Marine Mammals: Hearing and Echolocation at Coconut Island

Paul E. Nachtigall
Marine Mammal Research Program
Hawaii Institute of Marine Biology
P.O. Box 1106
Kailua, Hawaii 96734
phone: (808) 247-5297 fax: (808) 247-5831 email: nachtiga@hawaii.edu

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LONG-TERM GOALS

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.

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

Examine the control of hearing during echolocation.

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.

Comparatively examine the basic hearing mechanisms of marine mammal species.

Develop and refine the measurement of hearing during echolocation particularly the hearing of the outgoing signals and the echoes from nearby and distant targets.

Examine automatic gain control mechanisms in odontocete echolocation.

Develop an understanding of the basic processes used by odontocetes to actively discriminate fine differences in echolocation targets and to model those processes for use in the development of improved sonars.

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14. ABSTRACT
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 16 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.

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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 16 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 2009).

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 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. While that works well for cetaceans, we also use individual tone pip AEPs for those marine mammals, like the polar bear, that are not as prone to rapidly follow amplitude modulated stimuli. Our work with the polar bear is conducted with the staff of Kolmården Djurpark in Sweden, particularly Mats Amundin.

The disruption of echolocation is examined by first training an animal on a discrimination task, establishing baseline behavior, then presenting a disrupting sound to see whether or not the performance was disrupted prior to returning to the baseline task.

Temporary threshold shift work is primarily accomplished by testing the hearing of the dolphin, exposing it to sound, then retesting hearing immediately using evoked potential measures. Last year we published data on the effects of intermittent sounds produced by navy midfrequency sonar (53 C) to see whether the sonars produce the predicted amount of TTS.

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.

WORK COMPLETED

Examined the discrimination capability and click parameters of the false killer whale as a function of the development of presbycusis

Completed the project examining the effects of disrupting echolocation with sound

Examined the effects of TTS with both long and short exposures and further tested the equal energy hypothesis.

Published data on the effects of exposure to 53C sonar pings and tested the number of pings and level required to produce TTS

Continued the measurement of hearing during echolocation

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

Tested the hearing directionality of the false killer whale.

RESULTS

Found a decrement in echolocation performance of the false killer whale with decrease in high frequency hearing along with a change in click frequency parameter

Published results showing echolocation can be disrupted when sound is sufficiently loud.

Published results indicating that TTS was found not to follow the Equal Energy Hypothesis. Short exposures took more energy to produce shift than longer exposures.

Published results indicating that 53C sonar sound would require the animal to be approximately 40 meters from the ship for 5 minutes to produce TTS.

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.

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

IMPACT/APPLICATIONS

Echolocation can be disrupted by the introduction of loud sound. It is the primary tool for foraging.

The total energy likely to produce TTS is greater for short sounds than it is for longer sounds. Shorter exposures of an equal amount of energy are less likely to produce temporary hearing loss in dolphins.

At least some delphinids hear very well up to 180 kHz, an area where many high frequency sonars operate. High frequency sonar issues may be an important area for future issues.

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

Odontocete echolocation is a very dynamic process in which the hearing of the animal is changing to meet the situation encountered in the environment and the targets. There is no other auditory system that is controlled in this manner. The animal's overall hearing changes while it echolocates. Does it control its hearing in a voluntary way? Can this be used for mitigation?

All odontocetes are not alike. 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. Modeling may well assist.

TRANSITIONS

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. The 53C Sonar data can be used to predict ranges for potential hearing damage to at least one odontocete species. Our data were cited in the recent Supreme Court ruling regarding Naval Training and Marine Mammals.

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.

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.

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