Detection of Ultrasound and Marine Mammal Echolocation Clicks by the American Shad (Clupeidae)

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Abstract: Clupeid fishes (herrings and shads) are among the prey of echolocating cetaceans. Recent studies have shown that some clupeids are repelled by intense sounds from ultrasonic transducers. We determined the hearing thresholds of a clupeid, the American shad (Alosa sapidissima) using classical conditioning. Shad could detect sounds from 0.2 kHz to 180 kHz, with two regions of best sensitivity—one from 0.2 kHz to 0.8 kHz and another from 25 kHz to 150 kHz. American shad were also able to detect simulated bottlenose dolphin (Tursiops truncatus) echolocation clicks with a threshold that suggests they could detect an echolocating dolphin at distances up to 187m.

INTRODUCTION

Investigations of the distribution of blueback herring (Alosa aestivalis), a member of the teleost taxonomic order Clupeiformes (herrings, sardines, and shads), demonstrated that these fish swam away from echosounders, suggesting that at least some species of clupeids may be able to detect ultrasound. It was also shown that high-intensity pulsed ultrasound could be used to repel several other clupeid species from the cold water intakes of power plants, and it has been suggested that sounds produced by pingers attached to large fishing nets to repel dolphins also may repel the clupeids that are being sought with the nets. While these data suggested that clupeids can detect ultrasound, it contradicts all earlier studies of fish hearing, which suggest that fishes can detect sounds to a maximum of 3 kHz. In order to test whether a clupeid could detect ultrasound, we determined the audiogram of American shad from 200 Hz to 180 kHz, and their threshold for detection of simulated 80 kHz echolocation clicks.

METHODS

Experimental Setup
American shad were restrained in a holder and tested in a round fiberglass tank. The ultrasonic transducer was located 15 cm from the fish, and the low-frequency transducer was located 30 cm from the fish. The transducer cables were electrically shielded and the low-frequency transducer was shielded by placing it in a grounded metal mesh. Tone frequencies at and below 12.8 kHz were digitally generated with a 50 kHz sampling rate. Tone frequencies above 12.8 kHz were generated by a function generator. All tones had a 50 ms rise-fall time. Click trains were generated by repeatedly triggering the function generator to generate one cycle at 100 kHz. The period of the click train was 50 ms. This signal was then attenuated with a programmable attenuator, and played through the ITC-1042 transducer. The system was calibrated with an LC-10 hydrophone positioned in the fish holder without the fish.

Classical Conditioning
Shad were anesthetized for insertion of the electrode used to record electrocardiograms. Shad were then trained using classical conditioning of heart rate by presenting a 5-sec test tone followed by a brief 1V AC electric shock. Suppression of heart rate was determined by comparing the inter-heartbeat interval (IHBI) during the test tone, with the IHBI over the five second period prior to the test tone. A detection was considered to have occurred if the mean peri-stimulus IHBI was more than three standard errors greater than the pre-stimulus mean IHBI. Tone presentations and heartbeat monitoring were automated with TDT equipment.

Threshold Determination
Thresholds were determined using a modified staircase method. The threshold was defined as the average of at least six levels at which there was a change from detection to no-detection and no-detection to detection responses. One threshold from each of five or more fish were used to calculate the mean threshold at each frequency. For the click stimulus, the mean threshold was calculated using the thresholds from four fish.

RESULTS
American shad have two regions of sensitivity, one at low frequencies typical for fish, and one at high frequencies where no fish have been previously tested. The low frequency thresholds were likely masked by
background noise from pumps, and so cannot be considered absolute thresholds. American shad could also detect simulated bottlenose dolphin echolocation clicks, which had a 50 ms click duration, a 50 ms inter-click interval, and a peak frequency at 80 kHz. The mean threshold for detection was $170.8 \pm 1.9 \text{ dB re 1 \mu Pa peak-peak}$. 

![Graph showing audiograms of American shad and bottlenose dolphin](image)


As a control to help rule out possible artifacts, such as low-frequency sound or electrical noise, that the shad could be detecting rather than the ultrasound, goldfish were trained to detect a 0.8 kHz tone at 130 dB re 1 \mu Pa using the same classical conditioning procedures as used for the shad measuring either heart rate or respiration. None of the four goldfish tested could detect 80 kHz tones at the maximum amplitude possible with our system (160 dB re 1 \mu Pa). This suggests that ultrasound detection by the American shad was not artifactual.

**DISCUSSION**

Ultrasound detection is probably not widely found among fishes. The only species other than the American shad known to detect ultrasound is the cod (*Gadus morhua*), which can detect 38 kHz with poor sensitivity (194 dB re 1 \mu Pa). It is not clear that cod are hearing or whether they are using somatosensory receptors to detect the very high stimulus levels.

Even though their sensitivity is not nearly that of dolphins, shad can likely detect the echolocation clicks of odontocetes, which are typically high frequency and high intensity short duration sounds (e.g. *Tursiops truncatus*: 220 dB re 1 \mu Pa, p-p source level (SL), 50-80 ms duration). Assuming spherical spreading, shad should be able to detect echolocating *Tursiops truncatus* at a range of 9-187 m for clicks from 190-220 dB re 1 \mu Pa p-p SL.

While we have no data on how shad detect ultrasound, we hypothesize that they use their ear. All clupeids, have a unique ear structure in which a pair of thin air-filled tubes project from the swimbladder to terminate in air chambers that are connected with the utricles of the inner ear.

The ability of American shad to detect ultrasound is reminiscent of the results of studies showing that moths (and many other insect species) perform an elaborate behavioral evasive repertoire in response to bat echolocation, and there is evidence that clupeids undergo an escape response when they detect ultrasonic clicks.

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**REFERENCES**