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Underwater click hearing thresholds of a harbour seal, *Phoca vitulina*

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Summary

Underwater hearing thresholds of a harbour seal (*Phoca vitulina*) presented with short duration sounds (clicks) were measured. Single square wave pulses which produced a broad bandwidth spectrum were detected at 93 to 95 dB re 1 μPa peSPL (peak equivalent sound pressure level). Detection thresholds of other short duration, broad bandwidth sounds were no higher than 99 dB re 1 μPe peSPL. As with humans listening in air, these values are 30–40 dB above the detection threshold of a continuous pure tone at the most sensitive frequency. Assuming a similar detection threshold, the underwater click vocalization produced by harp seals (*Phoca groenlandica*) would have a detection range of 0.064–1 km.

Introduction

Harp seals (*Phoca groenlandica*) emit a wide variety of underwater vocalizations. Call types range from almost pure tones lasting seconds to clicks that are shorter than 0.1 msec (Møhl *et al.*, 1975). The bandwidth of a sinusoidal pulse can be approximated by the inverse of its duration (Garner, 1947). It is not possible to produce a pure tone a few cycles long; such sounds present energy over a wide frequency band. Clicks thus present a broad bandwidth of energy for a very short duration. The underwater, pure tone, hearing thresholds for various seal species have been measured (Møhl, 1968; Terhune & Ronald, 1972, 1975; Ridgway & Joyce, 1975; Terhune, 1988). To estimate the sensitivity of seals to clicks, underwater detection thresholds of a harbour seal (*Phoca vitulina*) were determined for a number of very short duration sounds. By comparing this sensitivity to the sound pressure level of clicks produced by harp seals (Møhl *et al.*, 1975) the maximum communication distance of this call type can be estimated.

Materials and Methods

This study followed an investigation of the underwater hearing thresholds of a harbour seal presented with pure tones of various durations (Terhune, 1988). Testing was conducted in an indoor, 4.5 m diameter, 1 m deep tank. During testing, a stimulus switch was lowered into the centre of the tank, 0.5 m from the bottom and 0.5 m from the sound source (a Bruel and Kjaer 8100 hydrophone). A 5-year old harbour seal (used in the previous study) had been trained to indicate the presence or absence of a test sound when it pushed the underwater stimulus switch. It did this by pushing 1 of 2 additional switches ('yes' or 'no'). Correct responses were rewarded with pieces of fish. A pulse generator and signal generator combination was used to trigger a Wavetek 112 signal generator when the seal depressed the stimulus switch (signal mode). The signal was passed through a step attenuator (Wavetek 5080) and an amplifier-voltmeter (Bruel and Kjaer 2409) to the transmitting hydrophone. In the no-signal (catch trial) mode, the experimenter opened the circuit and the signal generator could not be triggered by the seal.

For each sound type, detection thresholds were estimated using a modified constant stimulus method. Each testing session presented 2 or 3 warm-up trials followed by 10 signal trials (all of the same level) interspersed among 10 catch trials. The sound pressure levels of the 10 test trials presented at subsequent sessions were reduced by 4 dB steps (per session) until the seal's correct responses to both signals and catch trials (summed) was 12/20 or less. The sound pressure level of the next session was raised by 2 dB and, if appropriate, a final session 4 dB louder was presented. Data from 3 to 6 stimulus levels, (2 dB apart, 10 signal and 10 catch trials per level), were used in the threshold calculations. The thresholds (50% correct, signal and catch trial responses summed) were calculated using a constant stimulus method (Guilford, 1954). Three testing sessions per day, at least 2 hours apart, were conducted for 5–6 days per week.

Two sets of signals were presented to the seal. The first set consisted of single, 8, 16, 31 or 63 μsec rectangular pulses (i.e. the first half of a square wave of 64, 32, 16 or 8 kHz) at a rate of 10/sec. The second set presented unfiltered, 16 kHz sine wave pulses. Pulse lengths were 1600, 160, 16, 8, 4, 2 or 1 cycles long and were presented at repetition rates of 4 (1600 cycles only) or 10/sec. The square wave frequencies were selected in an attempt to present clicks having energy at different frequencies. The repetition rate was similar to that of a previous study (Terhune, 1988) as were the durations of the 16 kHz pure tones.

RMS (root mean square) sound pressure levels were determined by placing a calibrated hydrophone (Bruel and Kjaer 8100) at the place where the seal's head would be while it pressed the stimulus switch. The received signal was amplified (Bruel and Kjaer 2635) and passed to either a sound level meter (Bruel and Kjaer 2203) equipped with an octave filter (Bruel and Kjaer 1613) or a Gould 1425 storage oscilloscope. The output voltage to the transmitting hydrophone which resulted in the production of a particular sound pressure level was recorded.

It is difficult to measure the sound pressure level of a very brief sound (Stapells *et al.*, 1982). The loudness of a click can be described in terms of peSPL (peak equivalent sound pressure level). The peSPL is defined as the root mean square sound pressure level of a continuous pure tone having the same amplitude as the (click) transient (Stapells *et al.*, 1982).

With the transmitting and receiving hydrophones 15–20 cm apart, the peak-to-peak amplitude of a 0.5 sec, pure tone at 8, 16, 32 and 64 kHz was measured using the oscilloscope. The output voltage to the transmitting hydrophone was also recorded. For each of the signal types presented to the seal, the highest peak-to-peak amplitude of the received waveform was measured. By linking the received peak-to-peak voltages with the respective voltages going to the output hydrophone and the sound pressure levels generated at the seal's position by these output voltages of the 0.5 sec pulses, it was possible to calculate the peSPL for the various test signals presented to the seal. It was assumed that shorter duration sounds having the same output voltage as the 0.5 sec pulses would also generate the same peak sound pressure level. This method provided a link between the RMS sound pressure levels of longer pure tones and the peak-to-peak voltages of the shorter signals. The 15–20 cm distance between the transmitting and receiving hydrophones was required to obtain a sufficiently high signal to noise ratio for analysis purposes.

The spectral content of each signal type was estimated by passing the received signal (at high repetition rates) to a Tektronix 7L5 spectrum analyser (bandwidth 1 KHz). The output characteristics of the transmitting hydrophone (Fig. 1C) were measured by determining the spectrum of a continuous white noise signal (Dawe 419C).

Results

Although the duration of the rectangular pulses varied, the overall shapes of the resulting spectra (Fig. 1A) were similar to the output characteristics of the hydrophone (Fig. 1C). A transient (click) occurred at the onset of the 16 kHz sine wave pulses (including the single cycle). The peSPL of the transient was 8 dB above that of the sine wave. The dominant energy of the long duration sine wave pulses was at 16 kHz (Fig. 1B). As the pulses were shortened, the proportion of the energy contributed by the transient became predominant (Fig. 1B). The detection thresholds for the stimulus types presented are given in Table 1. The thresholds for the 16 kHz sine wave stimuli are presented using measures based on the signal output voltages at 16 kHz (RMS) and the peSPL of the transient.

Discussion

The calibration procedure used to estimate the spectral content of the various signal types necessitated the close proximity of the sending and receiving hydrophone. As a consequence, it is possible that the receiving hydrophone was in the near-field range at frequencies below 16 kHz. During testing, the seal may similarly have been in the near-field range for frequencies below 8 kHz. The output level of the transmitting hydrophone at these lower frequencies is very low but possible near-field influences cannot be discounted.

The broadband nature of the clicks was such that the acoustic signal followed the output characteristics of the hydrophone (Fig. 1A and 1C). The greatest sound energy presented was near 60 kHz which is the region in which the seal's hearing becomes quite insensitive (Terhune, 1988) and the seal loses its ability to discriminate pitch (Møhl, 1964). The four rectangular pulse thresholds are similar (Table 1) in spite of the fact that each was calculated using a different conversion between RMS and peak-to-peak (peSPL) values. The thresholds for one and two cycle 16 kHz sine waves (plus the transient) were three to six dB above those of the rectangular pulses. Thus, while the output characteristics of the transmitting hydrophone limited the energy distribution of the short sounds, the responses by the seal varied little. The seal hearing system may well be reacting to the amplitude of the pressure wave and not integrating the sound energy per sec. A study which presented short duration pulses suggested that the seal hearing system integrates a series of sound pressures, not sound energy (Terhune, 1988).

When medium differences are taken into account, the maximum sensitivity for long duration pure tones of humans in air is similar to that of seals underwater (Terhune & Ronald, 1972). Measures of human hearing thresholds for clicks (in air) range from 29.9 to 36.5 dB re 20 μPa peSPL (Stapells *et al.*, 1982). These values correspond to a sound pressure level range of 91.4 to 98 dB re 1 μPa peSPL underwater (Albers,

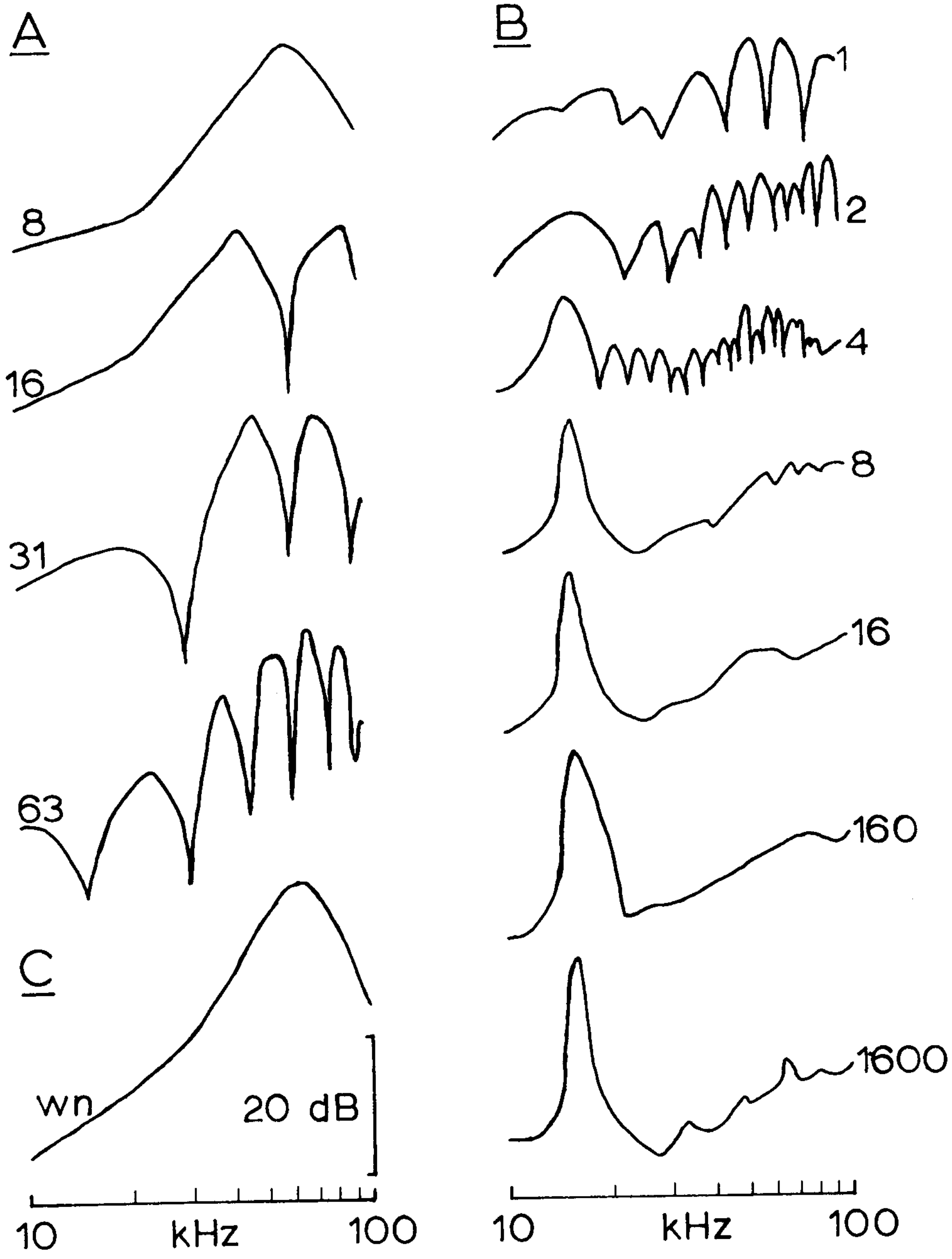

Figure 1. Spectra of the test signals and a white noise source; analysing bandwidth 1 kHz. A, rectangular pulses of various durations (µsec); B, 16 kHz since wave pulses, various number of cycles; C, output characteristics of the transmitting hydrophone determined by broadcasting white noise.

1965). That is, both sets of values are about 30–40 dB above the detection threshold of a continuous pure tone (at the most sensitive frequency).

Thresholds of the 3 longest 16 kHz sine wave pulses (Table 1) were within 4 dB of previous determinations (same seal) in which a filter reduced the

Table 1. Harbour seal underwater detection thresholds (± 1 standard deviation) for short duration sounds. RMS = root mean square sound pressure level of the sinusoidal pulse; peSPL = peak equivalent sound pressure level of the highest amplitude transient; all sound pressure levels in dB re 1 μPa

	Number of cycles	Sinusoidal Pulse (RMS)	Transient (peSPL)
Rectangular pulses			
8 μsec	1		93 ± 4
16 μsec	1		95 ± 4
31 μsec	1		95 ± 5
63 μsec	1		93 ± 3
16 kHz Sine wave			
	1600	64 ± 2	72 ± 2
	160	70 ± 2	78 ± 2
	16	81 ± 4	89 ± 4
	8	80 ± 14	88 ± 14
	4	75 ± 19	83 ± 19
	2	91 ± 4	99 ± 4
	1	90 ± 5	98 ± 5

onset and offset transients (Terhune, 1988). The spectra of these signals clearly indicate that the 16 kHz components are of the greatest magnitude (Fig. 1B). The spectra of the 4 and 8 cycle pulses indicate that sound energy is generated by both the centre frequency of the pulse (16 kHz) and the click transients (Fig. 1B). For the 1 and 2 cycle pulses, the higher frequency components generated by the transients predominate (Fig. 1B). Extrapolation of data obtained using filtered sine waves (Terhune, 1988) suggests that the thresholds for 2 and single cycle pulses would be 96 and 101 dB re 1 μPa(RMS). These values are similar to the click thresholds measured in terms of peSPL but almost 10 dB above the RMS estimates. It is likely that the thresholds of longer pulses are best expressed in dB(RMS) while those of the shortest pulses are best represented by the dB peSPL method of calibration. The large size of the standard deviations of the 4 and 8 cycle determinations (Table 1) may reflect the seal's uncertainty as a result of the transition from one signal type to the other.

This study is limited by the availability of a single seal, only one transmitting hydrophone (and hence only a single general output characteristic for the broad band pulses) and the lack of a suitable spectrum analyser which could record a single transient and thus permit an estimation of the absolute energy content of the clicks presented to the seal. The similarity between the various thresholds suggests that until more precise measures from a greater number of animals are obtained, the thresholds in terms of peSPL will serve to approximate the sensitivity of seals to clicks. Click vocalizations that have a very short duration, and hence are broadband, would not be greatly dissimilar from the click stimuli presented in this study.

Harp seal broadband clicks are between 131 and 164 dB re 1 μPa peSPL at 1 m and have peak energy at 30 kHz (Møhl *et al.*, 1975). Assuming spherical spreading loss, absorption losses and that harp and harbour seals have similar thresholds (Terhune & Ronald, 1972), these clicks would reach the 50% detection levels between 64 m and 1 km. It is likely that any behavioral significance associated with this vocalization will be limited to a relatively short distance.

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