Evolutionary novelties in vision

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A new study from SciLifeLab at Uppsala University published in *PLOS ONE* shows that genes crucial for vision were multiplied in the early stages of vertebrate evolution and acquired distinct functions leading to the sophisticated mechanisms of vertebrate eyes.

One striking feature of vertebrates is the prominent role that vision plays in almost all major animal groups. The vertebrate eye has a unique organization and is known to have arisen at the time of the first vertebrates over 500 million years ago. A new study by the research team led by Xesús Abalo and Dan Larhammar explains how ancient gene duplications have played decisive roles in the evolution of novel functions.

The first step in vision is the response to light by the cone and rod cells in the retina at the back of the eye. Twenty years ago, the first studies of the light receptors, proteins called opsins, in birds indicated that colour vision arose before the dim light black-and-white vision provided by rods. This hypothesis was recently confirmed by detailed studies of opsin genes in a broad range of vertebrate species (David Lagman and Daniel Ocampo Daza in the team of Abalo & Larhammar, *BMC Evol. Biol.* 2013). The authors found that new opsin genes were generated when the genome of the vertebrate ancestor was doubled twice at the dawn of the vertebrates. These massive gene duplication events resulted in many novel functions, not only for vision but also many other characteristic vertebrate features.

In the new study, David Lagman and co-workers describe evolutionary changes in the first relay step in the vision cascade, mediated by a family of G-proteins called transducins. These trigger the cellular response by activating a critical enzyme. Just like the opsins were multiplied and evolved distinct functions in early vertebrate evolution, also the transducins and their target enzyme were duplicated and diverged to separate functions.

The new study published in *PLOS ONE* presents a detailed description of the transducins in the retina of the zebrafish, a widely used experimental animal since more than thirty years. This species not only retains all five of the ancestral vertebrate opsins, two of which were lost in mammals including humans, it also displays a greater multiplicity of transducins. Whereas humans have three transducin proteins in cones and three in rods, the zebrafish boasts five cone transducins and four rod transducins thanks to a third genome doubling unique to the group of ray-finned fishes called teleosts.

The authors have explored the fates of all nine transducin genes in the zebrafish retina and report that each duplicate differs from its template in a striking way. First, the zebrafish displays the same distinction as humans between cone versions and rod versions of the transducins. This shows that these two cell types had acquired their characteristic properties already before an early vertebrate ancestor approximately 420 million years ago gave rise to one lineage leading to teleost fishes and one leading to mammals.

Secondly, the teleost-specific duplicates provide novel specialisations. For one such duplicate pair, the two copies have quite different expression levels. For the second pair of transducin genes, one is present in the upper part of the retina and its duplicate is found in the lower part, presumably as a result of very different light intensities hitting the two parts. The one exposed to strong light from above may provide protection from damage. Furthermore, all three pairs of duplicates show differential expression in that one of the copies is also expressed in the pineal gland involved in endocrine regulation of the day-night cycle.

These results show that duplication of genes and genomes has been an important source of new genetic material that has subsequently evolved novel and more specialised functions. Gene duplicates may rapidly adopt altered expression patterns.

Does this mean that zebrafish can see better than humans? Zebrafish have long been known to have the capability to detect ultraviolet light and the retina has a much wider distribution of colour-vision cones than the human eye which has only a narrow cluster of cones in fovea. The new findings add gene specialisations in time, space and amount for duplicated genes. Even if we do not know how a zebrafish sees the world around it, gene duplications clearly allow evolutionary novelties to arise from altered use of spare gene copies, shaping a visual system that let them successfully inhabit a specific environment, just like any other species, including humans.

More information: Lagman D, Callado-Pérez A, Franzén IE,Larhammar D, Abalo XM (2015) Transducin Duplicates in the Zebrafish Retina and Pineal Complex: Differential Specialisation after the Teleost Tetraploidisation. *PLoS ONE* 10(3): e0121330. DOI: 10.1371/journal.pone.0121330

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Opsin and transducin gene evolution: Lagman & Ocampo Daza et al., *BMC Evol. Biol*. 2013. www.ncbi.nlm.nih.gov/pubmed/24180662

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