EXPERIMENTAL MEASURES OF BLAST AND ACOUSTIC TRAUMA IN MARINE MAMMALS

Darlene R. Ketten, Ph.D.
Associate Scientist
Dept. of Biology
Woods Hole Oceanographic Institution
Woods Hole, Mass. USA

Dept. of Otolaryngology
Harvard Medical School
Boston, Mass. USA

Phone: 508-289-2731
Fax: 617-573-4275
Email: dketten@whoi.edu

Grant Number: N00014-97-1-1030
ONR Program Officer: Dr. Robert Gisiner

Long-term Research Objective:

Although marine mammal middle and inner ears are similar to those of land mammals, there are sufficient differences that marine middle ear mechanisms in particular continue to be a hotly debated topic. To date there are surprisingly few direct investigations of marine mammal ear functions. While this project has an immediate goal of investigating intense pressure effects, it will also provide new data on both the structure and mechanical responses of a wide variety of marine ears. Therefore, in terms of basic research and the long term goals of this field, this work is expected to provide fundamental information that will improve our understanding of middle and inner ear response mechanisms specific to marine mammals.

S&T Objectives:

The explicit objective of this research is to determine the dynamic range of mechanical responses of cetacean and pinniped ears to intense pressure sources. Ears are the bell-weathers of pressure induced damage. Equally important, they are a crucial sensory system for marine mammals. Therefore, understanding differential impacts on marine mammal ears from a range of received pressures will provide a marine specific metric for determining blast and impulse noise exposure safety zones.

Approach:

Cetacean and land mammal ears differ in their robustness, stiffness, mass, vascularization, and pneumatization characteristics. Therefore, it is not possible to accurately extrapolate whale or seal auditory system responses to blast or impulse pressures from existing experimental results on air-adapted ears. These experiments are designed to provide direct measures from marine auditory systems of intense pressure responses. Post-mortem ears, given proper preservation, have been shown to have *mechanical* responses that are isomorphic with those of live ears. Because hearing loss and auditory system trauma from blasts and intense, short-term impulsive sources depend essentially upon mechanical responses of ear components, some of these effects are inducible and measurable post-mortem. In this project, carcasses of stranded marine mammals are first examined post-mortem by CT to assure normal ear structures. The ears and post-cranial organs that are susceptible to pressure damage are then implanted with pressure gages. The implanted, intact specimen is immersed in a test pond, exposed to a single blast designed to deliver received pressures ranging from 300 to 0 psi, re-examined by CT to document gross tissue changes, and, finally, fully necropsied to assess structural damage at the cellular and infrastructural level. All blast sequences are filmed using ultra-high speed video to confirm the position and reaction of the

specimen to the pressure wave as well as to graphically document pre and post-exposure external condition of the specimen. All necropsies are documented on film and by digital camera. Although auditory system effects are the focus of the exam, all body tissues are documented for completeness.

S&T Completed:
The following experiments have been completed since the grant's activation in Jan. 1999:
1) Four preliminary test mapping shots were performed to test the resilience of the specimen suspension system and to confirm received pressures for potential specimen placements within the test pond. 2) Two specimen simulation tests utilizing gages implanted in hams and two simulated cetacean ear tests were performed to confirm *in situ* gage integrity when implanted in soft tissues, in flexible air cavities, and at bone-soft tissue interfaces. For the latter tests, four pseudo-cetacean ears were constructed of acrylic shells equivalent to the volumes of small delphinid and larger baleen ears. Each shell was filled with varying combinations of flexible or semi-rigid walled air-cavities (balloon catheters or acrylic chambers), hydrated soft tissue only, and air only chambers. 3) Two actual tests of porpoise post-mortem specimens were tested with gages implanted in the ear, esophageal, and hypaxial musculature. The specimens were tested at 300 and at 200 psi. High received pressures were purposely chosen to test the feasibility of the measures and to determine how well the gages would respond in actual tissues.
The preliminary blast tests (1) without targets confirmed pressure simulations for this pond for lower test pressures and showed that the suspension rigging would withstand the test pressures anticipated without compromising received psi measurements. The simulated specimen tests (2) provided data for improvements in gage design and acted as trials for video equipment placement. These preliminary tests were required because the rarity and delicacy of appropriate postmortem specimens requires optimizing all recording equipment parameters prior to actual tests. The data from the actual specimen tests (3) are preliminary but encouraging. As a control, all specimen necropsies are performed and documented by AFIP-trained forensic and blast pathologists who are not privy to the received levels. Necropsy findings for the two specimens examined to date show distinct and unequivocal damage consistent with - and only with - blast effects. The injuries sustained by both specimens (e.g., peri-bullar and intracranial hemorrhage, subluxated ossicles, lung and liver disruption) were profound and likely mortal, but, interestingly, the severity of the impacts was precisely consistent with mass-dependent predictions for the two animals tested. Equally important, there was an apparent pressure dependent diminution of blast effects; i.e., the severity of injuries decreased at the lower received pressure. This implies that not only are these experiments likely to provide reasonably realistic auditory data, but also that the results may provide a continual dose-damage curve for multiple species.

Impact / Navy Relevance:
The Navy is required to mitigate effects on marine mammals from blasts required for ship shock trials as well as other explosive and impulse sources. Currently, mitigation zones are being set by inference from land mammal experiments because we lack explicit data on pressure effects in marine mammals. As noted above, ears are vital sensory organs that are also primary indicators for pressure damage. By directly measuring and monitoring pressure damage in marine mammals and finding the endpoints for pressure-induced trauma, this project will provide the navy with the necessary baseline data for accurate aquatic mitigation zones.

Planned Research Efforts:
A minimum of 10, maximum of 20, specimens are expected to be tested, ranging from small cetaceans through larger pinnipeds, with replicate runs at 300, 200, 100, 50, 20, 10, and 0 psi, as required, to determine zones (based on received psi) of lethality, recoverable injury, permanent, temporary, and no significant functional auditory damage.

References: none
Other Sponsored Science & Technology: none

Part 2

EXPERIMENTAL MEASURES OF BLAST AND ACOUSTIC TRAUMA IN MARINE MAMMALS

Darlene R. Ketten, Ph.D.
Associate Scientist
Dept. of Biology
Woods Hole Oceanographic Institution
Woods Hole, Mass. USA
and
Dept. of Otolaryngology
Harvard Medical School
Boston, Mass. USA

Phone: 508-289-2731

Fax: 617-573-4275

Email: dketten@whoi.edu

Grant Number: N00014-97-1-1030

ONR Program Officer: Dr. Robert Gisiner

Subcontractors:

James Craig - funded outside ONR
Physicist
Naval Surface Warfare Center
Bethesda, Md.

G. Richard Price, Ph.D. - $45,255
Senior Research Scientist
Army Research Laboratory
Aberdeen, Md

Greg Early - $39,061
Associate Curator
New England Aquarium
Boston, Mass.

Charles W. Oliver - $16,120
Computer Specialist
NOAA/NMFS/SWFC
La Jolla, Calif.

Productivity:

Technology Transfer:

None at this point. Significant progress was made in the development of a multi-species computer simulation model of blast effects but it is still under development.

Journal Articles

1. Ketten, D.R., Skinner, M., Wang, G., Vannier, M., Gates, and Neely, G. (1998) *In vivo* Measures of Cochlear Length and Insertion Depths of Nucleus® Cochlear Implant Electrode Arrays *Annals of Otology and Laryngology*, vol. 107, no. 11(2), pp. 1-16.
2. de Muizon, C., D.P. Domning, and D.R. Ketten (1999) *Odobenocetops peruvianus*, the walrus-convergent delphinoid from the lower Pliocene of Peru (in press, *Smithsonian Cont. Paleobiol.*).
3. Ketten, D.R. (1998) Marine mammal ears: An Anatomical perspective on underwater hearing. *Jour. Acous. Soc. Amer.: Proc. Int. Cong. on Acoust.*, vol. 3, pp.1657-1660

Reviews, Chapters, and Editorials

1. Ketten, D.R. (1998) Marine mammal Hearing and Acoustic Trauma: Basic Mechanisms, Marine Adaptations, and Beaked Whale Anomalies. In: Report of the Bioacoustics Panel, NATO /SACLANT publ. , A. D'Amico and W. Verboom (eds.), pp. 2-21, 2-63-78.

2. Ketten, D.R. (1998) Marine Mammal Auditory Systems: A Summary of Audiometric and Anatomical Data and Its Implications for Underwater Acoustic Impacts. NOAA Tech. Memor. NMFS, NOAA-TM-NMFS-SWFSC-256, 74 pp.
3. Popper, A., Ketten, D.R., Dooling, R., Yost, W., Brill, R., Ridgway, S., and Schusterman, R. (1999) Effects of Anthropogenic Sounds on Hearing in Marine Animals. ONR Tech. Rpt.
4. Wartzok, D. and D.R. Ketten (1999) Sensory Biology. In: Marine Mammals. J. Twiss and J. Reynolds (eds.), Vol. 1, Smithsonian Institution Press, (in press).
5. Ketten, D.R. (1999) Ear Structure and Sound Pathways. In: Hearing by Whales and Dolphins, W. Au, A. Popper, and R. Fay (eds.), Springer-Verlag, (in press).

Invited Lectures

1. Ketten. D.R (1998) Imaging the Auditory System from Stem to Stern: Inner ear disease and cochlear implantation, *Invited Lecture*, Special Session on Imaging, American Academy of Audiology.
2. Ketten, D.R. (1998) Marine mammal Hearing and Acoustic Trauma: Basic Mechanisms, Marine Adaptations, and Beaked Whale Anomalies. *Invited lecture,* Bioacoustics Session. NATO/SACLANT Mtg. on LFS Effects, La Spezia, Italy.
3. Ketten, D.R. (1998) *In Vivo* Imaging of Intracochlear Electrode Positions, *Invited lecture*, Cochlear Implant Workshop, Amer. Academy. of Otolaryngology-Head and Neck Surgery
4. Ketten, D.R. (1998) *In Vivo* Analyses of Insertion Trauma, *Invited lecture*, Surgeon's Workshop on Cochlear Implantation, Amer. Academy. of Otolaryngology-Head and Neck Surgery.
5. Ketten, D.R. (1998) Acoustic/Explosive Effects on Marine Mammals, *Invited lecture*, 1998 Information Transfer Meeting, Minerals Management Service, New Orleans, LA.
6. Ketten, D.R. (1998) Man-made noise in the oceans: Irrelevant or irreparable? ***Plenary lecture***, World Marine Mammal Conference; joint meeting., European Cetacean Society and the Society for Marine Mammalogy, Monaco.
7. Ketten, D.R. (1998) Marine mammal ears: An Anatomical perspective on underwater hearing. ***Plenary Lecture***, Acoustical Society of America.
8. Ketten, D.R., H. Krum, E. Chiddick, and C. Merigo (1999) Acoustic Fatheads: Parallel Evolution of Soft Tissue Conduction Mechanisms in Marine Mammals, Turtles, and Birds, joint meeting, Acoustical Society of America/ European Acoustics Association, Berlin.
9. Ketten, D.R. (1999) Acoustic impedance matching mechanisms in marine vertebrates. 1st Intern. Conf. on Sensory Processing of the Aquatic Environment, Great Barrier Reef, Australia

Published Abstracts

1. Ketten, D.R., Dolphin, W.F., Chiddick, E.J., Krum, H.N., and Merigo, C. (1998) *In vivo* imaging correlated with otoacoustic emissions as a metric for ear disease in seals, World Marine Mammal Conference; joint meeting., European Cetacean Society and the Society for Marine Mammalogy, Monaco.
2. Ketten, D.R. (1998) Dolphin and Bat Sonar: Convergence, Divergence, or Parallelism. Fourth International Biosonar Conference, Algarve, Portugal.
3. Brill, R.L., P. W. B. Moore, L. A. Dankiewicz, and D.R. Ketten (1998) Specialized sound sites in the dolphin's peripheral hearing system. Fourth International Biosonar Conference, Algarve, Portugal..
4. Roitblat, H. L., Ketten, D., Au, W. W. L., Lemonds, D. W. & Nachtigall, P.E. (1998, November). A model of early stages of dolphin hearing. 39th Annual Meeting of the Psychonomic Society.
5. Ketten, D.R. and J. R. Potter (1999) Anthropogenic ocean noise: Can we quantify the impact? joint meeting, Acoustical Society of America/European Acoustics Association, Berlin.

Patents (indicate status, e.g., filed, issued): none

Honors, awards or prizes received during the reporting year: none

Number of Students Supported (minimum of 1/4 of their support):

Post Doctoral:___O_ Doctoral:_2___ Masters:_____ Undergraduate:__1__

Of these students, the number who were:

Females:__1___

Under-represented Ethnic groups:__1 (Hispanic)__

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. Agency Use Only	2. Report Date	3. Report Type and Dates Covered
		Performance Report - Annual 9/1/98 - 8/31/99

4. Title and Subtitle:
Experimental Measures of Blast and Acoustic Trauma in Marine Mammals

5. Funding Numbers
N00014-97-1-1030

6. Author(s)
Darlene Ketten

7. Performing Organization Name(s) and Address(es)

Woods Hole Oceanographic Institution

8. Performing Organization Report Number
WHOI Proposal No. 2036.1

9. Sponsoring/Monitoring Agency Name(s) and Address(es)
Dr. Robert Gisiner
ONR, Code 335
800 N. Quincy Street
Arlington, VA 22217-5660

10. Sponsoring/Monitoring Agency Report Number

11. Supplementary Notes

12a. Distribution/Availability Statement

Approved for public release; distribution is unlimited

12b. Distribution Code

13. Abstract

Ears are the bell-weathers of pressure induced damage. Equally important, they are a crucial sensory system for marine mammals. Although marine mammal ears are similar to those of land mammals, there are also sufficient differences to prevent extrapolation of damage criteria from air adapted ears to marine systems. Therefore, understanding how intense pressures affect marine mammal ears is required in order to properly mitigate effects from man-made impulse and explosive devices. Because hearing loss and auditory system trauma from blasts and intense, short-term impulsive sources depend essentially upon mechanical responses of ears, some of these effects are inducible and measurable post-mortem. Properly preserved post-mortem ears have been shown to have mechanical properties isomorphic with those of live ears. This project will determine intense pressure effects on marine mammal ears specifically by exposing post-mortem specimens of marine mammals to underwater blast sources and measuring their auditory system mechanical responses in situ.

14. Subject Terms

15. Number of Pages

16. Price Code

17. Security Classification of Report	18. Security Classification of this Page	19. Security Classification of Abstract	20. Limitation of Abstract

NSN 7540-01-280-5500

Standard Form 298 (Rev. 2-89)