

Tradução em: [[Musgrave - Camundongo cego vs Behe](#)]

Blind Mice vs Behe; the Evolution of Vision

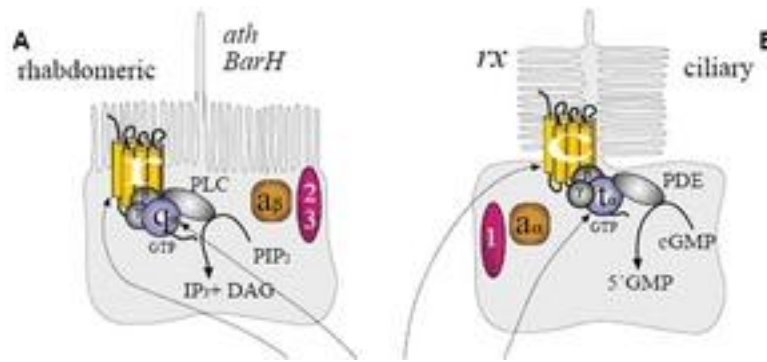
By [Ian Musgrave](#) on November 14, 2006 2:39 AM | [9 Comments](#)

Last week the first draft of the [complete genome of the Sea Urchin](#) was announced. In amongst the wealth of data were new clues to the evolution of the immune system, and the discovery that Sea Urchins express both rhabdomyeric and ciliary opsins, without having specialised eyes, gives us new clues to the evolution of the eye.

But several months ago, a paper was published with far less fanfare. In this paper, the photosensitive pigment from an alga was inserted into the retinal ganglion cells of blind mice, and their visual responses were restored (Bi et al., 2006). This paper may lead to the treatment of certain kinds of blindness, but also blows away one of Behe's arguments.

The [evolution of the mammalian camera eye](#) seems at first glance to non-biologists to be highly improbable, but we know that the camera eye lies at the end of a series of increasingly sophisticated part-eyes, from the simple concentration of photosensitive opsins in the tentacles of Sea Urchins, to simple pigment cups, to pinhole eyes and so on (see Arendt, 2003, Gehring 2004, Nilsson 2004 for example). Each form is reachable by small, selectable variational steps from simpler forms.

Behe apparently accepts the evolution of the [camera eye](#) from a simple eye spot. But he has claimed that the evolution of the visual transduction pathway is too complex to be a product of evolution, and the eye spot itself could not get started (Behe 1996). In actual fact the visual transduction system isn't terribly complicated at all; there is a photopigment ([opsin](#)), an adaptor protein, an enzyme, and a target protein. Invertebrates and vertebrates use very similar photopigments (rhabdomyeric and ciliary opsins respectively) and related adaptor proteins, but different final pathways (more about this later). It is enough to note that the adaptor proteins and specific enzymes are parts of ubiquitous families that have roles in other signalling systems, and/or have stand alone roles. There are a number of accessory proteins as well, which Behe adds in to pad out the system. For example he counts the accessory proteins arrestin and retinoid binding protein, but these can be completely absent in vertebrates with either no effect or mild night blindness (eg. Gonzalez-Fernandez, 2002).



Proteins of the invertebrate and vertebrate phototransduction system, Taken from Arndt 2003. r and g; Rhabdomic and Ciliary opsins. Q and T, adaptor proteins. PLC, phospholipase C. PDE, phosphodiesterase.

Behe's core claim is that if a modern system breaks when you remove a part, then you can't build that system by incremental evolutionary steps. For example, he would claim that a photopigment without any linkers or down stream signalling molecules would be useless, and unselectable by natural selection. Really?

One of the iconic light spots is that of the eukaryotic single-celled organism *Euglena*. The *Euglena* signal transduction cascade consists of a single protein, the light harvesting protein and the protein that generates the single signaling molecule is one and the same (Iseki et al., 2002). This is a simple "one step" cascade that is eminently evolvable.

However, the photopigments of vertebrates and invertebrates isn't closely related to the light harvesting pigment of *Euglena*. In fact they are a member of a family of ancient proteins, the [rhodopsins](#). Rhodopsins are [seven transmembrane domain proteins](#), and are present in bacteria (Bacteriorhodopsin) and eukaryotic algae (*Volvox* and *Chlamydia*) as well as invertebrates and vertebrates.

ID apologists aren't known for generating testable hypotheses, and generally ordinary scientists have to do it for them. This case is no exception, as the above information suggests an experiment. If Behe is right, then putting a microbial rhodopsin, which doesn't use vertebrate visual signal transduction pathways, into an ordinary vertebrate neuron, which doesn't have the vertebrate visual signalling pathway, should do absolutely nothing. Well, Bi et al (2006) did that experiment (but for reasons totally unrelated to ID).

In certain diseases the photoreceptors degenerate. However, the supporting retinal ganglion cells, which pass on the nerve impulses from the photoreceptors to the brain, often remain intact. These retinal ganglion cells are not light sensitive. Bi and colleagues used a mouse model of photoreceptor degeneration. As the mouse ages, it progressively loses photoreceptors (and vision). When all the photoreceptors had gone, and the retinas of the mice no longer responded to light, the researchers transfected the retinal ganglion cells (with no visual

transduction pathway remember), with the microbial rhodopsin (which doesn't link to the vertebrate pathways anyway).

And visual responses were restored. The ganglion cells transfected with the microbial rhodopsin responded to light, depolarised and passed signals on to the visual cortex (Bi et al., 2006). They are not quite as effective as photoreceptors, as the retinal ganglion cells do not have the stacked membranes of the photoreceptors that increase light harvesting efficiency, nor the amplification of the vertebrate signal transduction cascade. But they do work. It's not just mice, other researchers have transfected these receptors into non-photosensitive nerves in worms, and they become light sensitive and moved away from the light (Nagel et al. 2005).

So Behe is wrong, and his claim that the visual signal transduction system is unevolvable is blown out of the water.

Looking deeper reveals the reason why. The microbial rhodopsins used are [ion channels](#). Illumination of the rhodopsin opens a channel in the protein which allows ions to flow through, depolarizing the cell the rhodopsin is in. This very simple mechanism underlies the activity of rhodopsins in many archebacteria, and the eukaryotic algae *Volvox* and *Chlamydia* (which are intermediate between archebacterial rhodopsins and invertebrate and vertebrate opsins (Ebnet et al. 1999)). Both the colonial algae *Volvox* and the unicellular algae *Chlamydia* have simple "eye spots", and the depolarization of these spots is sufficient to allow them sense light and act accordingly. For a nerve cell, depolarization, no matter how achieved is enough to make it fire, and enough to restore visual responses in mice and create photoresponses in worms.

But the modern vertebrate and invertebrate opsins are not ion channels (at least not anymore, despite still having central pores). How can we get from ion channel rhodopsins to modern opsins. Relatively easily as it turns out. Seven transmembrane domain proteins are surprisingly promiscuous in their ability to link to other proteins. Modern vertebrate ciliary opsin binds to the adaptor protein transducin. Transducin is part of ancient family of adaptor proteins, and even modern seven transmembrane domain proteins can bind to multiple members of this adaptor family, as well as other proteins. For example, the cAMP receptor of the colonial amoeba *Dictyostelium*, the non-rhodopsin closest in structure to the channel opsins such as the one used to restore vision in mice (Gehring 2004), binds to a transducin family adaptor protein, but also initiates ion influx in an adaptor protein-independent manner (Brzostowski & Kimmel 2001).

So you see that in principle, an ion channel rhodopsin could secondarily acquire linkage to amplifying pathways via any number of mutations. While the ion conducting rhodopsin by itself will be sufficient for simple vision, adding in amplifying cascades has a clear benefit of increasing sensitivity. After a while the ion conductance could be lost (or incorporated into the activation mechanism), and the rhodopsin rely entirely on the adaptor protein pathway. We can see how this works with some kinds of bacterial rhodopsins. They have become linked to the chemotactic receptor pathway, and the ion channels no longer pump ions into the cell, but provide the conformational change necessary to activate the chemotactic pathway (Spudich 1998).

In modern opsins, the central ion-conducting pore is retained, but no-longer conducts ions. In non-chordate invertebrates, opsin is linked via the adaptor protein to an enzyme called phospholipase C, and in chordates and vertebrates, it is linked to a phosphodiesterase enzyme. In both cases, the light sensing molecules have co-opted existing signaling systems to work though, just as the microbial systems have co-opted the chemotactic signaling system. You may ask how the phospholipase C and phosphodiesterase cascades were put together, these are relatively simple and highly flexible systems cobbled together from proteins with other independent functions (and you can mess around with these cascades quite a bit).

Behe is wrong, it is quite possible to evolve the visual system in small, selectable steps. The restoration of visual signals in blind mice, and production of light responses in the nerves of worms, all from the simple addition of a single ancestral rhodopsin show how the visual system can evolve. Once again, a cherished ID hypothesis withers under the light of investigation.

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