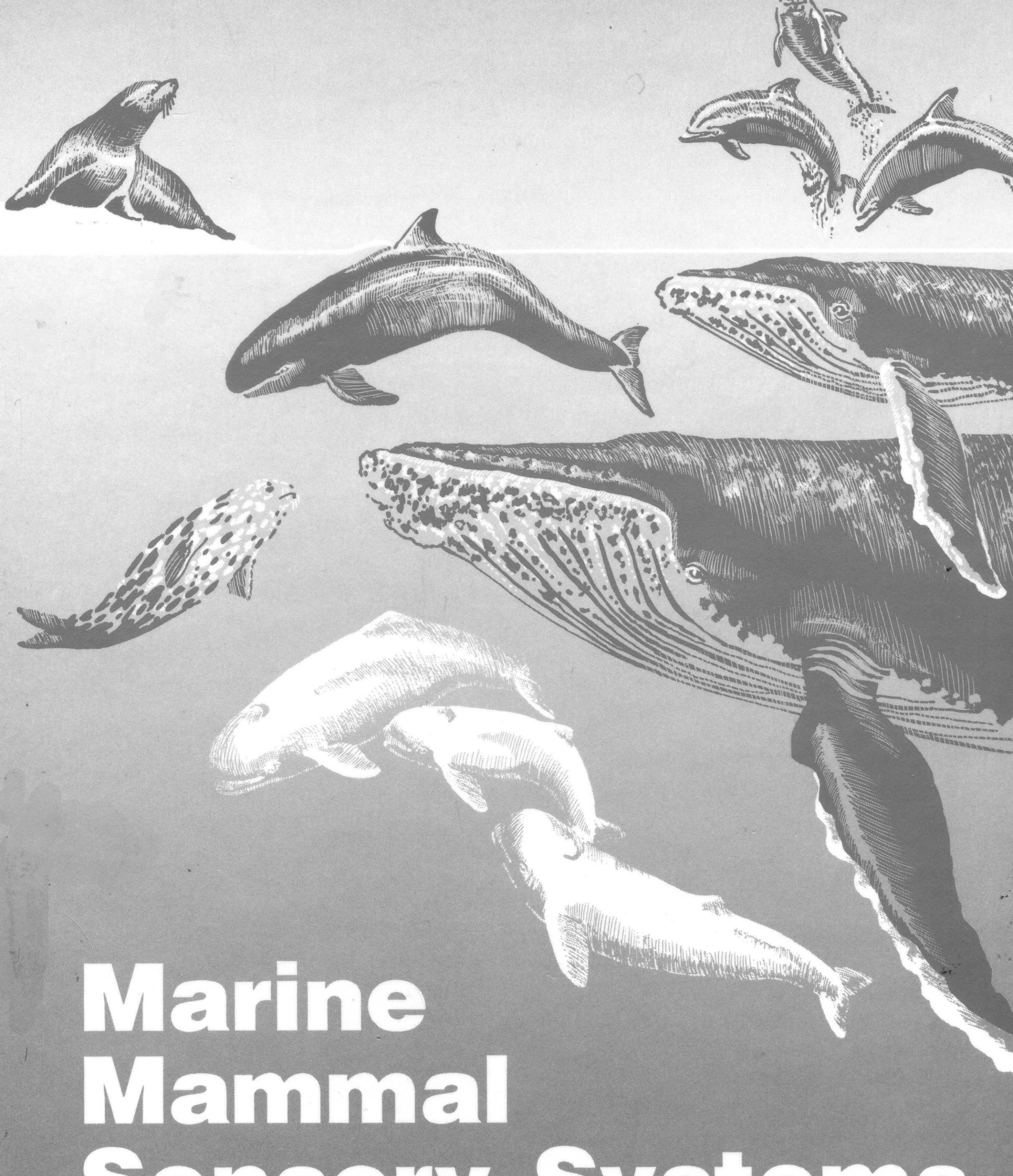

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DISCRIMINATION OF SPHERICAL TARGETS BY A BOTTLENOSE DOLPHIN (TURSIOPS TRUNCATUS) IN THE PRESENCE OF INTERFERING CYLINDERS

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INTRODUCTION

We found earlier that the bottlenose dolphin is able to discriminate targets falling close together at the angle far less than the width of their transmission beam pattern (Zaslavsky, 1983). It was found that the angular separation threshold between targets varied from 0.4 to 1.5^{o}, depending on target parameters, whereas a 3-dB beam width was 6 to 10^{o}. Distribution of the acoustic field in the plane of the targets indicated that the dolphin orients the beam axis apart from the targets. As a result, targets were at different levels along the beam rim pattern, as Figure 1 shows. In such a way the dolphin might achieve the most different echoes intensity from targets. Following-up on earlier work we studied target discrimination in reverberation by an echolocating dolphin.

PROCEDURES

The experiment was conducted with an adult female Tursiops truncatus in a concrete pool of 20 x 13 x 3 m. The dolphin was trained to stay on a start position and to echolocate the targets which were placed at each side of a separating net (Fig. 2). Upon the activation of a tone cue, the dolphin commenced echolocation for determining the position of on of the targets.

The dolphin's position, both in vertical and horizontal planes, was recorded by above-water and underwater cameras. Five hydrophones in a horizontal array were aligned with the targets, 60 cm behind them. The hydrophones had a flat frequency response ($\pm$3 dB) up to 170 kHz (Bezrukov et al., 1973). The hydrophones were connected to a five-channel oscilloscope for recording echolocation signals simultaneously with the dolphin's position.

Brass spheres of 3 and 5 cm diameter were used as targets. Unwanted echoes were induced by adding nearby steel cylinders. By changing the diameter of the cylinders, the energy in the unwanted echoes were varied under our control. Target and

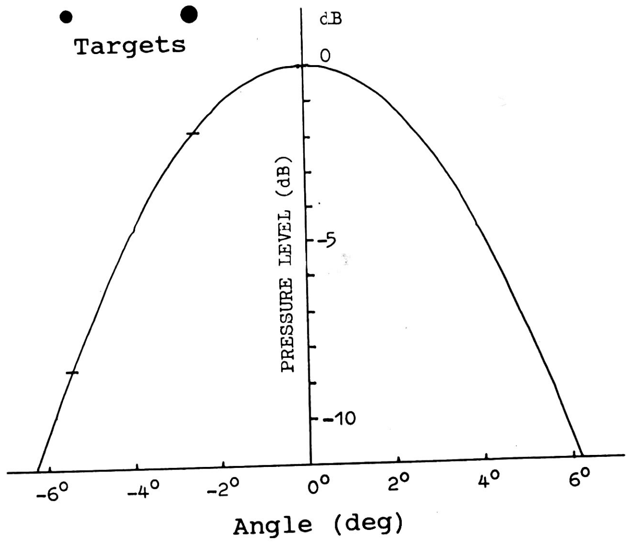

Fig. 1. Example of orientation of the dolphin's horizontal beam pattern relative to the targets.

cylinder depth was 1 m and distance from the start position was 7.5 m. Two spherical targets as well as two interfering cylinders were placed symmetrically to the net (Fig. 2).

RESULTS

With the spherical targets located at azimuths of ± 0.35° or ± 1.4° relative to the separative net, the discrimination accuracy was found to decrease as the angular deviation of the cylinders increasing up to ± 4° to ± 5° (Fig. 3). The decrease of the correct discrimination level to 50% was observed when the cylinders were placed in the vicinity of the acoustic axis of the transmission beam of the dolphin. This result is a direct consequence of the dolphin's using the steep rims of the beampattern for angular resolution of the targets.

It should be emphasized that the angular resolution of the spherical targets and the cylinders by the echolocation system of a dolphin can be explained merely by the directivity of the radiation of an echolocating click without consideration of binaural hearing.

The results of another behavioral experiment also is out of line with well-known models of binaural hearing. We supposed that the extra third cylinder installed between the targets (as shown at the top of Fig. 3) would interfere even more with the discrimination of the targets. However, the central cylinder did not increase the difficulty to discriminate the targets, and even reduced the masking effect of the lateral cylinders. In presence of the central cylinder of 6 cm diameter and 15.0 cm length, the threshold angle between cylinders of the same diameter decreased from 12 to 8°. The insertion of the central cylinder proved to be equivalent decreasing the diameter of the lateral cylinders from 6 to 0.6 cm and length from 13 to 6 cm.

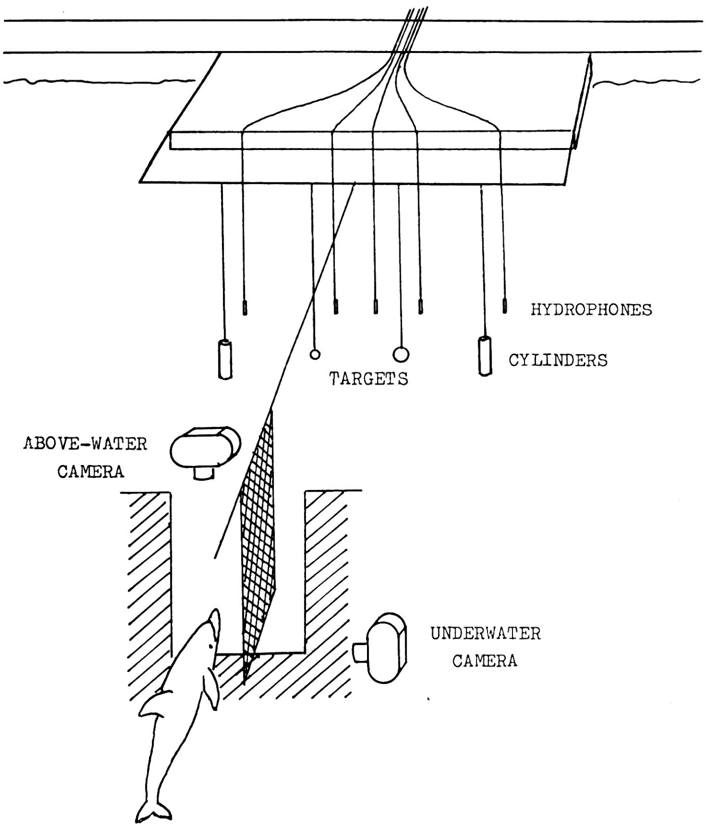

Fig. 2. Diagram of the experimental configuration showing the dolphin in the start position, the separating net and arrangement of spherical targets and interfering cylinders.

Animal's performance varied from 100% to 50% correct response as the diameter of the central cylinder decreased from 6 to 1 cm. Correct discrimination also fell to 50% after the central cylinder was shifted forwards or backwards more than 8 cm from the plane of the targets. Path distance between the central and lateral cylinders in this case was too different to cause echo interference.

A similar effect of the breakdown of the masking effect took place in the case of greater angles between the targets: 12.6°. Four cylinders placed at each side of the spherical targets did not prevent the dolphin from discriminating spheres. At the same time, the correct discrimination value fell to 50% without the central cylinders.

DISCUSSION

It may be assumed that the dolphin uses destructive interference of echoes from the central and one lateral cylinder surrounding the spherical targets to decrease masking. In presence of the three cylinders, the dolphin was observed to

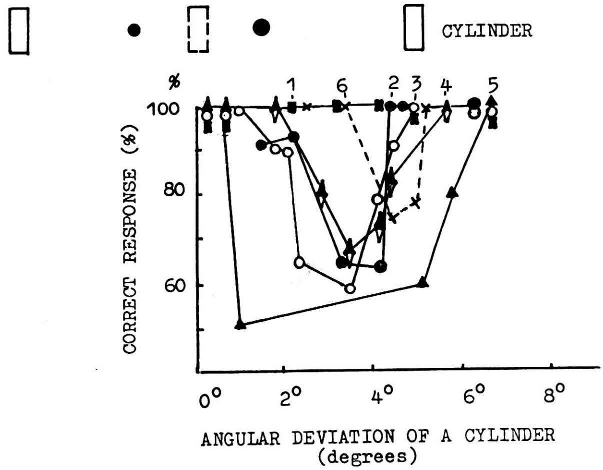

Fig. 3. Dolphin's performance as a function of the angular deviation of cylinders relative to the separating net, without the extra third (central) cylinder. Diameters of the cylinders: 1 and 6 - 0.15; 2 - 0.25; 3 - 0.6; 4 - 1.0; and 5 - 6.0 cm. Spherical targets are placed at angles: 1 to 5: $\pm 1.4^{\circ}$; 6: $\pm 0.35^{\circ}$. The scheme above the curves shows the arrangement of the targets (solid circles), the central and lateral cylinders.

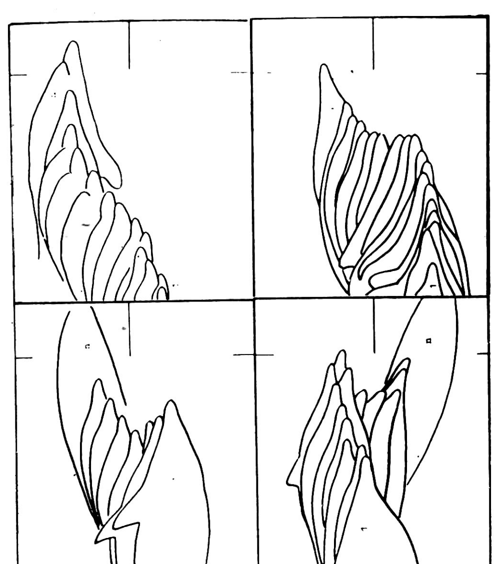

Fig. 4. Four examples of the dolphin's movements on the start position while examining targets with echolocation.

migrate, as a rule, slowly at the start position apparently for a searching a point where the cylinder's echoes largely suppress one another (Fig. 4). Searching for such a point seems to be a hard task for the dolphin because trial times increased from a few seconds without the central cylinder to up to 30 to 40 s with a central cylinder.

When the sound from a certain direction is followed by a similar sound from another direction, a human listener hears only one sound (Blauert, 1969/70). For time-delays smaller than 600 μs this sound sensation occurs in the direction determined by the kind of signal, the direction of incidence of primary sound and reflection, the intensity difference, and the difference in their arrival times. This effect is known as "summing localization". If the law of "summing localization" is valid for the dolphin hearing, two echoes from the cylinders at each side of the target would produce only one "phantom" echo in the direction of the target. This phantom echo source would mask the target stronger than the echo of the lateral cylinder alone.

Thus, the results of the experiments raise doubts about applicability of the conventional theories of the binaural hearing to the dolphin's echolocation system.

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