The Importance in Species Axial Length Impacting the Evolution of the Eye

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**Introduction**

The evolution of the eye began merely 500 million years ago, indicated through a composition of calcite. Within its first phases, cells were able to develop a sensitivity to light. These cells are known as photoreceptor cells, involving opsin, chromopore, and pigment absorption. Ultimately this is known as an eye spot, the most simple form of the eye. Although eyespots are able to react to light intensity, it cannot distinguish specific objects. Organisms were able to detect light, and the perceptual sense of direction. Planarian, for example, have cupped eyespots. This is distinguished through a depression to allow the eyespots to have directional differentiation. The process involves a number of photoreceptive cells reacting to different angles of light. When it comes to cupped eyespots, the deeper the depression—formation of the pit—the sharper the directional differentiation becomes. The formation of the pit allowed an opening for light to enter into the eye onto the retina. This is a lining covered in photoreceptive cells within the back of the eye. The retina is responsible for translating light into nerve signals that would then be decoded by the brain. Throughout the process of eye evolution, lens formation occurred by specific enzymes and heat-shock proteins, explaining the difference in some organism eye designs. Vertebrates are known to have crystallin lenses, involving heat-shock proteins (Duncan, Cvekl, et. al, 2004). The composition of organismal lenses differ and are seen to be taxon-specific. Trilobites, an extinct arthropod, were able to independently develop a composition of multiple lenses within its eye. An organism’s pathway in eye development is highly based on its evolution in visual behavior. These behaviors serve as the fundamental basis where organisms are forced to develop to obtain peak performance in order to survive and maintain.

Humans contain complex eyes, an incredible organ that has the ability to perceive the outside world in a way we can interpret and understand. It is composed of a cornea, ocular muscles, a crystallin lens, as well as three layers that help the brain receive nerve impulses through the ocular nerve. Because this is such a complex network, genetic and environmental factors have played a key role in refractive errors such as myopia. Myopia involves the elongation of the axial length, the distance from the front of the eye to the back of the eye. This refractive error creates blurry images, due to the light entering the eye, falling short of reaching the focal point found on the retina. Refractive errors and myopic cases are commonly found in humans, but what about other species? Within the evolution of the eye amongst species, is axial length found increasing amongst various animals such as other mammals, fish, lizards, or birds? Obtaining information known about each of these species and their eye evolutionary pathway, maybe their lack of axial length change and inability to develop a refractive error can serve a purpose to humans and their high increase of myopia.

**Fish Eye**

Fish eyes have common attributes in relation to human eyes: lens, rod and cone cells. The lens is found to be spherical or oval shaped, and is responsible for the majority of the light refraction. Developmentally, these lenses aren’t flexible and do not change shape, so fish must focus on objects by moving their lens closer to the retina or further away from the retina. The movement of the lens gives reason to believe that axial length and myopic cases should not affect the visual clarity of the fish. However, an overgrowth can allow myopia to occur in fish. This abnormality is found involving genetic loci and visual parameters. Maintaining a homeostatic axial length must be achieved to regulate the growth and any remodeling done to the ocular shape. In a study using Zebrafish (*Danio rerio*) , researchers observed their myopic phenotypes.

Within the Zebrafish, darkness was associated with an increased growth in axial length. The overall research stated that this particular eye is under consistent growth, where the body size and diameter of the lens normalize the size of the Zebrafish eye.

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*Figure 1. Zebra Fish Axial Length.* The blue points represent the individual Zebrafish that had their axial lengths measured in millimeters. These Zebrafish contain a combination of myopic, normal, and hyperopic errors. The myopic measurements can be seen at 1.5 and above, hyperopic recorded at 0.5 and below, with a normal rage found within the middle. Data collected from Collery, 2014.

**Lizard Eye**

Lizards eyes contain rods and cones cells, along with the ability of compressing and stretching their lenses to be able to focus on objects. Their pupils react in response to light, found in either variation of circular or a slit. The lizard eye develops in representation of its behaviorisms. These behaviorisms result in either diurnal or nocturnal ocular needs (Hall 2009). Because many lizards have developed nocturnal behaviorisms, their cone cells have reacted in response by becoming more light sensitive. This degree of change has allowed some to obtain photopigments that are able to sense ultraviolet, blue, and green waves. Some lizard eyes are even able to retrieve information in the dark in association to color. When lizard eyes developed to adapt to the atmosphere of the night, it was necessary to obtain a larger pupil as well as a shorter focal length. Without these additions to a nocturnal lizard eye, visual acuity is found to be blurred. Unlike some other organisms, lizards have a sclerotic ring that contains where the eyeball protrudes from its orbit. Because there is a bony structure placed in the front of the eye, I believed the sclerotic ring to play a role in subsidizing a prevention in axial length growth. It turns out from research conducted by Lina Roth, amongst an observation of geckoes, a myopic error was found while mapping the refractive powers of their eyes.



*Table 1. Measurements and averages of various lizard species axial lengths.*

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*Figure 2. Various Lizard Axial Lengths.* Plotted above are the various axial lengths amongst different species of lizards. Due to the various body sizes, their axial lengths are vastly scatted amongst this plot. There seems to be no significant correlation.

**Bird Eye**

The bird eye holds many similarities with the lizard eye, such as the sclerotic ring, flexibility of the lens, as well as its diurnal and nocturnal behaviors (Hall 2008). Nocturnal eyes here will still hold a higher light sensitivity, limit color detection, and have tubular eyes, while diurnal eyes are prone to larger axial lengths. Once again, I believed the presence of a scleral ring would hold some sort of control to the elongation of axial length, thus preventing myopic errors. However there have been cases of myopic errors in smaller birds, where their eyes are too small to acquire quality vision at night, and require them to function in diurnal behaviors. This forced behavior takes a toll on their nocturnally developed eyes, enabling myopic errors to become present.



*Table 2. Axial length measurements for five species of bird.* Under the species with multiple measurements, notable variations in axial lengths, taken in millimeters, are seen. These measurements were provided by Hall, 2008.

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*Figure 3. Various Bird Axial Lengths Based on Species.* The graph above shows the plotted points of recorded axial lengths listed in *Table 2.* Body size in proportion to eye size deems the axial lengths here, provided in millimeters.

**Dog Eyes**

Dogs are commonly discussed to be color blind. They are not, however, they do present fewer cone cells in comparison to humans. These cone cells are limited to blue and yellow wave lengths. When it comes to rod cells, dogs contain a high concentration of these photoreceptor cells, to increase their visual acuity in the dark. A special type of tissue called tapetum lucidum, provides extra light to reflect into their retina. Within their evolution, the dog eye has developed muscles that appear around the eyes that have allowed them to generate facial expressions. This is presumed to assist the communication between domesticated dog and its owner. Myopia has become prevalent in old age, as well as some species of dog, such as German Shepherd, Rottweiler, and Miniature Schnauzer (Murphy et al. 1992).

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*Figure 4. German Shepard Axial Lengths*. This figure presents seventy-three German Shepherd subjects who’s axial lengths were measured and recorded in millimeters. The average axial length for normal vision is found to be around twenty-two millimeters. The closer the measurements were towards twenty-three millimeters shows an axial length that will hold myopic qualities. Data was provided by Murphey and Manis, 1992.

**Conclusion**

An increased axial length has been known to be the sole contributor towards the refractive error known as myopia. Myopia is increasing in prevalence in human eyes, but much isn’t said about myopic tendencies in other species. Dogs, lizards, birds, and fish, all happen to show myopic errors due to environmental and genetic factors, just as humans. I believed that there would be very minimal axial length variation within birds and lizards due to the presence of a sclerotic ring, but there was data that supported a presence of refractive error. Myopia seems to hold prevalence in all eyes, but varies in severity according to species. This could just be another step in the overall evolution of the eye.

Works Cited

Collery, Ross F et al. “Rapid, accurate, and non-invasive measurement of zebrafish axial length and other eye dimensions using SD-OCT allows longitudinal analysis of myopia and emmetropization.” PloS one vol. 9,10 e110699. 21 Oct. 2014, doi:10.1371/journal.pone.0110699

Duncan MK, Cvekl A, Kantorow M, Piatigorsky J . Lens crystallins. In: Robinson ML, Lovicu FJ (eds). Development of the Ocular Lens. Cambridge University Press: Cambridge, UK, 2004, pp 119–150.

Hall, Margaret I. “The anatomical relationships between the avian eye, orbit and sclerotic ring: implications for inferring activity patterns in extinct birds.” Journal of anatomy vol. 212,6 (2008): 781-94. doi:10.1111/j.1469-7580.2008.00897.x

Hall MI. The relationship between the lizard eye and associated bony features:

a cautionary note for interpreting fossil activity patterns. Anat Rec (Hoboken).

2009 Jun;292(6):798-812. doi: 10.1002/ar.20889. PubMed PMID: 19462447.

Murphy, C J, et al. “Myopia and Refractive Error in Dogs.” Investigative Ophthalmology &amp; Visual Science, U.S. National Library of Medicine, July 1992, [www.ncbi.nlm.nih.gov/pubmed/1634344](http://www.ncbi.nlm.nih.gov/pubmed/1634344).