

Supplement 2 for Voltage-dependent K^+ Channels Improve the Energy Efficiency of Signalling in Blowfly Photoreceptors

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1 The cost of PIP_2 signalling

To calculate the cost of the phototransduction cascade of *C. vicina*, we assumed that it contains the same set of molecular components as that of the fruit fly, which has been studied extensively [Hardie, 2012]. A photon absorbed by a single rhodopsin molecule activates around 5 G-proteins and 5 phospholipase C (PLC) molecules in *D. melanogaster* [Hardie, 2012]. Mini-bumps 4 times smaller than light-induced quantum bumps are found in the housefly, *Musca domestica* [Minke and Stephenson, 1985]. Assuming that these mini-bumps are produced by a single G-protein activation, as in *D. melanogaster* [Hardie et al., 2002], a single photon is likely to activate in the range of 4-5 G-proteins and PLC molecules also in the housefly. We assume the same to be true for the blowfly.

In *D. melanogaster*, each PLC protein phosphorylates PIP_2 at a rate of 1000 s^{-1} before being inactivated by Ca^{2+} ions that have entered through the Trp1 or Trp channels [Hardie and Minke, 1994, Hardie, 2012, Chu et al., 2013]. Assuming that the time-to-peak of the flash response (20 ms in the dark and less than 7 ms for a light-adapted cell at 29° [Tatler et al., 2000]) in the blowfly *C. vicina* corresponds to the period of PLC activity, each photon absorption triggers the phosphorylation of approximately 80-100 PIP_2 molecules in a dark-adapted photoreceptor dropping to 28-35 PIP_2 molecules upon light adaptation.

Each hydrolysed PIP_2 dissociates into diacylglycerol (DAG) and inositol (1,4,5) trisphosphate ($InsP_3$). Phosphorylation of DAG, at the cost of one ATP, produces phosphatidic acid (PA), which is subsequently phosphorylated to generate phosphatidylinositol (PI) at the cost of a cytidine triphosphate (CTP). The hydrolysis of CTP to cCMP is equivalent to ATP to cyclic adenosine monophosphate (cAMP). Finally, PI is phosphorylated twice to PIP and then to PIP_2 costing a further 2 ATP molecules.

Consequently, each PIP_2 molecule is recycled at a cost of 4 ATP molecules, so that a single photon absorption costs 320-400 ATP molecules in a dark-adapted photoreceptor dropping to 112-140 ATP molecules upon light adaptation. A blowfly photoreceptor can transduce $\sim 3 \times 10^6$ photons per second (9×10^4 microvilli processing a photon every 30 ms [Hochstrate and Hamdorf, 1990]) incurring a total cost of PIP_2 signalling at the highest light intensities of 3.3×10^8 to 4.2×10^8 ATP/s.

References

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