A Comprehensive Model for the Fast Photovoltage in the Vertebrate Retina

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On stimulating vertebrate photoreceptors by an intense flash of light a transient extracellular current flow along the photoreceptors is evoked which yields a fast photovoltage (FPV) across the receptor layer. The FPV consists of two components with opposite polarity, R_1 and R_2, whose contribution to the signal varies dramatically with temperature. In order to explain this phenomenon it is necessary to study in detail in which way the extracellular current flow is produced. The current source are charge displacements in the plasma membrane of the outer segment which are closely related to the photolysis of the visual pigment rhodopsin. Only if the signal shaping mechanism at the receptor structure is known it is possible to separate the time course of the initial charge displacement from the measured FPV. This mechanism is described by a simple equivalent circuit proposed by Govardowskij (1) basing on the electric receptor properties: The rhodopsin containing plasma membrane of the outer segment and the non pigmented membrane of the remaining receptor part, both are represented by separate capacitors which are connected in parallel via the electrolyte resistances of the extra- and intracellular medium. After the flash, charge flows primarily onto the first capacitor and is simultaneously redistributed between both capacitors. The primary charging occurs with the "active" time constant of the molecular event whereas the charge spreading takes place in the "passive" recharging time of the circuit.
In this model the fast photovoltage measured in rat, fog and cattle retinae in a temperature range from 0 - 60 °C can be described with high accuracy. The corresponding signal separation gave the following results:

1. The active time constant of the R_2-generating process determines the signal decay because it is normally larger than the passive time constant (s. poster Lindau et al.).
2. The active time constant has a large, the passive a small temperature dependence.
3. For the cattle retina the active time constant of R_2 is identical with the reaction time for the slow phase in the meta transition of rhodopsin (s. poster Schnitzkewitz et al.).
4. The absolute value of the passive time constant is in accordance with the known electric parameters of the photoreceptor.
5. The dramatic temperature effect on the FPV-waveform is mainly due to the strong temperature dependence of the R_2 charge displacement.
6. The R_1-generating process is faster than the lumi-meta I transition.

1. Govardovskij, V.I. (1979) Biophysics 23, 520 - 526.