# PROBLEMS IN IMAGE-FOCUSING AND ASTIGMATISM IN CETACEA - A STATE OF AFFAIRS -

*by Dral, A.D.G., Netherlands Institute for Sea Research, Texel, Netherlands, and Dr. W.H. Dudok van Heel, Curator Dolfinarium Harderwijk, Netherlands.*

*Summary*

It is apparent from the literature over the last 10 years that vision in Cetacea can not be as poor as has been held in previous years. Discussion of the relevant publications would lead us beyond the scope of this paper, so we will confine ourselves to stating that evidence is published for good visual performances, in air as well as in water, for a number of odontocete species, and suggestions in the same direction for some mysticete species.

The first step to good visual performance is the formation of well focused and undistorted image on the retina. In this respect accommodation and astigmatism - among many others - are factors of primary importance. Information, gathered by approach from various angles, is accumulating. It may be worth while to draw up the balance-sheet and see how far we understand the role which these factors play in cetacean vision.

*A brief summary of former research*

In animals, requiring to see above as well as below the water, two types of accommodation should be distinguished: a moderate one (comparable with our own), used with the eye remaining in the same medium to bring objects at various distances into focus, and secondly, a very powerful one, used to overcome the tremendous myopia which arises when the head emerges from the water and the corneal refraction becomes effective (or, equally justified to say: used to overcome the tremendous hypermetropia which arises when the head is submerged and the corneal refraction becomes ineffective). As a rule, in mammals the accommodation is carried out by the ciliary muscles, affecting the shape of the lens. With regard to cetaceans, a search through the literature yields a collection of conflicting statements about the presence and power of such a musculature. However, positive statements a-

bout the presence of ciliary muscles of any significance in cetacean eyes can be traced back to mistaken observation, often referred to again and again. Moreover, the cetacean eye lens is not easily deformable, so we can take it for certain that accommodation, accomplished in a way like this, in cetaceans is non-existant. Nevertheless, evidence that accommodation takes place in *Tursiops truncatus* has been reported in recent times; we will return to this later.

From the mechanisms, realized in nature to accomplish the powerful accommodation which is required in amphibious vision, only the use of a stenopeic pupil has been repeatedly reported to be functional in cetaceans. In fact, based on the anatomy of the eye, this seems to be the only mechanism which deserves consideration. Moreover, stenopeic vision, in which the pupillary aperture is constricted to a pin-hole size or a narrow slit, is an effective cure for the second aspect of cetacean vision to be discussed here: the corneal astigmatism.

Up to recent times the cetacean eye has been known for its strong astigmatism, at least in air, due to the fact that the radius of curvature of the cornea is not the same in all planes. MATTHIESSEN (1893) was the first and remained the only one to elaborate quantitatively the optical consequences for some Mysticeta. In his paper on the eye of an Odontocete species (MATTHIESSEN, 1886) astigmatism is not mentioned. Subsequent morphological descriptions, however (p.e. PUTTER, 1903; ROCHON-DUVIGNEAUD, 1940), leave no doubt that also in this suborder the eye in air suffers a severe astigmatism. The currently accepted opinion about the highly astigmatic cetacean eye, as resulting from the morphology of the cornea, was functionally interpreted in hydrodynamical terms by JAMIESON, (1971). As said before, its consequences in vision in the air can be eliminated by stenopeic vision. MATTHIESSEN (1893) already calculated the beneficial effect of the ovally shaped pupil in Mysticetes and recently DAWSON, BIRNDORF and PEREZ (1972) defended on good grounds the same point of view for *Tursiops*. Doubtless, stenopeic vision is a serious candidate to solve the problems of astigmatism as well as powerful accommodation. There are complications, however, which we will discuss now in combination with a few unpublished findings.

*Discussion of recent literature and some unpublished observations*

In discussing the image-focusing in Cetacea, we will start

with considering the moderate type of accommodation. Because all relevant recent publications are concerned with *Tursiops truncatus* with the eye submerged, our discussion is restricted to this species, being in that situation.

Apart from the behavior of the animals, which strongly suggest the existence of such an accommodation, some evidence in support was reported by DRAL (1972) after ophthalmoscopical examination. DAWSON c.s. (1972) arrived by measurement and calculation at a refractive error of -5.1 D of the eye, after its internal muscles had been paralysed by cycloplegia. The authors assume that this error is easily corrected in eyes with normally functioning internal musculature. In fact, DRAL (1972) measured emmetropia in non-paralysed eyes.

We must, therefore, accept the existence of a moderate accommodation power in *Tursiops*. If we try to indicate the affecting mechnism, however, we are subject to speculation. Adjustment of the optical system of the eye requires a force, exerted on the lens, either to change its curvature or to displace it. In absence of ciliary muscles, the only muscles apt to do the job are located in the iris. The hypothesis that these muscles are indeed active in accommodation is not yet supported by solid evidence. On the other hand, available knowledge does not contradict the supposition. In the above mentioned experiments the cycloplegic agents, administered by DAWSON c.s., only paralysed the iridial muscles, as only these are present. A hypermetropia of 5.1 D was measured. During the measurements carried out by DRAL without use of cycloplegia, the pupil was fairly well dilated, showing the shape of a wide "U", but with the dorsal, opercular, part of the iris certainly remaining in contact with the lens. In this case emmetropia was found. Due to iridial action? Our limited knowledge makes us suppose so.

Also the results of a research on visual acuity under conditions of near darkness, recently carried out by HALL, HALL, CALDWELL and CALDWELL (1972), can be interpreted to fit in the above hypothesis. If accommodation is carried out by the iris operculum, no accommodation can take place if the operculum is fully raised, as will be the case in near darkness. The eye will be hypermetropic (DAWSON c.s.) or, to suppose the best, focused on a long distance. One might expect then that the visual acuity will improve with increasing distance between eye and target and that is exactly what resulted from the above mentioned research. Admittedly, this all is poor support,

but the fact that no more information is available may illustrate our lack of knowledge.

It seems to us that additional suggestions, favouring the iris as the accommodative mechanism, is met with in considering the facts and views on the powerful accommodation, needed in amphibious vision. In an earlier paper (DRAL, 1972) we gave the results of ophthalmoscopical measurements on *Tursiops*, which revealed that the eye is emmetropic in water as well as in air. That this dual emmetropia is restricted to a part of the visual field is irrelevant in this context. We observed emmetropia in air also in the eyes of *Stenella longirostris*, *Steno bredanensis* and *Delphinapterus leucas*. Though we did no measurements with the eye in water in these three species, it may be assumed that the eye is emmetropic also in that medium. Especially in *Stenella* and *Steno*, observed under the bright sun of Hawaii, the pupils were tightly constricted, the operculum completely expanded and reaching the opposite border of the iris, so that only two small, pin-hole like apertures were left at the nasal and temporal corners of the pupil respectively. An unexpected movability of the operculum in sideward directions was quite apparent in *Steno*, by which one of the apertures, either the nasal or the temporal one, could be closed. *Delphinapterus* was examined on a rainy day in the Duisburg Zoo. Also in this animal the operculum was lowered to a great extent: only a very narrow slit remained at the ventral part of the U-shaped pupil, at both sides widening to at most one millimeter. Sideward movements of the operculum were observed in this species too; their significance remains obscure.

In each of these three cases the stenopeic effect of the pupillary constriction must have been sufficient to render the eye emmetropic without any adjustment of the lens. Nevertheless we may doubt whether such an adjustment did not take place, based on the fact that, in contradiction with the reasonings of DAWSON c.s., the above mentioned emmetropia in air in *Tursiops* can not be explained by stenopeic vision. We carried out the observations on this species in the buildings of the Dolfinarium at Harderwijk, Netherlands. In air as well as in water the dolphin's pupil had the shape of a wide U, the operculum being not lowered further than halfway. Notwithstanding the fact that these conditions take stenopeic vision out of consideration, the above reported dual emmetropia was observed. We can not avoid the conclusion that, at least in this case, optical

adjustment had taken place.

Summarizing the above paragraphs, we may state that moderate and powerful accommodation is accomplished by adjustment of the refractive power of the eye in at least one odontocete species. With regard to the mechanism, affecting the adjustment, the iris is suspected, but evidence lacks.

While the recent efforts to clear the problems of accommodation in dolphins seem to have produced more questions than answers, the same is true with respect to astigmatism.

As described in a brief paper DRAL (1972) found by measuring the eye of *Tursiops truncatus* in axial direction an astigmatism of (roughly) about 15 D. Keratoscopy revealed a ratio between the horizontal and vertical radii of curvature of the cornea to be (roughly again) about two to one. No astigmatism was found in the nasal (or at least naso-ventral) quadrant of the eye, which, together with accommodation, contributes to the fact that the eye of *Tursiops*, at least in this direction, is emmetropic and free of image-distortion in water as well as in air.

We could observe such a teaspoon-like shape of the cornea also in *Stenella longirostris* and *Steno bredanensis*. Apparently an eye being astigmatic in axial direction and non-astigmatic in nasal or naso-ventral direction, is not exceptional in Odontocetes. That it is not a general rule is illustrated by *Delphinapterus leucas*. In this species the non-astigmatic nasal part of the cornea appeared to be quite more extensive; in fact, as far as could be observed with Placido's keratoscope, astigmatism was apparent on the temporal side of the cornea only. By regarding the behavior of animals of this species in the Duisburg Zoo the impression was readily gained that they have a good vision in air in a very wide field. It could be ascertained that this species is able to look upward, to locations above the head, which is not the case in *Tursiops*.

Also DAWSON c.s. (1972) made observations on the corneal curvature of *Tursiops truncatus*. Surprisingly, these authors found no astigmatism in this species, though they worked (as confirmed by correspondence) with instruments by which an astigmatic error of $\pm$ 0.1 D can be resolved. Moreover, the fundus-photograph, published by these authors, shows no sign

of astigmatic distortion. There is no reason whatsoever to distrust their observations. It is admitted that the measurements by DRAL were crude and the value of ca 15 D mentioned by him (and measured on one animal, viz. Kiana) may be several diopters outside the truth. That it should be reduced to zero, however, is highly improbable. We repeated our observation by simple keratoscopy with another animal (Yogi), and found again that the animal's eyes are highly astigmatic in axial direction.
Thus we are confronted with contradictory results, obtained in one and the same odontocete species. And there is no hint to help us make a choice.

*A proposal for coordinated research*

As discussed before, the shape of the cornea plays an important role in vision in air - at least in those cases where stenopeic vision can be ruled out. The value of the visual sense for dolphins is recognized nowadays, so we should recognize the value of a correct knowledge of its details either. It is clear then that the subject of astigmatism is worth more study. In view of the available data we must face the possibility that both types of eyes, non-astigmatic as well as highly astigmatic, find their representatives in *Tursiops*. This sounds admittedly as an improbability, but, forced by the facts, we should find out its merits. To this end studies should be done on a great number of animals, comprising several populations. In the first instance only a distinction needs to be made between non-astigmatic and highly astigmatic corneae; an eventual slight astigmatism is of no interest in this connection. These extremes are easily distinguishable, without special skill or instruments, so that any trainer, veterinarian or other person who has access to dolphins, can do the observation without much trouble. One should regard the image of a regularly shaped object (a round saucer for instance) or of a familiar object (one's own face or hand), being reflected by the cornea. As long as the image seems natural and undistorted, the cornea can be considered to be free of astigmatism. As soon as distortion takes place (a circle becoming oval f.i.), astigmatism is present. An idea about the images to be expected can be obtained by looking into the eyes of a fellow-man (non-astigmatic) and at the backside of a shining spoon (astigmatic). Everybody who has the opportunity to do these simple observations on any individual of any Cetacean species is invited

to let us know his findings. We will be glad to compile them.

At the end of this discussion of some problems in cetacean vision we must conclude that progress has been gained, with the result that we seem to be farther away from the solution than has been ever imagined before. This is a challenge for further research.

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