their sensitivity. Instead, they use a lower sensitivity at which they capture 99% of the information from naturalistic stimuli. This strategy is efficient because it avoids the wasteful amplification of noisy inputs and reduces energy consumption.

The membrane model is a typical RC-circuit in which two opposing conductances (light-gated and potassium) determine the response amplitude and time constant. The light-gated conductance is driven by a Poisson process whose rate varies according to mean luminance and the contrast power spectrum of moving naturalistic scenes viewed through blowfly optics (van Hateren, 1992)¹.

Membrane impedances, transfer functions for stimulus contrast, and signal and noise power spectra were measured intracellularly in 12 photoreceptors and used to fit a circuit model to each cell. The model defines landscapes that connect transduction gain and potassium conductance to information rate and energy consumption. By measuring where each photoreceptor positioned itself on its landscapes we could see that a small loss in information (<1%) was being traded for a large (>x4) reduction in energy.

Figure 1. (a-b.) Theoretical information and energy surface as a function of light-gated (g_{Light}) and potassium conductance (g_{K}). MI corresponds to the maximum information and D to the theoretical value at the conductances measured in an experiment with white noise presentation. One can see that the experimental information is located at the edge, where still 99% of the maximum information is available while the energy is drastically reduced. The blue dots on the surfaces correspond to combination of conductances that achieve 99% of the maximum information. The blue dots on the energy surface span a variety of different energy consumptions, while all leading to roughly same information rate. (c.) The theoretical maximum and minimum energy consumption that achieves at least 99% of the maximum information are shown in grey lines at increasing intensities. The black lines are the experimental energy consumption.