Waveguide contribution to the spectral sensitivity of human cones.

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The spectral sensitivities of human cones have been previously modeled using geometric optics. However, because the outer segment diameter of human cones is comparable to the wavelength of light, waveguide rather than geometric optics must be used to model the spectral sensitivity. To find the dependence of light absorption on wavelength in cone outer segments, we numerically solved Maxwell equations. Cones were arranged in a periodic triangular array. Each individual cone consisted of inner and outer segment with constant refractive indexes and of an ellipsoid – a region where refractive index varied gradually from inner to outer segment. Inner segment and ellipsoid had real refractive index. Outer segment had complex refractive index whose imaginary component corresponded to the absorption by visual pigment. To model the wavelength dependence of the absorption, we used Govardovskii's templates of the visual pigment extinction coefficient. Using our numerical solution, we derived an analytical description of the distribution of electromagnetic field. The electromagnetic field can be described as a superposition of three modes with an appreciable amount of energy travelling between outer segments. Because light is not absorbed between outer segments, the effect of self-screening is less pronounced than that expected on the basis of geometric optics considerations. The shape of the spectral sensitivity derived from our numerical and analytical calculations agrees with the psychophysically determined shape better than that predicted on the basis of geometric optics. Our calculations show that waveguide contribution can account for small, but significant discrepancy between psychophysically determined cone spectral sensitivity and the estimates of this sensitivity based on geometric optics.