MYSTICETE HEARING: PROGRESSING THE SCIENCE OF BALEEN WHALE HEARING

E&P SOUND & MARINE LIFE PROGRAMME

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Mysticetes are a suborder of marine mammals that includes some of the largest species, such as fin, blue and humpback whales. These animals, commonly referred to as baleen whales, are found throughout the world's oceans, including areas of oil and gas exploration. The oil and gas industry is concerned that the most sensitive hearing range of some whales may overlap with dominant airgun frequencies, making them potentially more sensitive to and more responsive than other marine mammals to low-frequency sound sources like air guns or commercial shipping.

While the hearing of many dolphin and seal species has been measured directly, no direct measure of hearing has been performed with any mysticete whale. Mysticete whales are obviously difficult to maintain in captivity, making standard behavioural hearing test methodology difficult, if not impossible to apply. Using physiological methods to test hearing such as Evoked Potential (EP) audiometry is theoretically feasible, but requires access to mysticete whales in the wild under some level of controlled access. Additionally, the present state of technology and methods for EP measurement of hearing are not yet optimized for detecting signals from the auditory system of baleen whales. For these reasons, no directly-measured mysticete hearing data exist to inform industry risk assessments or to set science-based safety zones.

The International Association of Oil and Gas Producers (IOGP) Sound and Marine Life Joint Industry Programme (SML JIP) in conjunction with other sponsoring organizations has been progressing the science of mysticete hearing through funding a series of research projects including:

- An Auditory Weighting Function Review project (by the National Marine Mammal Foundation)
- Baleen Whale Anatomical Modeling (by Boston University and Woods Hole Oceanographic Institution)

Auditory Weighting Function Review

Current regulatory guidelines in the United States of America for estimating the risk of potential hearing loss are based on auditory weighting functions. Auditory weighting functions are mathematical approaches used to estimate frequencies at which animals (human and non-human) are most sensitive compared with those that they hear less well. In other words, for two frequencies, which one will an animal sense as being louder or softer even though the sounds are at the same intensity? Deriving hearing curves for different baleen whale species is a critical step towards enabling the appropriate use of auditory weighting functions for noise impact predictions.

A thorough review of the state of the science in the use of auditory weighting functions was recently concluded by researchers from the National Marine Mammal Foundation, US Navy Marine Mammal Program, University of California – Santa Cruz, and Arizona State University.[1]

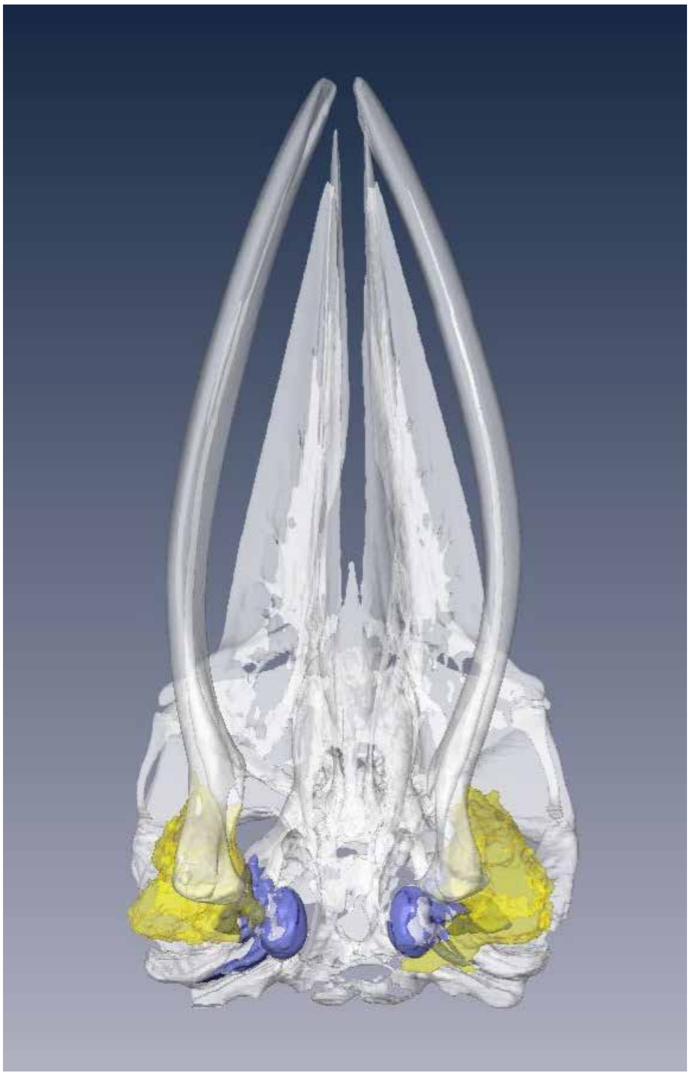
1 Houser D.A.; Yost W., Burkard R., Finneran J., Reichmuth C., Mulsow J. (2017). A review of the history, development and application of auditory weighting functions in humans and marine mammals. The Journal of the Acoustical Society of America 141, 1371 (2017). http://asa.scitation.org/doi/10.1121/1.4976086

The review found that the application of weighting functions to marine mammals, and particularly baleen whales, continues to be complicated by factors such as limited data, the large number of marine mammal species to which they might be applied, and unknowns regarding physiological similarities and differences amongst species. For these reasons, this study made research recommendations to address data gaps and assumptions underlying marine mammal auditory weighting function design and application. One recommendation is audiogram prediction and validation of auditory models and weighting functions, which are currently being pursued by the JIP.

Baleen Whale Anatomical Modeling: Snapshot of Research

In the absence of direct hearing measurements, one approach to mysticete hearing has focused on developing comprehensive models for the sound reception and processing systems of baleen whales. Model input is based on information obtained from anatomical measurements of animal ear structure. New models were developed in a collaborative effort between Boston University and Woods Hole Oceanographic Institution with SML JIP funding.[2]

The mysticete species with the most complete anatomical datasets currently available are minke and humpback whales. Using anatomical measurements of minke and humpback whale heads and ears, this study produced estimated hearing ranges for these mysticete species. Hearing range models were also created for two odontocetes: the bottlenose dolphin and harbour porpoise. The purpose of creating the odontocete models was to validate the models by comparing previously published hearing data obtained from live animals with the model outputs. This research team constructed its models utilizing 3-D reconstructions of Computed X-ray Tomography (CT)-scanned sections of an animal's head. A significant finding was the discovery of a body of fat attached to the minke whale middle ear bones, similar to the fat bodies of dolphins that are thought to be the primary channels for underwater sound to the ear. This "acoustic fat" may play/plays a key role in odontocete hearing and is a potential indication that the mechanics of mysticete hearing are more closely aligned with odontocete hearing than previously thought.

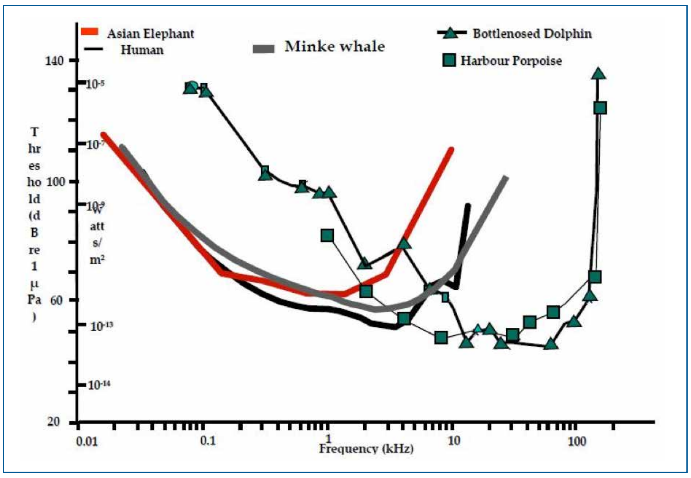


Computerized Tomographic (CT) imaging of juvenile minke whale head, adapted with permission from http://csi.whoi.edu.

The project produced a preliminary prediction for a minke whale audiogram, with the most sensitive auditory region spanning between 40 Hertz and 15 kiloHertz (kHz). More recently, using this approach the project predicted a best frequency range for the humpback whale between approximately 20 Hz and 3 kHz or between 400 Hz and 9 kHz depending on which of two potential stimulation locations were used in the model. The research also shows that like most mammals, these whales have hearing that gradually tapers off in sensitivity at the low and high extremes of their hearing range. While this study implies that the minke and humpback whales can hear virtually all frequencies produced by airgun arrays, it does not yet predict the effect of these sounds on the hearing of the animal.

[2] Tubelli, A. A.; Zosuls, A.; Ketten, D. R.; Mountain, D. C. (2018). A model and experimental approach to the middle ear transfer function related to hearing in the humpback whale (Megaptera novaeangliae). The Journal of the Acoustical Society of America, 144, 525 (2018). https://asa.scitation.org/doi/pdf/10.1121/1.5048421

A longer-term goal would be to develop anatomically-based hearing models for additional species of interest, such as the blue and bowhead whale, as these are representative species that potentially have more sensitive hearing at lower frequencies. The team is currently working on creating a mathematical model to estimate the hearing range and optimal hearing frequencies of these baleen whales (bowhead and blue whales). All of the models require validation, and it is important to consider means by which measurements of hearing sensitivity and the frequency range of hearing might be obtained (e.g., EP methods or playback experiments). With proper validation, greater accuracy and confidence in hearing model predictions can be obtained. Through this multi-faceted approach, better predictions of noise impacts in mysticetes will be obtained.



An anatomically-derived theoretical audiogram is shown for the minke whale in comparison behavioural audiograms for other species. The shape of the minke curve and the minimum threshold are speculative at this time.[3]

[3] Ketten, D. R.; Mountain, D. C. (2011). Final Report: Modeling Minke Whale Hearing, IOGP SML JIP.

ABOUT THE JIP

One of the most extensive environmental industry research programmes bringing together the world's foremost experts across industry, academia and independent research centres.

This fact sheet has been produced by the IOGP E&P Sound and Marine Life Joint Industry Programme (JIP). The JIP was founded in 2005 and supports research to help increase understanding of the potential effect of sound generated by oil and gas exploration and production activity on marine life.

To learn more about the JIP and our research, please visit www.soundandmarinelife.org

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