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Marine Mammals: Hearing and Echolocation at Coconut Island

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LONG-TERM GOALS

1. Broaden the baseline of hearing measures of marine mammals by increasing the number of animals and species measured. The effects of sound on wild populations of animals can best be determined if baseline hearing measures are known.

2. Develop an understanding of the basic processes of odontocete echolocation for ecosystem management. Echolocation is the principal sense for odontocete foraging and its understanding is therefore crucial for estimating the effects of sound on foraging and populations and ecosystem management.

3. Examine the control of hearing during echolocation.

4. Improve the measurement of marine mammal hearing by developing and refining hearing procedures particularly those that will rapidly measure the hearing of stranded and temporarily caught animals.

5. Comparatively examine the basic hearing mechanisms of marine mammal species.

6. Comparatively examine the hearing during echolocation of species in addition to that of the false killer whale

7. Examine automatic gain control mechanisms in odontocete echolocation.

OBJECTIVES

Marine Mammal sensory systems have evolved to effectively use acoustic energy in the oceans. Our objectives are to develop a basic understanding of hearing and echolocation so that knowledge can then be applied to the solution of practical problems as they arise. The most basic hearing measurement is the audiogram which is a series of thresholds across frequencies. It basically describes the hearing of an organism. Audiograms are the most basic of the hearing measures and are essential for describing the audiometrics of a species of animals. Of the 85 species of dolphins and whales we

now have audiograms on 17 species. Audiograms on additional cetacean, and other marine mammal, species may be obtained from stranded animals, from animals in captive display situations, and from catch and release scenarios. We intend to obtain as many valid audiograms as possible as we seek new opportunities in new situations. Most marine mammal audiograms are obtained on individuals and published individually. Population estimates obtain increased validitity with increased numbers of measurements. Other hearing measures such as directionality of hearing, and the mechanisms underlying that directionality, are also very important and little is known on most marine mammals. These measures will also be obtained whenever possible.

Most of our initial audiometric work measured hearing using behavioral responses (Nachtigall et al, 2000). Measures of auditory evoked potentials (AEP) produce the benefit of being obtained rapidly without requiring captivity or lengthy training. Our work (Yuen et al, 2005) shows that the two procedures, while not producing exactly the same results, are certainly comparable. So, we intend to continue using AEP measures to measure the hearing of new species and to continue to measure hearing in other situations.

Our initial work on temporary threshold shifts (Nachtigall et al 2003, 2004) with exposures up to 50 minutes combined with shorter term exposures led to an equal energy hypothesis in which it was assumed that the amount of TTS was dependent on the amount of energy received relatively independent of the time of exposure. An objective of our recent work (Mooney et al, 2009a) has been to examine whether the equal energy hypothesis is valid for short exposure times and to examine the direct effects of the Navy 53C on the hearing of the bottlenose dolphin (Mooney et al, 2009b).

While much was known about outgoing dolphin echolocation signals, little was known about what animals heard while they echolocated until we developed a procedure to measure AEPs during active echolocation experiments (Supin et al. 2003). Our current objective is to examine the automatic gain control of hearing during echolocation with targets present and absent (Supin et al 2011).

We are further interested in basic echolocation processes and the interaction of hearing an echolocation. What specifically contributes to the outstanding echolocation discrimination capability of the odontocetes. How important is high frequency hearing to echolocation discrimination.

Echolocation is the primary foraging tool of odontocetes, it is the sensory tool that allows them to catch fast-swimming fish. How may echolocation be disrupted? Does sound disrupt echolocation?

APPROACH

The ability to obtain hearing data on new species requires opportunistic motivated action. A permit from the NMFS to test the hearing of stranded animals, and keep in touch with the stranding networks in the US, allows us opportunities for testing stranded animals when they become available. Animals in public display facilities also occasionally become available for hearing examination especially if the audiometric tests are conducted for short periods of time like those for AEP measures. The AEP measures can also be used on boats so that temporarily caught animals can be tested. All of these approaches allow us to increase the species and the number of animals tested. We work closely with Alexander Ya. Supin from the Russian Academy of Sciences to test the hearing of new species of animals, especially those that require a new technique or adaptations to new procedures.

We primarily use the envelope following response (EFR) auditory evoked potential approach in which we present amplitude modulated sounds to the animals and monitor the brain wave patterns in response to the amplitude modulation rate.

Hearing is examined during echolocation by measuring the hearing when the outgoing pulse is produced and when the echo is returned by measuring the brain response timed from the outgoing pulse. Target strength is varied by changing the distance and target strength of the targets. The animal is required to echolocate and report the presence or absence of the target and AEP recordings of its hearing while doing that are the important dependent variable. Our work on the False killer whale shows precise control of hearing during echolocation. Our most recent work (Li et al, 2011) shows the same processes occur with other odontocetes like the bottlenose dolphin.

WORK COMPLETED

Measured the audiogram of a stranded beaked whale Mesoplodon densirostris and showed that its best hearing was the same as its published echolocation return frequencies at 40 to 50 kHz.

Continued the measurement of hearing during echolocation on the false killer whale demonstrating the ability of the whale to change hearing during echolocation

Completed comparative measurements of hearing during echolocation on the bottlenose dolphin and the harbor porpoise. Both demonstrate control of hearing in a manner similar to the fale killer whale

Examined whether or not there were additional automatic gain control mechanisms in the hearing of the false killer whale during echolocation.

Tested the comparative hearing pathways of the bottlenose dolphin and the false killer whale.

RESULTS

The formerly stranded beaked whale heard relatively well in the midfrequency sonar range (5.6 kHz) at 79 dB.

Published results indicating that a formerly stranded long finned pilot whale and a recently stranded pygmy killer whale showed audiograms with high frequency hearing.

Found that there is an automatic gain control in the hearing system of an echolocating false killer whale. There are at least three mechanisms of automatic gain control in odontocete echolocation – echolocation and hearing are a very dynamic process. Began experiments to determine whether the control of hearing was confined to echolocation.

Found that it is unlikely that the control of hearing during echolocation is accomplished via a stapedial mechanism in the same way that it is controlled by bats

Found that hearing pathways differ between the false killer whale, the bottlenose dolphin and the beluga whale. Initial work indicates that the hearing pathway of sound in the dolphin may not be the traditionally assumed lower jaw acoustic window route. Additional work and modeling is necessary

IMPACT/APPLICATIONS

High frequency sonar issues may be an important future area . Exposure to loud sound effects echolocation. Long term exposure can result in decrements in echolocation and foraging. Long-term ecosystem effects are likely.

We still do not know the hearing range and sensitivity of the mysticete whales. We presume they hear low frequencies, but perhaps like the polar bears, they hear much higher frequencies than we assume. If that is true, it is reasonable to be concerned about the effects of sound on mysticete whales. The mysticete whale hearing issue remains and important one to be resolved. We continue our efforts to obtain a subject for hearing examination and have written the mysticete whales into our new permit.

The false killer whale's, the bottlenose dolphin's and the harbour porpoise's overall hearing changes while it echolocates. Does it control its hearing in a voluntary way? Can this be used for mitigation? Can a warning sound be given that allows the animal to change its hearing?

All odontocetes are not alike. The audiogram of the beaked whale differs greatly from other odontocetes. We assume that the Sperm whale will differ even more. The idea of using the bottlenose dolphin as a template for all odontocete hearing is not a reasonable assumption for modeling or for regulatory purposes.

Belugas and false killer whales hear directionally very differently than the bottlenose dolphin. We must be cautious when we extrapolate from species to species. More work is needed. A combination of modeling and empirical hearing data is necessary

TRANSITIONS

The audiogram on the beaked whale (*Mesoplodon densirostris*) provides the Fleet with an actual good estimate of the hearing thresholds of beaked whales in the mid-frequency sonar frequency. This data is essential for planning fleet sonar excercises and for determining the number of 'takes' in permits where beaked whales are likely to occur.

Our results on Hearing and also TTS are used by the U.S. Naval Fleets in their requests for LOAs and permits for Training. Our data are also cited by NOAA, NMFS in their Biological opinions required under the Endangered Species Act for issuance of opinions regarding Fleet Training and in Navy and NMFS NEPA requirements. The SPAWARSYSCEN in San Diego California uses the basic procedure that we developed to test dolphin hearing with auditory evoked potentials in research and also to measure the hearing of Navy systems animals.

RELATED PROJECTS

In a related project, funded via the University of Southern Denmark we are working with a graduate student, Meike Linnenschmidt and her professor Magnus Wahlberg, to expand the effort of examination of hearing during echolocation looking at harbour porpoises. The results indicate that the harbor porpoise hears during echolocation in a manner similar to the false killer whale. A manuscript has been written and submitted for publication by Ms. Linnenschmidt.

We continue to examine the directionality of hearing and work with the modeling efforts of both Ted Cranford at San Diego State University and Darlene Ketten and Aran Mooney at Woods Hole Oceanographic Insitution. We are specifically examining the head related transfer function of the bottlenose dolphin in collaboration with Dr. Cranford.

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HONORS/AWARDS/PRIZES

Paul Nachtigall became a Fellow of the Acoustical Society of America and was chosen as an "Honorary Member" of the European Association for Aquatic Mammals. He was also nominated as an Outstanding Graduate Faculty Mentor at the University of Hawaii.