TESTING THE ACOUSTIC TOLERANCE OF HARBOUR PORPOISE HEARING FOR IMPULSIVE SOUNDS

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INTRODUCTION

The planned construction of offshore wind turbines in the North and Baltic Seas involves the emission of high numbers of intense impulsive sounds when turbine foundations are driven into the ground by pile driving. Based on knowledge about other odontocete cetaceans (Finneran et al. 2002), it can be assumed that the source levels, which will on average exceed 225 dB re 1 µPa at 1 m, bear a risk at least for temporary threshold shift (TTS) in the auditory system of harbour porpoises *Phocoena phocoena* that inhabit these waters. In order to base the definition of noise-exposure criteria on information on the acoustic tolerance of this species to single impulses, an auditory study was conducted.

METHODS

The measurements were conducted on a male harbour porpoise held at Fjord&Baelt in Kerteminde, Denmark, in a seminatural enclosure that is open to the adjacent harbour area on two sides. All baseline hearing data were collected by presenting amplitude-modulated sounds to the animal at selected carrier frequencies and by measuring the evoked auditory potentials on the skin surface of the animal (AEP method). The animal was trained to dive to an underwater station and position itself there for the audiometric tests. After achieving baseline hearing data over the animal's functional hearing range, three frequencies (4, 32, and 100 kHz) were selected to represent the low-, mid-, and high-frequency hearing. At those frequencies, the hearing threshold was tested repeatedly for its daily variation and to define a TTS criterion based on twice the standard deviation from the average threshold value. In a controlled exposure experiment, the animal was subsequently exposed to single air gun stimuli at increasing received

levels over a period of four months. Immediately after each exposure, the animal's hearing threshold was tested again for any significant changes at the three selected frequencies. The received levels of the air gun impulses were increased until TTS was reached at one of the frequencies.

RESULTS

The animal's hearing threshold values were elevated over the entire frequency range by over 30 dB on average in comparison to previously measured data (Kastelein et al. 2002). The TTS criterion was exceeded at 4 kHz when the animal was exposed to an impulse at a received level of 200 $dB_{peak\text{-}peak}$ re 1 µPa at 1 m. At the same received level, the hearing threshold at 32 kHz was elevated but did not exceed the criterion, whereas no effect on hearing sensitivity was documented at 100 kHz.

DISCUSSION

The differences in thresholds in this study compared to previously achieved data might be attributed to several reasons. A hearing loss at higher frequencies could be related to the comparatively old age of the animal tested (11 yr). The acoustic characteristics of the auditory stimuli used in the different auditory studies might account for a systematic difference in the sensitivity over the entire frequency range. In addition, the active positioning of the animal at its underwater station is likely to have caused an increased signal-to-noise ratio in the AEP data and thus led to a systematic electrophysiological masking, i.e., an overestimation of the true threshold values over the entire frequency range. In addition, the high background noise level in the enclosure might have caused an acoustic masking of the animal's hearing thresholds. Therefore, the achieved harbour porpoise's hearing sensitivity does not represent absolute, but masked, hearing threshold levels. Nevertheless, this has no implication on the tolerance of the animal's hearing system for intense impulsive sounds (Finneran et al. 2002). The documented TTS level of the harbour porpoise is considerably lower than that of other odontocete species tested so far. It is most likely that differences in the tolerance of the auditory system are related to the size of the species tested. The results will have implications for the regulatory procedures for the construction of offshore wind turbines in German waters as well as other impulsive sound sources.

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SOUND EXPOSURE CHAMBER FOR ASSESSING THE EFFECTS OF HIGH-INTENSITY SOUND ON FISH

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INTRODUCTION

There are a variety of anthropogenic sources that can expose fish to high-intensity underwater sound in the audio-frequency range. These sources include active sonar, seismic surveying, explosive munitions, and pile driving for bridge and pier construction. These sources have the potential to produce physical damage in fish or to adversely alter their natural behaviour. Determining the effects of such exposures is challenging because fish are difficult to observe and monitor in situ and because it is difficult to achieve representative sound exposures in a laboratory setting.

In order for a sound exposure to be representative of what a fish would encounter, the exposure signal must have the same temporal/spectral characteristics as its archetype for both its pressure and fluid-velocity components. Additionally, the subject must have the appropriate fluid loading in order to ensure that its response to the exposure is representative of its free-field response.

METHODS

A device called the fishabrator was designed and built for the exposure of fish to intense underwater sound in a laboratory setting. The device consists of a rigid-walled travelling-wave tube driven at each end by a 670N electrodynamic shaker. The tube's dimensions and end conditions were selected to make fluid loading on the subjects similar to that in a free-field condition. The device can provide either a free-field plane-wave exposure (p/v ~ 1.5 MRayl) or an exposure that is dominated by either its pressure or velocity component in order to identify damage mechanisms. The test subjects swim freely in the 20-liter volume of the device. The sound field is reasonably uniform throughout this volume. Incidence angles with respect to the horizontal are controlled by changing the orientation of the tube around a central pivot. Both continuous and transient signals can be produced with frequency content in the range of 10 to 5,000 Hz and sound pressure levels up to 210 dB re 1 μPa. The exposure signals are controlled and monitored with a PC-based signal-generation and data-acquisition system.

Because of the rigid walls of the tube, the wave speed of the lowest order mode (no radial variation) in the fluid is very close to the speed of sound in water. Appropriate control of the driving force on the pistons at either end of the tube produces any axial standing-wave field that can be decomposed into travelling plane waves in water. This, obviously, includes travelling waves in both axial directions. A pressure-dominated exposure is achieved when the pressure components of each travelling wave add in phase in the tube's centre. A velocity-dominated exposure is achieved when they are 180° out of phase. Appropriate driving signals for achieving each of these four conditions are determined empirically by driving the device with two orthogonal signal sets while measuring pressure and velocity at the centre of the tube. The complex weighting coefficients that allow the measured conditions to be summed to yield the desired conditions are then computed and used to weight a sum of the sets. Impulse responses derived in this way can be convolved with any desired pressure or velocity signal to determine the appropriate drives to generate that waveform and condition.

A correct acoustic radiation load on the subject is maintained because the volume of water is small in comparison with an acoustic wavelength and large in comparison to the subject's volume. It is also necessary that the pistons be lightweight and softly suspended. These requirements have been analyzed in previous papers (Lewis 1998; Martin 2005).

RESULTS

The completed fishabrator with its major components labelled is shown in Figure 1. In initial testing, the device has met its design criteria.

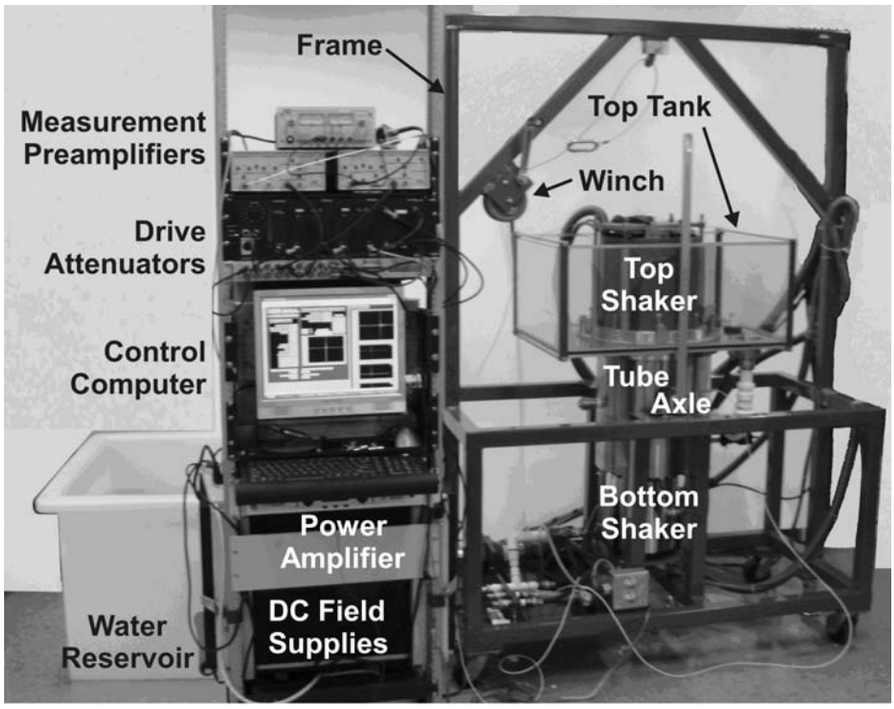

Figure 1. Assembled fishabrator.

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