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Auditory Thresholds of a Killer Whale *Orcinus orca* Linnaeus

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Using standard operant conditioning techniques, a killer whale, *Orcinus orca* Linnaeus, was trained to respond to pure-tone auditory signals by pushing a response manipulandum. An audiogram was obtained for frequencies between 500 Hz and 31 kHz. Greatest sensitivity to the signal was observed at 15 kHz at a level of -70 ± 5 dB *re* 1 dyn/cm². The observed upper limit of hearing was 32 kHz. At no time during training or testing did the animal respond to an undistorted signal above 32 kHz. Frequencies below 500 Hz were not tested, owing to high ambient tank noise levels.

INTRODUCTION

During the last 20 years, several investigators have studied the hearing capability of certain of the odontocete cetaceans. Kellogg and Kohler (1952), Kellogg (1953), and Schevill and Lawrence (1953) studied hearing in the Atlantic bottlenose dolphin, *Tursiops truncatus* Montagu, prior to the more quantitative work done by Johnson (1966). Johnson found *Tursiops truncatus* capable of hearing tones between 75 Hz and 150 kHz. Belkovich and Solntseva (1970) reported that the common dolphin, *Delphinus delphis* Linnaeus, has a hearing capability between 18 Hz and 280 kHz, while Andersen (1970) found the harbour porpoise, *Phocoena phocoena*, capable of hearing tones from 1 to 150 kHz.

The purpose of the study described below was to determine the pure-tone detection thresholds of a killer whale, *Orcinus orca* Linnaeus, over a large portion of its range of hearing.

I. METHODS AND PROCEDURE

This study was conducted at Sea World Inc. oceanarium in San Diego, California, between 1 November 1969 and 1 June 1970. A subadult male killer whale, 5 m long and weighing 1820 kg, and a circular concrete tank, 13 m in diameter and 2.5 m in depth, were leased from Sea World for use during the study. The whale had been in captivity for 3 years and had been used as a show animal. During training and testing he was fed 55 kg/day jack mackerel (*Trachurus symmetricus*) and 2 kg/day Pacific bonita (*Sarda chilensis*).

All data were collected using the up–down or staircase method of psychophysics used by Tavolga and Wodinsky (1963) and Johnson (1966). Data sessions lasted from 45 to 90 min, depending on the whale's behavior and the number of no-tone trials (catch trials) used. These sessions were concluded when the whale had indicated that he was unable to hear the auditory stimulus six to eight times. The sum of the attenuation settings was determined and a raw data mean was calculated. The electronics used to project and monitor the auditory signal are shown in Fig. 1.

Data were taken for thresholds between 7 and 31 kHz using the Atlantic Research LC-10 projector. Thresholds between 500 Hz and 7 kHz were tested using the pioneer UL-3 projector, and then repeated for frequencies between 7 and 31 kHz with the Pioneer UL-3. By using two different projectors, we were able to obtain comparative data for thresholds taken at the same frequency.

The sound-pressure levels (SPLs) produced by the LC-10 and UL-3 at the anterior tip of the animal's rostrum were measured using a U. S. NOTS sound measuring set and a Hewlett–Packard model 310A wave analyzer.

The ambient noise levels in the tank were measured using the Naval Ordnance Test Station sound measuring set and the H-P 310A wave analyzer. We measured the noise level by removing the whale from the tank, shutting off all water supply, and allowing the water level to stabilize to the overflow level.

Once we had stabilized the tank to normal auditory test conditions, the noise measuring hydrophone (CH-26B) was lowered into the tank to various depths at several locations around the perimeter of the tank and also at the center of the tank.

Each trial began with the whale at the feeding station, watching the trainer in the equipment hut. The trial

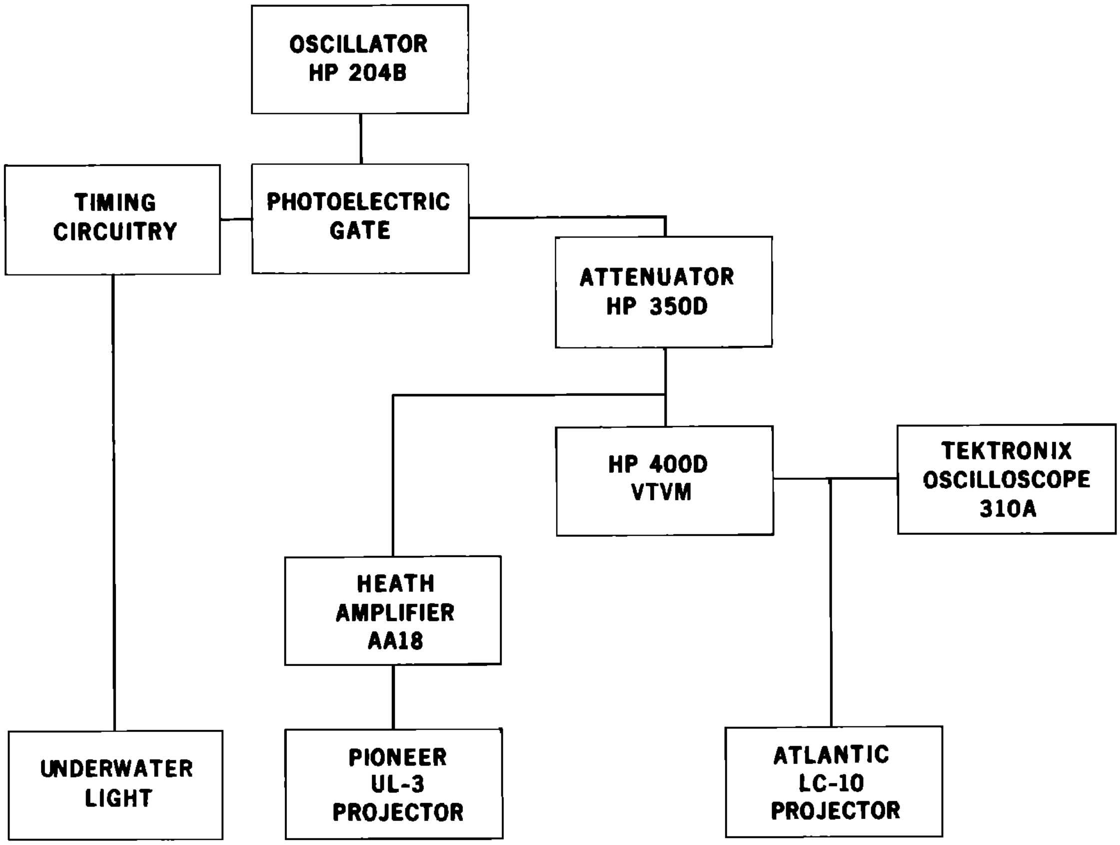

FIG. 1. Block diagram of electronics used to project and monitor auditory signal.

was initiated with a visual cue by the trainer (a horizontal movement of the outstretched hand). The whale, upon seeing the cue, would swim across the tank to the redwood stall and submerge with his head partially in the stall (Fig. 2). He would then watch for an underwater light mounted in the stall to be turned on. The light acted as a precursor to the auditory stimulus and remained on for 15 sec. When the light was turned off, the auditory signal was automatically turned on for 8 sec. If the whale heard the signal, he would back out of the stall, swim across the tank, and push the response manipulandum. A correct response was bridged with a door-bell buzzer and was rewarded with 3 to 5 jack mackerel. If no tone was presented (a catch trial) or he was unable to hear the tone, he remained in the stall until a new trial was initiated by the onset of the light, or until he received the bridging stimulus in the case of a catch trial. The no-tone, or catch trials, constituted a minimum of 25% of the total daily trials and eliminated prospecting by the whale.

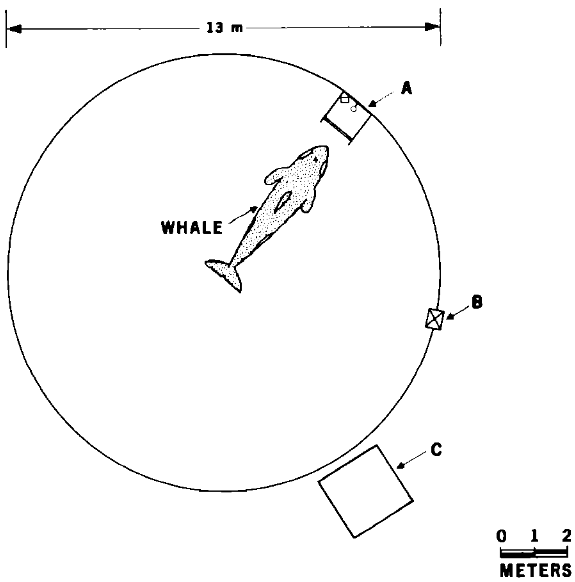

FIG. 2. Diagram of experimental pool and equipment placement, with whale in the listening position. A—the listening stall with light and projector to left and center of the whale; B—the response lever; C—the equipment hut.

II. RESULTS

By using the above technique, an audiogram was obtained for frequencies between 500 Hz and 31 kHz. The latter was the highest undistorted signal the whale would respond to reliably. During the eight months of training and testing, the whale responded to a 32-kHz (0 dB *re* 1 dyn/cm^2 SPL) signal only three times and never responded to a tone above 32 kHz. We were

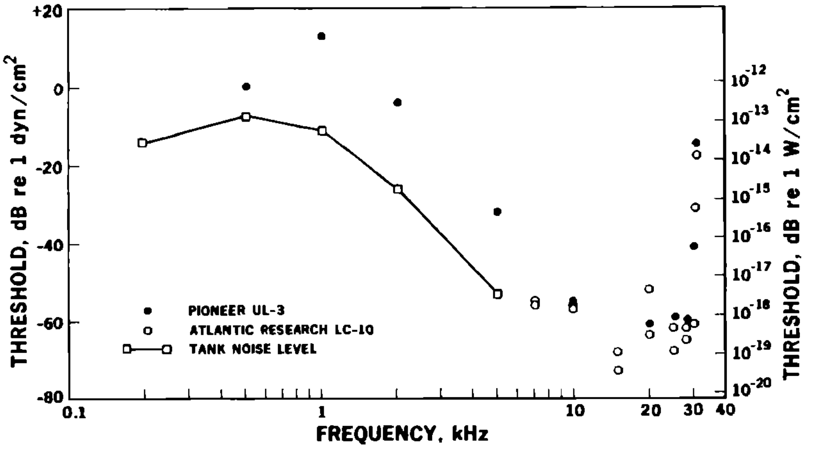

FIG. 3. Graph of the auditory response of the killer whale. Closed circles (●) are thresholds with the Pioneer UL-3 projector. Open circles (○) are thresholds with the Atlantic LC-10. Solid line (□—□) represents the tank noise level.

unable to test below 500 Hz, owing to high ambient noise levels in the tank over which we had no control, and the thresholds below 10 kHz are probably noise masked. Maximum sensitivity was observed at 15 kHz at a level of -70 dB *re* 1 dyn/cm². The uncertainties in the thresholds are estimated to be ± 5 dB. Thresholds for frequencies between 500 Hz and 31 kHz are illustrated in Fig. 3.

III. DISCUSSION

As pointed out by Johnson (1966), what is really being measured in a study using the above experimental design is the level at which the animal is willing to respond. It can be seen from Fig. 3 that the data collected with LC-10 (triplicate replication of threshold) and the UL-3 (duplicate replication) are generally in good agreement. It is felt that this consistency of data represented an effort on the part of the animal to respond to near threshold signals.

The optimum decibel step size for this work was found to be 4 dB. With a step size of 1 dB, once a "no tone" response was obtained, it would often take three or four trials before a "yes tone" response. This type of procedure tends to extinguish the animal's behavior, because there are too many trials between rewards.

Johnson (1966) indicated that the ability of an animal to detect slight intensity changes, e.g., 1 dB, would be valuable in echolocation. He found *Tursiops truncatus* able to detect these slight intensity changes (Johnson, 1970). The echo-ranging capability of the killer whale has been demonstrated by Hall and Evans (1970). It would be interesting to examine the echolocation discrimination threshold in *Orcinus orca*, as has been done in *Tursiops truncatus* and *Inia geoffrensis* by Evans *et al.* (1970). In the echolocation discrimination study, Evans *et al.* found that neither *Tursiops truncatus* nor *Inia geoffrensis* was able to discriminate between two targets whose echo strengths differed by less than 1 dB.

If the echolocation discrimination experiment were repeated with *Orcinus orca*, and the whale was unable to differentiate between targets whose echo strengths differed by 3 or 4 dB, this would agree with our study's data and would indicate that the whale in our study was detecting the auditory signal at near-threshold level.

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