Measurement of photon statistics with live photoreceptor cells

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Abstract: We analyzed the electrophysiological response of an isolated rod photoreceptor of *Xenopus laevis* under stimulation by coherent and pseudothermal light sources. Using the suction-electrode technique for single cell recordings and a fiber optics setup for light delivery allowed measurements of the major statistical characteristics of the rod response. The results indicate differences in average responses of rod cells to coherent and pseudothermal light of the same intensity and also differences in signal-to-noise ratios (SNR) and second-order intensity correlation functions.

Rod photoreceptor cells of the retina, represent miniaturized self-consistent photodetectors of about 50x5 μm² containing a photosensitive element along with a “built-in” chemical power supply. They have sensitivity down to a single photon level and demonstrate a remarkably low-noise operation [1]. Unique properties of such nature-generated photodetectors stimulate considerable interest in searching for manifestation of quantum properties of light in biological systems. In this work we accomplished an important step towards this goal by measuring photoreceptor response to well-controlled classical sources of coherent and thermal light.

In the experiment with coherent light we used pulses of a 532 nm Nd:YAG laser. The pseudo-thermal light source was realized by filtering a single speckle of a laser beam, scattered on a rotating ground glass disc. The laser beam or the speckle were attenuated, split by a 50/50 beamsplitter (BS), and coupled into two single mode fibers. One fiber was connected to a single photon avalanche photodiode (APD), whilst another one was used to stimulate the cell. Cells from *Xenopus laevis* frog were used. Photocurrents of isolated rod cells were recorded with conventional suction electrode technique [2]. A tapered single mode optical fiber was used for optimized light delivery into the cell, see Fig 1a [3].

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**Fig. 1 (a, b, c).** (a) Microscope image of the rod cell, constrained in a recording pipette, and a tip of an optical fiber. Dependence of the normalized amplitude (b) and SNR (c) of the cell response on the number of impinging photons for coherent (closed symbols, solid lines) and pseudo-thermal (open symbols, dashed lines) sources. Different shape of the symbols corresponds to different cells. Lines are theoretical calculations.

The dependences of the normalized amplitudes on the average number of impinging photons for coherent and pseudo-thermal sources are shown in Fig.1b. The results clearly indicate that the saturation of the response for the coherent source is significantly steeper than for a pseudo-thermal source, which is explained by the differences in the statistical properties of the two sources. We also observed that at relatively low number of impinging photons SNR grows linearly for the coherent source and remains constant for the pseudo-thermal one, see Fig.1c. However, as the cell approaches the saturation region they rise steeply for both sources.

In conclusion being inspired by the ultimate characteristics of rod photoreceptors, we investigated the impact of photon fluctuations of classical light sources on its response. Our experimental results, supported by the theoretical model, reveal a crucial influence of the photobleaching of the rod on the fluctuations of its response. The results form the basis for future efforts on interfacing biological detectors with quantum light [4].