The role of an oil droplet lens in vision enhancement

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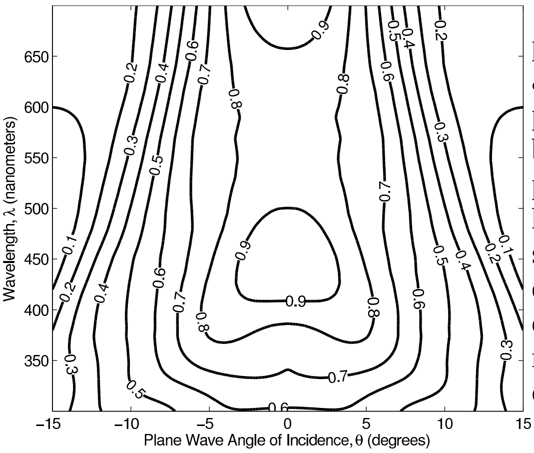
The cone photoreceptors of all birds and some reptiles, amphibians, mammals and fish contain both coloured and transparent oil droplets (Walls, 1942). The light incident on the photosensitive region of such receptors is preconditioned by this oil droplet lens. Coloured oil droplets (which form the majority of the oil droplet population) act as long-pass filters and are thus responsible for spectral tuning. The prevalence of transparent oil droplets throughout the vertebrate classes, such as the T-type oil droplets found in the Ultraviolet or Violet-Sensitive (UVS/VS) photoreceptors of birds, suggests an auxiliary dioptric function operating outside of colour filtering (Young & Martin, 1984). It is hypothesized that an oil droplet lens enhances light collection efficiency and - perhaps more importantly - detection directionality. The outstanding features of an idealised photoreceptor can be modelled in the framework of the electromagnetic theory. The table indicates the set of characteristic parameters that are used in the construction of this model.

Model Parameter	**Value (μm)**
Oil Droplet	2.5
Outer Segment (OS) Length	10.0
OS Base Diameter	1.5
OS Tip Diameter	1.0
Region	**Refractive Index**
Cone Outer Segment	1.387 - 0.0011*i*
Extracellular Matrix	1.340
Transparent Oil Droplet	1.480

The geometric optics approximation cannot be applied to this problem since the wavelength of light and the dimensions of the system are of a comparable order of magnitude. The dioptric function of oil droplets has previously been considered in the context of the Mie scattering theory, which provides an analytic solution to Maxwell's equations of electromagnetics for spherical particles (Ives, Normann & Barber, 1983). Due to the complexity of any realistic photoreceptor structure, a complete analytic solution is not possible. Rather, numerical methods within electromagnetic theory must be employed. The Finite-Difference Time-Domain technique (FDTD) appears to be an attractive alternative to investigate the light coupling efficiency of the photosensitive region in the presence of an oil droplet. FDTD provides a full field solution of Maxwell's equations for some specific dielectric structure. Numerical data sets have been obtained for the vertebrate photoreceptor structures of rods, cones and cones containing transparent oil droplets under broad-band plane wave excitation. Preliminary results show that in the presence of an oil droplet, cones have an increased light coupling efficiency whilst in the retinal mosaic.



The normalised plane wave coupling efficiency of a cone photoreceptor containing an oil droplet is shown in the figure. It is a function of both the wavelength and the angle of incidence of the plane wave. Maximal coupling at normal incidence is significantly blue-shifted when preconditioned by an oil droplet lens. Since the photopigment found in UVS/VS photoreceptors characteristically have absorption maxima between 360 and 430 nm, such peak shifting is indicative of spectral tuning. Both the geometry and dielectric properties of photoreceptors are expected to change during *in vitro* analysis. Thus, numerical investigation of the model parameters that determine the degree of peak shifting is currently being conducted.

Ives, J.T., Normann, R.A. & Barber, P.W. (1983) *Journal of the Optical Society of America* **73**(12), 1725-1731.

Walls, G.L. ed. (1942) *The vertebrate eye and its adaptive radiation.* Bloomfield Hills, Cranbrook Institute of Science.

Young, S.R. & Martin, G.R. (1984) *Vision Research* **24**(2), 129-137.