side. Since sexual activity was at a peak during this period little was thought about these „scratches" until the lesions became more open instead of healing in the normal manner of such a wound. Samples were also taken from Mama's lesions, but no chains of globose cells were found in nor were any organisms isolated from this material.

Acknowledgement

The authors are grateful to Dr. W. H. Dudok van Heel and his staff at the Dolfinarium Harderwijk, for their kind cooperation in observations, case-histories and collecting samples.

References

MIGAKI, G., M. G. VALERIO, B. IRVINE and F. M. GARNER, 1971. Lobo's disease in an Atlantic Bottle-nosed Dolphin. J. Am. Vet. Med. Ass. 159, 5: pp. 578-582.

VRIES, G. A. DE and J. J. LAARMAN, 1973. A case of Lobo's disease in the dolphin *Sotalia guianensis.* J. Aq. Ma. 1(3): pp. 1–8.

WOODARD, J. C., 1972. Electron Microscopic study of Lobomycosis *(Loboa loboi).* Laboratory Investigation 27, 6: pp. 606-612.

– – –

UNDERWATER VISUAL ACUITY IN THE BOTTLE-NOSED DOLPHIN

Tursiops truncatus (Mont.)

by Noordenbos, J. W. and C. J. Boogh, Laboratory of Comparative Physiology, State University of Utrecht, Netherlands.

Summary

A female bottle-nosed dolphin *(Tursiops truncatus)* was trained to select a grating pattern, which consisted of black and white lines of equal width, over a flat gray pattern. Its performance was measured aqainst the line width of the grating. From the 75% performance level a minimum angle of resolution was computed of 27 minutes of arc at a viewing distance of 1 meter and of 26 minutes at 4 meters. Artificial light was used for illumination, which was 400 lux, measured in the horizontal direction. The experiment was carried out under water.

Introduction

When observing dolphins in captivity, it seems very unlikely that they use only their sonarsystem for orientation. In order to jump through a hoop, to take fish out of the hands of a trainer etc. an acute visual sense seems necessary. Underwater a blindfolded animal is obviously handicapped when for instance it has to retrieve objects thrown into the water.

WALLS (1963) stated that the dolphin eye is predominantly an „underwater eye". This because of the ball-shaped lens, the slightly ventral direction of the eye-axis, the relative thick cornea and the absence of lachrymal glands. This is fortified by opthalmoscopic measurements. The eye of *Tursiops truncatus* is underwater either emmetropic (DRAL, 1972) or slightly hypermetropic (DAWSON c.s., 1972), but in air the eye appears to be strongly myopic and astigmatic when observed in the traditional way. However DRAL (1972) showed that part of the eye when looking from the beak is emmetropic in air. Under strong light conditions the eye may form an image by means of a stenopaic aperture (WALLS, 1963; DAWSON c.s., 1972).

Several experiments have been carried out on the visual acuity of dolphins. SPONG and WHITE (1971) tested visual acuity of a killer whale *(Orcinus orca)* and a white side dolphin *(Lagenorhynchus obliquidens)* and determined respectively 5.5 and 6 minutes of arc. These results were probably optimisticly biased due to the nature of the test objects. The two-line versus one-line discrimination test which was used, also provides a brightness discrimination (RIGGS, 1965).
HALL c.s. (1972) tested visual acuity of a bottle-nosed dolphin *(Tursiops truncatus)* with a checkerboard pattern projected on a screen behind a window at the side of the tank. The best resolution found was 42 minutes of arc, but under non-optimal light conditions.
PEPPER c.s. (1972) measured in air visual acuity of a bottle-nosed dolphin *(Tursiops truncatus)* in daylight and found a minimum angle of resolution of 18 minutes of arc.

In the experiment reported in this paper under water visual acuity has been measured of *Tursiops truncatus.*

Methods

In this experiment two bottle-nosed dolphins were used, a male Yogi and a female Sherry, both 3 years old. The male dolphin only completed the training phase because of health problems. The animals were fed with 4 Kg of mackerel *(Scombrus scombrus)* and 1 Kg of herring *(Clupea harengus)* a day. Half of it was cut into pieces and used as food reinforcements. The other half of the daily ration was given as whole fish at the end of the day.

The experiment was carried out in the service section of the Dolfinarium Harderwijk, Holland (DUDOK VAN HEEL, 1970). The tank used measured 12 x 6 m with a depth of 2,5 m (Fig. 1). The channels leading to the other pens were closed with doors or gates during testing. At one end of the tank a 1.50 m high bulkhead was placed, which extended maximally 50 cm over the water (Fig. 2.) It had a dual function: behind it the experimentater could change targets unseen by the animal and, secondly, the construction, by which the target-holders could be lowered into, and

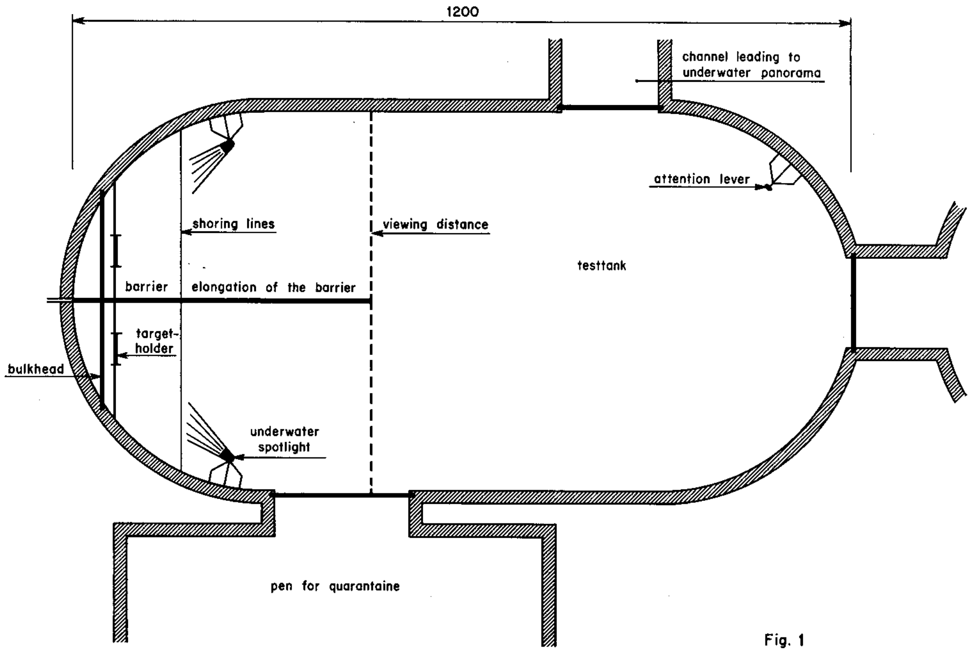


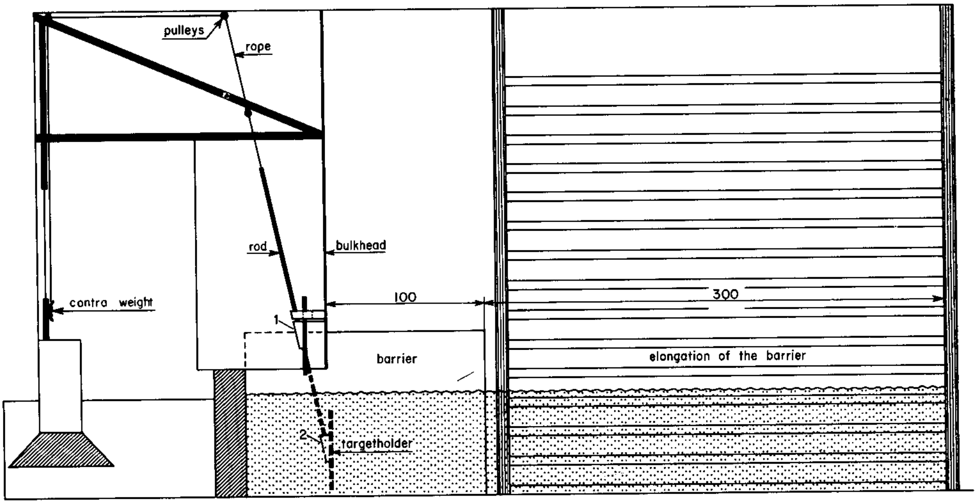
Fig. 1

respectively out of the water, was fixed to it. In the lower position the target-holders were completely under water and exactly in the plane of the bulkhead. The animal could make a response by pushing its rostrum against the edge of the target-holder. In the upper position the target-holder disappeared completely behind the bulkhead and the experimentater could change targets. The target-holders were constructed of 3 mm plywood and could contain a 40 x 40 cm stimulus card made of plexiglass (Fig. 3). The two target-holders were separated by a plywood barrier (305 x 150 cm). It extended 1 m in front of bulkhead and targets. In the last test series the barrier was extended up to 4 metres by an aluminium fence with horizontal bars.

The animals had to make a choice between a variable and a standard stimulus or target, which were presented simultaneously. The standard target consisted of a black and white grating of 26 lines per cm. At one meter distance the lines of this grating could not be resolved by a human observer. Several standard gratings were used in a random order. The variable targets consisted of gratings with line widths varying between 45 mm to 4.3 mm.

In order to prevent discrimination by sonar all gratings were reproduced on photografic paper (30 x 40 cm) and laminated between two layers of 3 mm plexiglass (40 x 50 cm). When placed in the target-holders the edges of the gratings were covered by the frontplate of the target-holder. The stimulus presented to the animals was thus a grating measuring 33 x 27 cm surrounded by a plywood border of 10 cm. The lines of the grating were oriented vertically. The variable targets and the standard targets had the same brightness. At a distance where the lines could not be resolved, standard and variable targets were indistinguishable for human observers.

Side view of experimental set'up



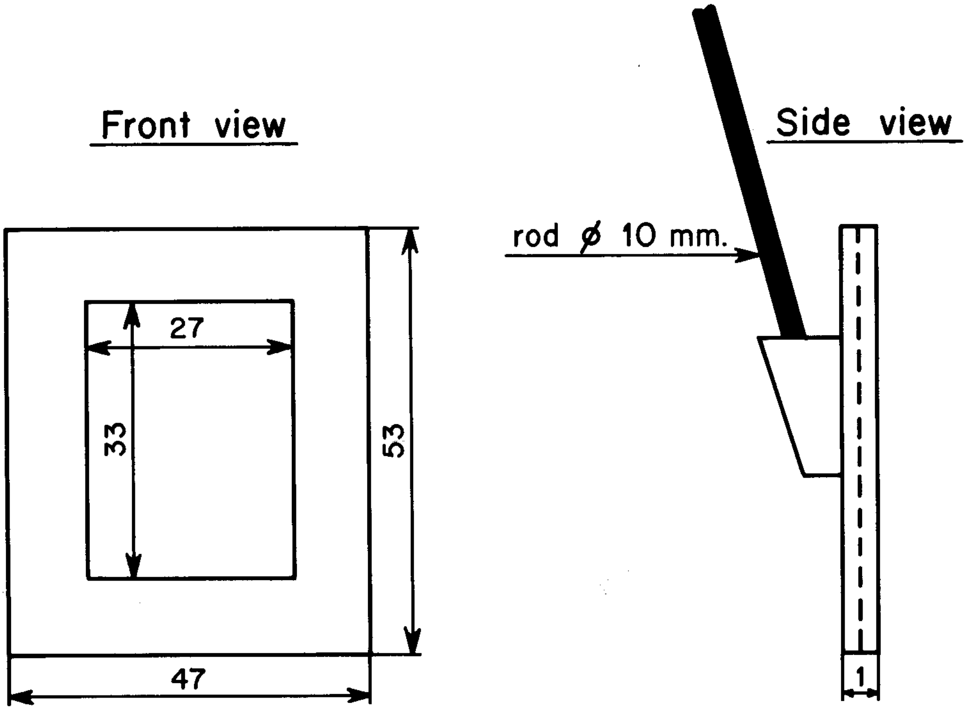
1 targetholder in upper position
2 targetholder in lower position

Fig. 2

During training and test I indoor illumination by fluorescent lamps was used. In test II and test III four 1000 watt iodine floodlights were added. These were mounted on the ceiling, 3 metres above the tank. Two 24 volt underwater spotlights were fixed at the sides of the tank shining directly at the targets to increase contrast between the lines of the grating. Underwater, measured in the horizontal plane, the illumination was 50 lux in test I and 400 lux in test II and III. Water conditions were such, that the lines of the larger gratings could be resolved by a swimmer with goggles over a distance of more than 18 metres.

On the other side of the tank an attention lever was mounted. After the animal pressed this lever both targets were lowered into the water. The animal had to swim directly to the variable target and press its rostrum against the edge of the target-holder. Correct procedure was immediately reinforced by a whistle and followed by a piece of mackerel. Passing the barrier on the wrong side or passing the barrier on the right side but not indicating a choice was cosidered an error and therefore not reinforced. After a trial was completed the target-holders were pulled up behind the bulkhead and new targets were installed for the next presentation.

During the tests two persons were present. One sitting on the side of the tank in line with the end of the barrier. He observed whether or not the animal actually passed the barrier, and he delivered the food reward. The other person changed targets and indicated by means of a whistle when the animal had made a correct response.



Targetholder

Fig. 3

Standard and variable targets were randomly changed with the restriction that a target never remained more than three times at the same side to reduce side preference. After every test the targets were removed from the holders and replaced whether they changed places or not. In this way the animal was unable to receive a clue for the discrimination between the targets other than by vision.

Results

Stimulus control was obtained by means of a brightness discrimination task. A small light was paired with the variable target and a black instead of a gray stimulus was presented as a standard target. After 700 trials (= two weeks) 100% stimulus control was obtained over this brightness cue.

Gradually the brightness discrimination was transformed into form pattern discrimination. The light behind the variable target was dimmed and the standard target was changed in several steps into gray of equal brightness as the variable target. With a variable target with lines of 12.5 mm wide stimulus control was lost every time when brightness of standard and target had reached equality. It was concluded that both animals were trained on a brightness difference only.

With a new target with lines 33.3 mm wide stimulus control could be retained. As control the variable target was paired with standard targets with gray values varying from white to black. A level of more than 90% could be retained for all these targets. At this stage we had to abandon training with Yogi, the male dolphin, because of problems with his health.

To approximate visual acuity a modified method of limits was used. After 3 correct responses a more difficult target was presented and after 1 incorrect response a more easy one. After 500 trials the threshold was bracketed between 25 and 45 minutes of arc. The behaviour of Sherry gradually improved during this test. The swimming speed was very much reduced and without leading additional extra obstacles at the sides of the tank the targets were approached along the midline of the tank. One very characteristic point was that when she made her choice, she accelerated to the target of her choice. For easy targets this happened some distance before the barrier, for the more difficult ones this choice was postponed as long as possible. She often reversed with her front flippers to change side at the very last moment.

However, the animal was quickly upset after one or several errors, that is after not getting her reward. Instead of approaching the targets cautiously, the animal rushed through the tank. This increased the chance of another mistake as she often passed the barrier inadvertently. Whenever this behaviour persisted the session was ended and not counted in the score. A „time-out" period had an even stronger upsetting effect, and herefore it was not used as a negative reinforcer.

With the method of constant stimuli three series of tests were made. Each day 4 sessions of 30 trials were held. Each session started with 5 „warming-up" trials of superthreshold stimuli. This was followed up by 25 trials of stimuli above or below the expected threshold. At least 3 different variable targets were used, which were used, which were presented in a random order. To avoid behaviour problems as mentioned above a bias was made towards the easier targets.

The results of three tests are plotted in Fig. 4. The 75% level was used as threshold criterion. The minimum angles of resolution thus found are:

illumination	50 lux	400 lux	400 lux
viewing distance	1 meter	1 meter	4 meters
minimum angle of resolution	34'	28'	26'

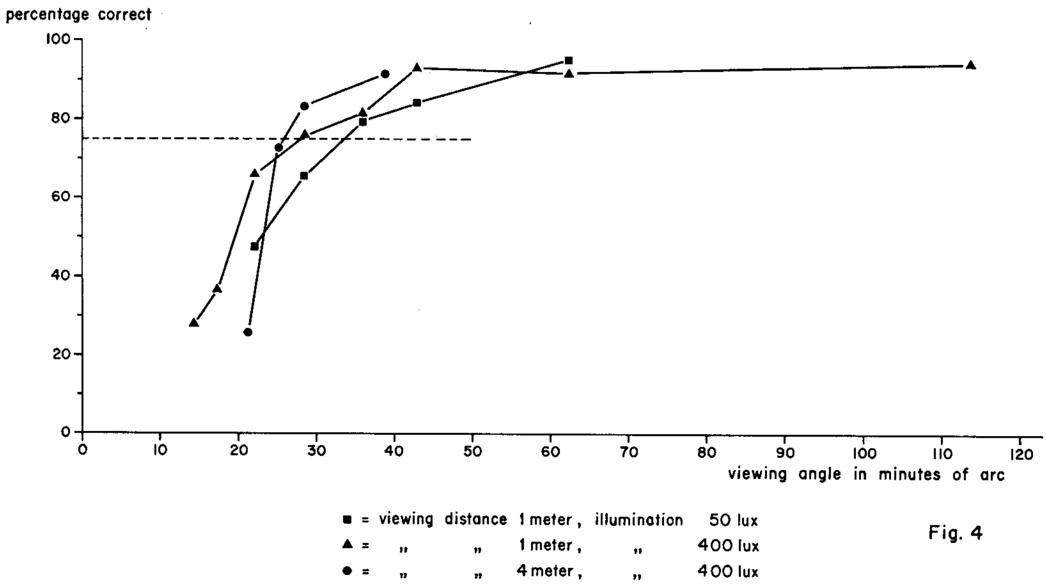


Fig. 4

Statistically no difference could be found between any of the standard targets. In test I no preference for one of the sides was found. The animal showed a light tendency for the right side in test II and for the left side in test III, in both cases only for sub-threshold targets. The indication of the viewing distance was poor because it was only indicated by the end of the barrier and the shoring lines 20 cm above the water. In test III the barrier was not only extended to 4 meters, but the viewing distance was also better indicated by a line with floats and a steel bar, both across the tank (Fig. 1). This resulted in a much steeper response curve. However, a marked difference in visual acuity was not found between tests II and III.

Discussion

Visual acuity found in this experiment was far lower than expected. On basis of the ganglion-sensecel ratio PEREZ c.s. (1972) predicted a visual acuity of 6 minutes of arc in the bottle-nosed dolphin. DRAL (1975) supposed on an anatomical basis a value of 10 minutes.

Although an improvement on the results of HALL c.s. (1972) was found (40') visual acuity was less than found by PEPPER c.s. (1972) in air. Recently PEACOCK c.s. (1974) measured visal acuity in-air and in-water using the same animal as PEPPER c.s. In daylight conditions he found in water an acuity of about 8' at a viewing distance of 1 meter decreasing to about 12 minutes at 2.5 meter. In air the acuity was about 17 minutes at 1 meter and increased to 12 minutes at 2.5 meter.

As our results differ significantly from what was expected and from what was found by other authors some possible reasons for this difference will be discussed.

The set-up we used was more or less similar to that which BALLIET & SCHUSTERMAN (1971) and SCHUSTERMAN (1972) used for testing visual acuity with otters and several kinds of Pinnipedia. The disadvantage of this set-up is laying in the fact that the animal had not only to respond to the variable target, but also was obliged to pass the barrier at the correct side. Even with easy targets the animal sometimes passed the barrier inadvertently at the wrong side, resulting in a score of less than 100%. With difficult targets the animal often changed its mind and turned to the other side after it had passed the end of the barrier. This increased the chance of making an error. In many cases the animal could have made a correct response if it had proceded up to the target. This behaviour caused a less than 50% score (chance level) for the most difficult targets. Therefore the 75% threshold criterion is perhaps too pessimistic with consequently a somewhat too low estimation of the acuity threshold.

With several species of animals visual acuity has been measured as function of (il)-luminance, such as the Indian elephant, *Elephan indicus* (ALTEVOGT, 1955) the Californian sealion, *Zalophus californianus* (SCHUSTERMAN, 1972), and the dog, *Canis familiaris* (NEUHAUS & REGENFUSS, 1976). Like the bottle-nosed dolphin, *Tursiops truncatus* (DRAL, pers. comm.), these animals had retinas with predominantly rod elements. In all these species maximal visual acuity had been reached at lower than the 300 lux level. The response curve of test II shows a slight overall improvement of that of test I. This can be a risult of improved light conditions. More likely it is due to the improved contrast between the black and white lines of the grating, as a result of the spotlights. We therefore conclude that the light conditions as such were not a limiting factor.

If the eye is not in focus, pupil size and hence illumination may have been of influence. Dolphins lack ciliary musclus (DRAL, 1972). Although accommodation by an other mechanism is supposed by him, it is in our opinion very likely that it fails altogether. In such a case the range of distances in which acute vision is possible depends on the size of the pupil. With low luminances, where the pupil is completely dilated, depth of field is very small. In these circumstances HALL c.s. (1972) found a visual acuity of 80 minutes at viewing distances of 46 and 98 cm, which increased to 42 minutes at a viewing distance of 198 cm. The only light source was of the projection of a slide on a screen. In these conditions human vision at least is not seriously affected and it is likely that dioptrical and not retinal factors are the cause of these large angles.

In daylight conditions, in which the pupil is contracted to a narrow slit, depth of field is such that without an accommodation mechanism acute vision is possible in air and in water (stenopaic vision). This is confirmed by an experiment in the sealion, *Zalophus californianus*,SCHUSTERMAN (1972) found that at high luminances in air and in water visual acuities were equal. In decreased luminance in air vision was much affected, but in water vision only very slightly. PEACOCK c.s. (1974) worked outdoors in bright daylight. They found equal visual acuities in air and in water both measured at 2.5 metres distance. Visual acuity, however, was not independant of viewing distance, as is to be expected with a great depth of field and/or an accommodation mechanism. Visual acuity increased in air and decreased in water as the viewing distance increased.

During our experiment the pupil of Sherry was more than half open. It had the shape of a crescent moon. No difference in acuity was found between viewing distances of 1 m and 4 m. Lack of time prevented us to test other distances in order to find a possible optimum. The data of HALL c.s. (1972) and PEACOCK c.s. (1974) both indicate a non-accommodative eye but contradict each other with respect to which distance-the eye is focussed. Is the dolphin eye underwater focussed at infinity or at close distance?

Assuming the eye being not in focus, a slight improvement might be found if the lines of the grating were presented in a horizontal position, as lines paralel to a slit pupil give a better resolution than perpendicular lines. The aperture of the pupil of Sherry was in vertical direction smaller than in horizontal.

Summarizing we conclude that the experimental circumstances and the methods used may have had some negative effects on the results. However the great difference with the results of PEACOCK c.s. (1974) cannot be explained. Our results point to a poor visual acuity under conditions where the eye of dolphins is most likely to function. Those conditions are under water, in relatively dimmed light (transmittance of 10 metres seawater is less than 20%, JERLOV, 1973), at moderated distances (water clarity often restricts vision to no more than 10 metres). Further research is needed to learn how important the visual system can be for dolphins.

Acknowledgements

The authors are indebted to the Dolfinarium, Harderwijk, especially to Dr. W. H. Dudok van Heel for the animals and the facilities put at our disposal. We thank Mr. A. D. G. Dral for his critical reading of the manuscript and his continuous interest during our work.

References

ALTEVOGT, R., 1955. Das visuelle minimum Separabile eines Indische Elefanten. Z.vergl. Physiol. 37: pp. 325–337.

BALLIET, R. F. and R. J. SCHUSTERMAN, 1971. Underwater and Aerial Visual Acuity in the Asian „Clawless" Otter *(Amblonyx cineria)*. Nature 234: pp. 305-306.

BRUNNER, G., 1934. Uber die Sehschärfe der Elritze *(Phoxinus laevis)* bei verschiedenen Helligkeiten. Z.vergl. Physiol. 21: pp. 296–315.

DAWSON, W. W., L. A. BIRNDORF and J. M. PEREZ, 1972. Gross anatomy and optics of the dolphin eye *(Tursiops truncatus)*. Cetology 10: pp. 1–12.

DRAL, A. D. G., 1972. Aquatic and Aerial Vision in the bottle-nosed dolphin. Neth. J. Sea Res., 5 (4): pp. 510–513.

DRAL, A. D. G. and W. H. DUDOK VAN HEEL, 1974. Problems in imagefocusing and astigmatism in Cetacea – A state of affairs –. J. Aq. Ma. 2 (1) pp. 22–28.

DRAL, A. D. G., 1974. Some quantitative aspects of the retina of *Tursiops truncatus.* J. Aq. Ma., 2 (2): pp. 28–31.

DUDOK VAN HEEL, W. H., 1970. The Dolfinarium at Harderwijk. Int. Zool. Yearb., 10: pp. 49–51.

HALL, N. R., H. I. HALL, M. C. CALDWELL and D. K. CALDWELL, 1972. Visual acuity under conditions of near darkness and discrimination learning in the Atlantic bottle-nosed dolphin *(Tursiops truncatus).* Cetology, 12: pp. 1–7.

JERLOV, N. G., 1973. General aspects of underwater daylight and definitions of fundamental concepts. In O. KINNE (Edt.): Marine Ecology, Vol. 1. London, New York. Wiley Interscience.

NEUHAUS, W. und E. REGENFUSS, 1967. Ueber die Sehschärfe des Haushundes bei verschiedenen Helligkeiten. Z. vergl. Physiol., 57: pp. 137–146.

PEACOCK, M. F., M. P. YUNKER, C. J. MADSEN and L. M. HERMAN, April 1974. In-air and in-water visual acuity in the bottle-nosed dolphin. Paper presented before the Western Psychological Association, San Francisco.

PEPPER, R. L., J. V. SIMMONS Jr., F. A. BEACH and P. E. NACHTIGALL. In-air visual acuity of the bottle-nosed dolphin. Proc. Ninth Ann. Conf. Biol. Sonar and Diving Mammals.

PEREZ, J. M., W. W. DAWSON and D. LANDAU, 1972. Retinal Anatomy of the bottle-nosed dolphin *(Tursiops truncatus).* Cetology, 11: pp. 1–11.

RIGGS, L. A., 1965. Visual acuity. In C. GRAHAM (Ed.): Vision and visual perception. New York, J. Wiley and Sons, Inc: pp. 321–349.

SCHUSTERMAN, R. J., 1972. Visual acuity in Pinnipeds. In H. E. WINN (Ed.): Behaviour of marine animals, Vol. 2. New York, London. Plenum Press.

SPONG, P. and D. WHITE, 1972. Visual acuity and discrimination learning in the dolphin *(Lagenorhynchus obliquidens).* Experimental Neurology, 31: pp. 431-436.

WALLS, G. L., 1963. The vertebrate eye. New York, Hafner Publishing Co.

WHITE, N. CAMERON, P. SPONG and J. BRADFORD, 1971. Visual acuity of the killer whale *(Orcinus orca).* Experimental Neurology, 32: pp. 230–236.