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Optical Characteristics of the Eye of the Flounder

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Summary. The winter flounder, *Pseudopleuronectes americanus,* is mildly hyperopic. However, chromatic aberration exists in significant amounts and therefore the eye may be emmetropic (zero refractive error) in natural conditions when light is restricted to shorter wavelengths. Large accommodative lens motion was observed along the direction of the pupil axis. This direction is rare among the teleosts and is the result of the unusual split origin of the retractor lentis muscle. While the lens is spherical, as in other teleosts, the retina is not uniformly distant from the lens. Rather, a vertical asymmetry exists such that dorsal and ventral portions of the retina are further from the lens than the central retina. In view of the existing large accommodative ability, this distortion of the globe is not likely to have an optical function but is probably due to the shape of the cartilagenous scleral cup supporting the eye in its extraorbital location. Further, the lens is overcorrected for spherical aberration so that rays passing through the periphery of the lens are focused further away. The value of a lens of this type is unclear.

Introduction

The fact that the teleosts are an ecologically widespread vertebrate group has meant that the optical characteristics of the cyc can vary considerably from one species to another (Sadler 1973; Sivak 1973). Flatfishes probably represent one of the more unusual examples of visual adaptation. This view is based on such factors as the metamorphic migration of one eye to the opposite side of the head, the extraorbital dorsal location of the eyes and their stalk-like appearance, and their lateral asymmetry.

Despite these interesting variations, there has been virtually no study of the flatfish visual system. In relation to other work, it has been shown that the eye of the gulf flounder (*Paralichtyes albigutta*) is capable of large accommodative lens motion along the direction of the pupil axis of the eye (Sivak 1975). Further, it was shown that the retina of the eye of the same flounder is not arranged hemispherically around the lens as is usual for the fish eye (Walls 1942). This is espccially true in the dorsal-ventral direction and is reminiscent of the shape of the eyes of skates and stingrays (Sivak 1976a).

The study of the flounder eye described below was designed to provide information concerning accommodation, optical structure, refractive indices, refractive error and control of aberrations.

Materials and Methods

The work was carried out during two summer periods at the Huntsman Marine Laboratory, New Brunswick, and the Mount Desert Island Biological Laboratory, Maine. The winter flounder (*Pseudopleuronectes americanus*) was the principal species used although a few windowpane flounders (*Scophthalmus aquosus*) were used for certain procedures as well. Specimens varied from 24 to 42 cm overall. All were obtained by trawling.

Refractive errors were measured retinoscopically through the flat face of an aquarium. All values are reported after compensation for retinoscopic working distance and the air-water interface effect. Accommodative changes in refractive error were induced with drugs. Tricaine methane-sulfonate (MS 222) added directly to the aquarium water was used to produce relaxation of the accommodative musculature. Contraction was induced with pilocarpine hydrochloride (6×10^{-2} M) injected intraperitoneally in small cumulative steps (totaling 1–3 ml) until no further refractive change was observed. Refractive changes were mainly monitored along the pupil axis of the eye, with occasional nasal, temporal and dorsal measurements. Chromatic aberration of the eye was found by chromoretinoscopy. This involved the measurement of refractive state through red (λmax = 656 nm), green (λmax = 250 nm) and blue (λmax = 496 nm) gelatin filters.

Accommodative lens motion was also monitored by photographing lens position relative to the cornea from above. For this purpose, a camera and bellows were mounted above the eye in question and photographs were taken when retinoscopy indicated maximum response to MS 222 and pilocarpine. This procedure has been used before (Sivak 1973) but is somewhat difficult with flatfish

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because the eyes are not laterally external to the body wall and the lens is less visible. Photographic results were adequate for 2 of 5 cases in which it was attempted.

The gross anatomy of the eye was determined by rapidly freezing enucleated eyes in liquid freon and sectioning them on a sliding bench microtome and freezing head. The eyes were kept frozen while being sectioned by the release of compressed CO_2. As thin sections of the eyes were removed, photographs of the remaining block of tissue were taken with a camera and bellows mounted above. Half the eyes were sectioned horizontally (nasal-temporal) and half vertically (dorsal-ventral). The photograph, in each case, showing the greatest lens diameter was assumed to represent a section through the geometrical axis on the eye. This process was followed for winter and windowpane flounder.

Refractive indices of the cornea, aqueous and vitreous humors and lens were measured with an Abbé refractometer. Since lens index is not uniform but is higher at the centre than at the periphery, the refractometer could only provide approximate values for lens zones.

The variation in lens index of the fish eye results in a lens with little spherical aberration (Walls 1942; Pumphrey 1961; Sroczynski 1977; Sivak and Howland, in preparation). To see if this is true of the flounder lens and to determine an overall or effective lens index, lens focal lengths for parallel laser light beams of varying separations were photographed while lenses were immersed in water. The laser used was a low power helium-neon one, the beam of which was condensed and divided with a rotatable beam-splitter. The lens was placed on a clay pedestal within a rectangular container. The beams were admitted through one glass face of this container. The insertion point of the lens muscle on the lens was used to maintain the appropriate axial orientation of the lens.

Results and Discussion

The refractive findings of the winter flounder are similar to those obtained earlier with the gulf flounder. Conventional retinoscopic measurements carried out on six flounders (12 eyes) indicate a refractive error, when unrestrained and unanaesthetized, ranging from -1 to $+4.75$, the average being $+2.50$. This slight tendency to hyperopia may be related to the spectral transmission of light in water and the eye's chromatic aberration (Sivak 1974). In fact, chromoretinoscopy findings, carried out under the influence of MS 222 to prevent accommodative changes, show variations in refractive error of 4 to 14 diopters for the red and blue extremes. The flounder eyes could therefore be considered to have no refractive error since conventional measurements are much closer to red values than blue ones and some restriction of aquatic light to the blue or blue-green end of the spectrum is to be expected. The dioptric variations in chromatic aberration (4 to 14 diopters) was directly related to animal size and hence to lens size and ocular refractive power. The greatest aberration is found with the smaller flounders. In fact, chromatic aberration is likely a fairly constant percentage of focal length (Sivak 1974; Sroczynski 1976).

Accommodative changes in refractive error show that the winter flounder like the gulf flounder is capable of large lens movement along the pupil axis of the eye. An average accommodative value (12 eyes) amounts to 12.4 D. The average would be still higher (15 D) if the low values of 3 and 4 dioptres found with the largest flounders (40 and 42 cm OA) are removed. Accommodative ranges of 16 and 18 D were reported earlier for *Paralichtyes albigutta* (Sivak 1975). This variation with size (a similar variation was observed with the gulf flounder) suggests that accommodation may be age related. It is unlikely that the teleost accommodative apparatus deteriorates mechanically with age since it is not an indirect system as that of the primates. Possibly, this change is related to change in feeding habits and eating behavior. For example, a shift from smaller to larger prey with growth may result in a decrease in the need for large accommodative abilities.

A point of further interest concerns the fact that the large accommodative ability of the flounder is found along the pupil axis of the eye and not close to the plane of the pupil. Thus nasal, temporal and dorsally directed measurements are always less than axially directed measures. Axial lens movements were also monitored photographically in two instances. In one example, lens motion of 0.325 mm for a 4.0 mm lens was interpreted dioptrically by determining lens focal length from the formula

$$f=\frac{r}{2}\,[1-(n_1/n_2)]$$

where r = lens radius, n = the refractive index of the ocular humors (1.3355) and n_2 = the refractive index of the lens (1.65 according to Walls 1942). The change in focal length equivalent to the lens movement measured indicates a refractive change of 15.5 D. The retinoscopic equivalent is 14 D. If the eye is assumed to be emmetropic, this means that targets from optical infinity (20 ft.) to 7 cm could be kept in focus.

Schwassmann and Meyer (1971) and Somiya and Tamura (1973) have suggested that large accommodative lens movements in fishes always take place close to the pupil plane (nasal-temporal). However, axial accommodative motion has been found in goldfish (Sivak 1973) and likely additional examples will be found when more species are studied.

Munk (1971) reported that the lens muscle, the retractor lentis, of certain species of teleosts has a split origin. This is also true of the flounders of the present study. As in other species, a dorsal suspensory ligament supports the lens and the lens muscle inserts ventrally and slightly anterior to the equator of the lens. The muscle's origin is split into a long and short root (Fig. 1). The long root travels horizontally and temporally to insert near the temporal root of the iris. The short root extends ventrally and somewhat equatorially to insert on to the ciliary body. The fact that the short root ends closer to the equator suggests