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THE EFFECTS OF VARIATIONS IN AMBIENT NOISE UPON HEARING THRESHOLDS IN THE COD

by

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INTRODUCTION

Experimental studies on the hearing of fish pose very special problems. Not only is it difficult, and often tedious, to determine whether fish hear particular sounds, it is also almost impossible to provide in the laboratory an underwater environment where sounds can be precisely controlled and measured.

Early hearing experiments were performed on fish confined in small thin-walled aquarium tanks, without precautions being taken to obtain anechoic conditions, or to reduce ambient noise. Such tanks were usually smaller than the wavelength of the sounds being transmitted, and were effectively totally surrounded by reflecting surfaces, causing severe distortion of the sound stimulus. In addition, the background noise was very different in quality from natural ambient noise with extraneous air-borne noise and structure-borne vibrations making significant contributions. These factors adversely affected the results obtained, and the data presented in the literature for most fish is inaccurate and often misleading.

We have recently performed a series of experiments on the hearing of cod (Gadus morhua L.). Instead of attempting to reproduce free field acoustic conditions in the laboratory, we examined fish confined in cages in the sea. Thresholds to pure tone stimuli were obtained using a simple conditioning technique, where a delay in the animal's heartbeat was established in response to the sound. The fish were situated in midwater, at a point relatively distant from reflecting boundaries, and were presented with sounds against an ambient sea noise background.

The hearing thresholds we obtained were very different from those previously reported for cod, and most other fish. They were generally lower than those obtained in laboratory experiments, indicating that cod were more sensitive to sounds than earlier workers had indicated. Indeed, we discovered that at certain frequencies the hearing of cod was limited only by the level of sea noise.

This paper describes the apparatus and techniques employed;

We will describe orally the effects of variations in both ambient sea noise and artificially generated noise upon the hearing of fish, and will further examine the ability of fish to discriminate pure tone stimuli from a background of noise.

THE UNDERWATER ACOUSTIC RANGE

The experiments were carried out at Loch Torridon, on the west coast of Scotland. A tower, constructed from free-flooding PVC tubing, was assembled on the sea-bed 100 m offshore. Individual fish were confined in a small PVC mesh cage at the top of the tower, and sounds transmitted from an adjacent projector, moored in midwater. The animal was held 6 m above the sea-bed, and 15 m below the sea surface (measured from chart datum level). The sound stimuli were monitored using a calibrated wide-band hydrophone which was placed beneath the head of the fish. Both the hydrophone and sound projector were connected to a shore laboratory by cables laid on the sea-bed.

Sound stimuli at frequencies between 30 Hz and 10 kHz were derived from a sine wave generator, which fed a gating circuit to provide a transient-free pulse lasting approximately 10 s. The rise time of the pulse was 300 ms, and the fall-time 600 ms. The gated signal was passed to an attenuator, and then amplified by a 10 W power amplifier before being fed to the moving coil projector (USN, type J-9).

In certain experiments, background noise was continually transmitted from the projector, and the pure tone stimulus superimposed by means of an adding circuit inserted at the input to the power amplifier. The response of the hydrophone was examined both before and after the experiments and was flat over the range 10 Hz to 10 kHz. The initial calibrations were performed in air, against a standard microphone, while later calibrations were carried out on an underwater sound range. The signal detected by the hydrophone was fed to the shore laboratory, amplified and the level of the pure tone stimulus measured using a constant percentage bandwidth frequency analyser. Frequency spectra of ambient noise were plotted on a logarithmic level recorder.

THE CONDITIONING TECHNIQUE

Fish for the experiments were captured in the shallower parts of Loch Torridon using baited hand-lines and were maintained in small aquarium tanks at the shore laboratory until required. Each fish to be tested was anaesthetised in a 1 part in 15,000 solution of MS-222 in seawater, and a fine silver electrode implanted beneath the skin, just anterior to the base of the pelvic fins. It was then placed in its cage, allowed to recover in fresh seawater, and transferred to the underwater tower by a diver. At the tower, the electrocardiograph (ECG) electrode was plugged into a cable running to the shore. The ECG signal (approximately 1 mV) was fed to a differential amplifier, filtered, and displayed on a UV recording oscillograph.

Immediately after transfer to the underwater site the heart rate of the fish was extremely rapid and regular. The animal was therefore left until the heart rate reached a slower and less regular value before conditioning commenced.

At each conditioning test, or trial, the fish was presented with a high level sound stimulus. At the end of the sound pulse a very brief 10 V d.c. electric shock was applied across the tail. The trials were continued until eventually (usually within 10 trials) the fish showed a delay in heartbeat AFTER the onset of the sound but BEFORE the application of the shock. After five consecutive positive responses had been obtained a threshold was determined using the staircase technique of von Békésy. Thus, after each positive response, the level of the sound stimulus was decreased by 3 dB, while after each negative response it was raised by 3 dB. Eventually, a threshold was reached where alternate positive and negative responses resulted. The 50% response level was calculated from these alternate values.

THE RESULTS

The cod readily responded to low frequency sounds and proved most sensitive to frequencies between 60 Hz and 380 Hz. They showed a sharp decline in sensitivity above 380 Hz, and a more gradual decline below 60 Hz.

Great variability was apparent in the thresholds obtained at all frequencies. While undoubtedly some of this variation could be attributed to individual differences between fish, it also became apparent that the thresholds obtained from a single fish to a particular frequency could alter as a result of naturally occurring changes in the level of ambient noise. At frequencies between 60 and 380 Hz any increase or decrease in the prevailing level of sea noise was accompanied by a corresponding shift in threshold, suggesting that the hearing of the fish was being masked.

The level of sea noise in Loch Torridon was dependent upon sea state, and wind and weather conditions. However, conditions were generally quiet during the experiments, and the ambient noise rarely reached the typical levels quoted for the open sea. We therefore performed a series of experiments where higher levels of artificial background noise were transmitted to the fish, and observed the effects of changing the bandwidth, and frequency of this masking noise. The full results of these experiments will be discussed orally.