Seeing Single Photons

What a cell can do

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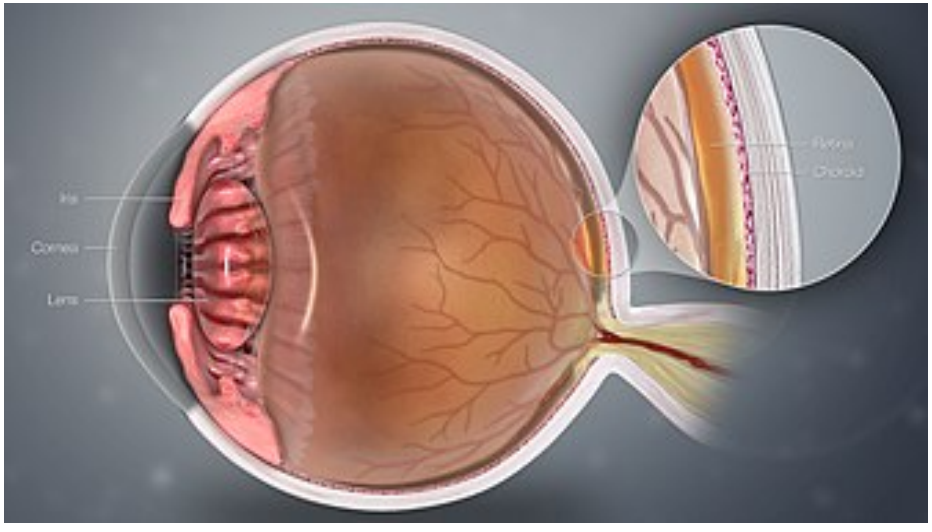
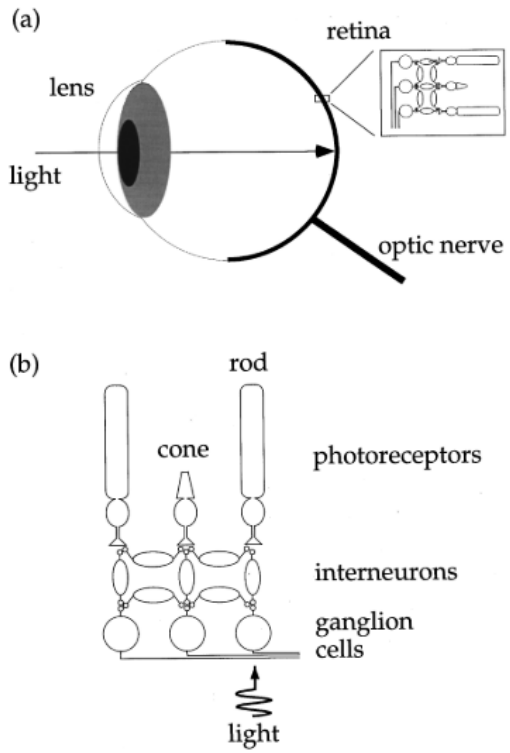
Physics/Neuro 141

Week 2



Recording from photoreceptors

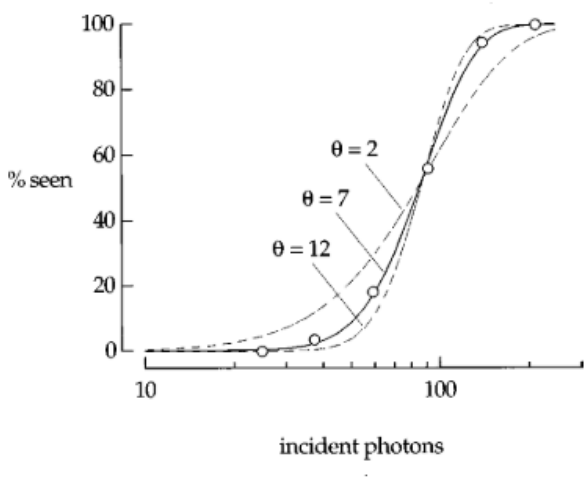
Eye, lens, and retina



Rods and cones

- We see over an enormous range of light intensity, from photon fluxes of less than 10^{-2} photons μm^{-2} sec^{-1} (starlight) to greater than 10^{8} photons μm^{-2} sec^{-1} (bright sunlight).
- The cone photoreceptors mediate vision over the upper 7–8 log units of the range. They mediate color vision and provide better temporal and spatial resolution.
- The rod photoreceptors mediate vision over the lower part of the intensity range. While they provide no color information and have poorer temporal and spatial resolution than the cones, the rods excel at detecting dim lights (*scotopic vision*)

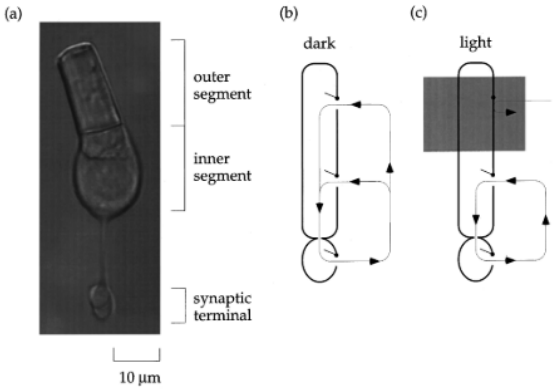
Analysis of frequency of seeing



Analysis of frequency of seeing.

- The open symbols are measurements from a single human observer of the probability of seeing a flash plotted against the logarithm of the number of photons incident on the front of the eye for several flash strengths.
- These experimental measurements are compared to calculations for thresholds of 2, 7, and 12 photons.
- Each of the calculated curves has been shifted along the log intensity axis by varying the constant which accounts for the fraction of incident photons producing a response in the rods.

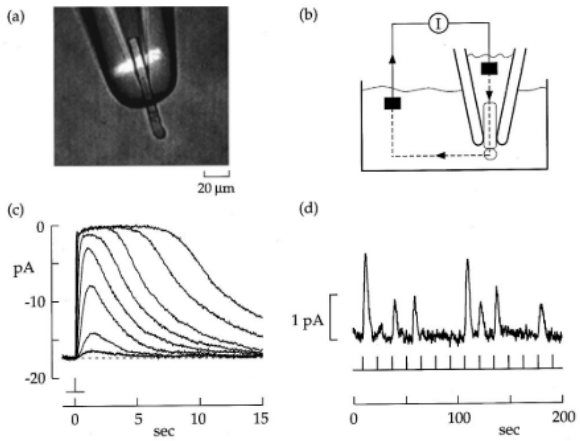
Rod photoreceptors



Dark current and the light response

- The outer segment transduces light into an electrical signal.
- The inner segment keeps the cell alive.
- The synaptic terminal transmits the responses to the retina.
- In darkness Na^+ enters the outer segment through membrane channels. The current loop is completed by the outward movement of K^+ ions in the inner segment.
- In darkness the current produces -40 mV between the inside and outside of the cell.
- Photons cause channels in the outer segment to close, circulating current decreases.
- The change in membrane voltage changes the rate of synaptic release.

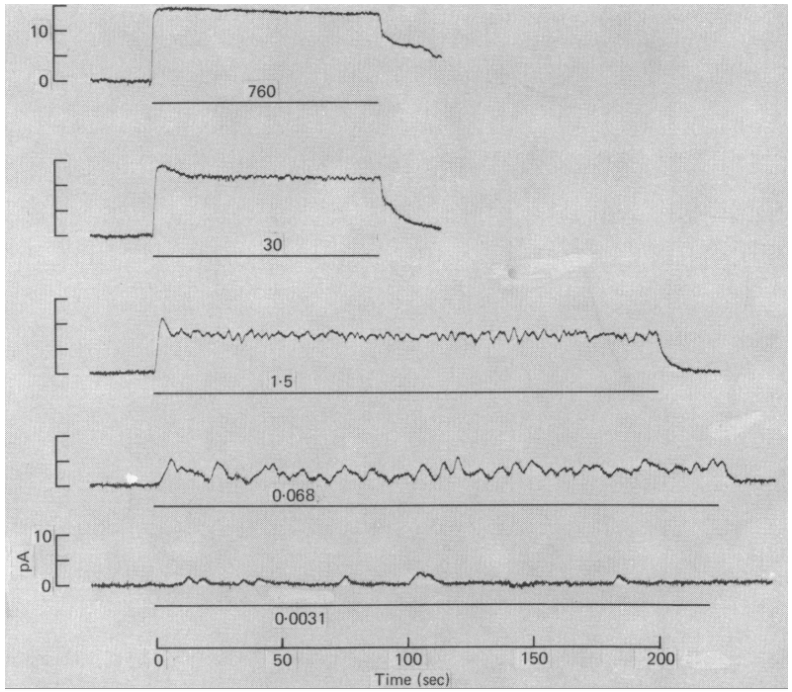
Rod photoreceptors



Suction electrode recording

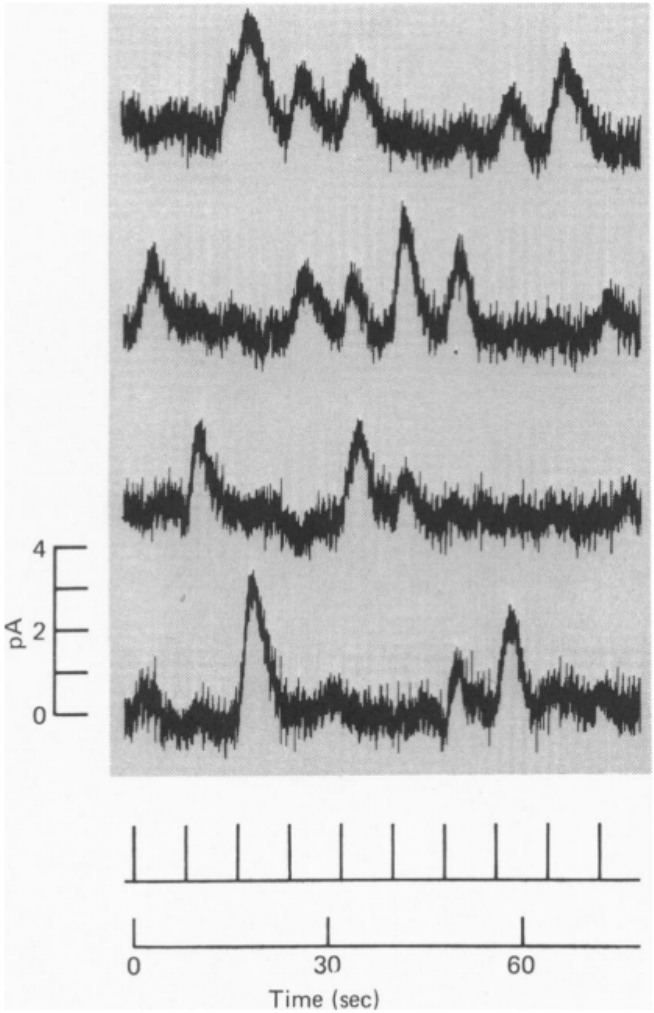
- The electrode collects the current entering the outer segment and allows changes in this current to be measured.
- Current flows through an electrode placed in the bath, through a current-measuring amplifier, and into the suction electrode. Thus changes in the outer-segment current can be directly measured.
- The smallest response is to a flash producing an average of about one photon absorption.
- The individual responses to this dim flash are quantized, corresponding to the effective absorption of 0, 1, or 2 photons.

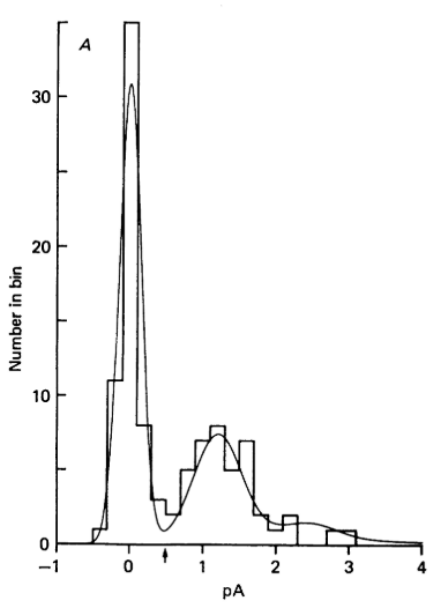
Quantal responses at low levels



Response of a rod outer segment to steady lights. Ordinate is outward change in membrane current from level in darkness. Bars beneath traces indicate duration of light stimuli; numbers give intensities in photons μm^{-2} sec^{-1}.

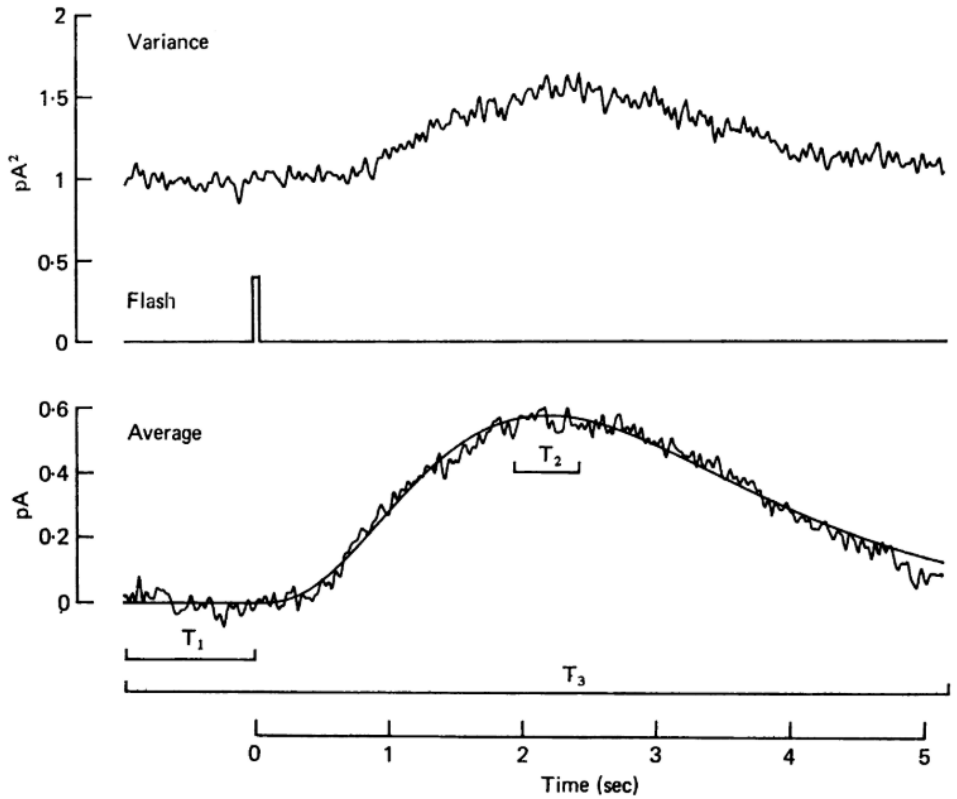
Low-light responses





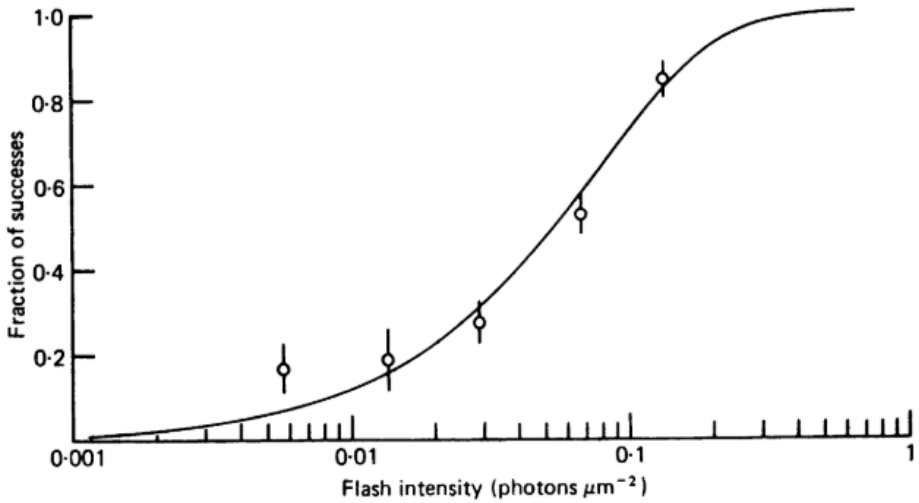
Amplitude histograms for flash responses. 99 trials. Response amplitude had mean μ=0.56 pA and variance σ^2 = 0.58 pA^2.

Poisson rules



Ensemble average and variance of ninety-nine flash responses

Frequency of seeing, single rod



'Frequency of seeing' experiment. Fraction of responses exceeding criterion level (ordinate) at five intensities is plotted against flash intensity on a logarithmic scale.