Aerial Hearing Sensitivity in a Steller Sea Lion

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The Steller sea lion (*Eumetopias jubatus*) is the largest of the otariid pinnipeds, and inhabits a geographic range in the North Pacific Ocean from Japan to Central California. Like all pinnipeds, the Steller sea lion is amphibious; while all foraging activity takes place in the water, breeding behavior is carried out on land in coastal rookeries. Males regularly use loud, relatively low-frequency calls to establish breeding territories. In addition, individually distinct vocalizations exchanged between mothers and pups are thought to be the main modality by which reunion occurs when mothers return to crowded rookeries following foraging at sea. Detection of vocal cues amongst individuals is therefore of critical importance to Steller sea lion reproductive behavior.

Although no data regarding aerial hearing capabilities are available for Steller sea lions, aerial hearing sensitivity curves have been obtained for two of the nine otariid pinniped species: the California sea lion (*Zalophus californianus*) and the northern fur seal (*Callorhinus ursinus*). The audiograms obtained for these two species display similar characteristics; an increase in sensitivity between 1 and 2 kHz, a decrease in sensitivity between 2 and 4 kHz, and a sharp decrease in sensitivity indicating an upper-frequency limit between 16 and 32 kHz. While extrapolation of hearing data from these two otariid species to the Steller sea lion may by of some general use, the latter exhibits differences both in body morphology and sound production that may influence hearing capabilities.

We measured the unmasked aerial hearing sensitivity of a one-year-old male Steller sea lion using psychophysical methods and positive reinforcement. All testing took place in a hemi-anechoic sound-attenuating chamber in which ambient noise levels were measured. Testing was conducted across a frequency range from 0.125 to 34 kHz. Three thresholds per frequency were collected using a modified method of limits (or "staircase") procedure. False alarm rates for all frequencies were between 6 and 26 percent, with the exception of 20 kHz, where the subject had a false alarm rate of 0 percent.

The audiogram displayed a characteristic mammalian U-shape with a steep high-frequency roll-off above 28.2 kHz and a shallower low-frequency roll-off below 1 kHz (Figure 1). The subject's thresholds were consistent between sessions, resulting in a relatively small spread of data for the three thresholds determined at each frequency. The range of best hearing sensitivity was between 5 and 14.1 kHz. Maximum sensitivity was found at 10 kHz, where the subject had a mean threshold of 7 dB re: 20 μPa. Ambient noise levels in the sound-attenuating chamber were measured at the position of the subject's head without the subject present (Figure 1). Noise levels, measured in dB re: 20 μPa/√Hz, generally decreased with increasing frequency, dropping below 0 dB above approximately 0.6 kHz. At the frequency of maximum sensitivity, the noise spectrum level was approximately 12 dB below the subject's threshold. The noise levels at the mid to high frequencies were probably the result of electrical limitation of the measurement system. True acoustic noise levels were; therefore, most likely lower than the measured values at the mid to high frequencies. Thus we have assumed the subject's thresholds to be unmasked across the tested frequency range.

In terms of frequency range of hearing and absolute aerial sensitivity, these results are similar to those previously reported for the California sea lion and the northern fur seal. Of note is the decrease in

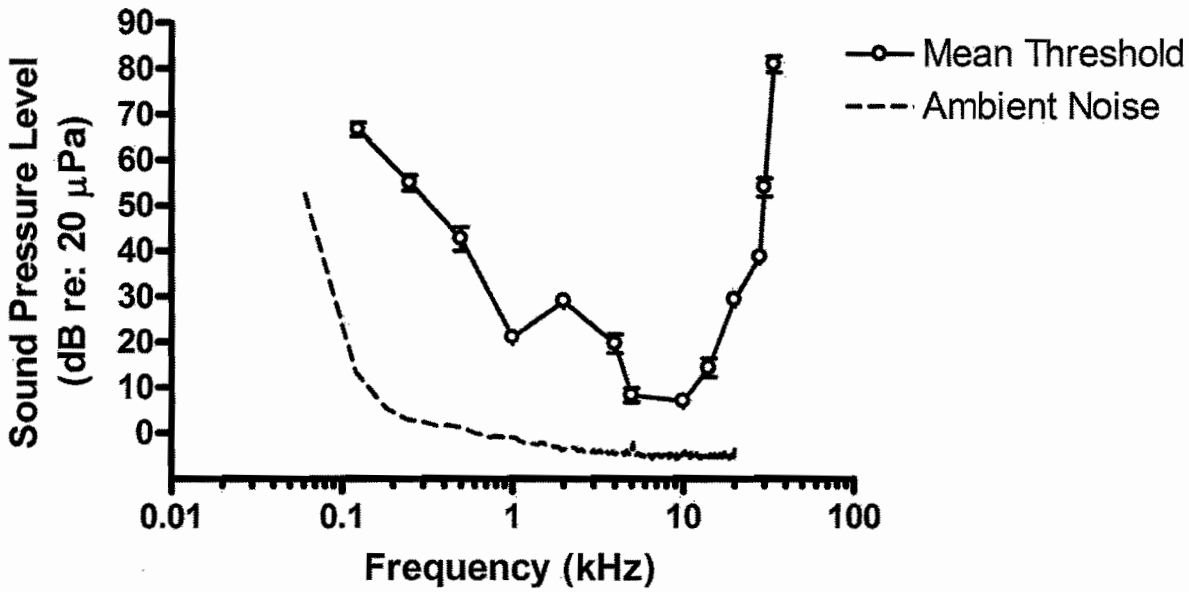

Fig. 1. Aerial audiogram of a one-year-old male Steller sea lion. Error bars (when larger than data symbols) indicate standard deviation. The dashed line is a measurement of the ambient acoustic noise level in the testing environment in dB re: 20 μPa/√Hz, measured at the location of the head of the subject.

sensitivity at 2 kHz, a feature which is also present at similar frequencies in the two previously tested otariid species. Based on the absolute aerial sensitivity and frequency range of hearing in the three species tested to date, it seems that it may be reasonable to treat otariid pinnipeds, despite differences in size and sound production, as a functional hearing group with respect to aerial capabilities.

When these data are compared to previously reported underwater hearing thresholds for the Steller sea lion (Kastelein et al., J. Acoust. Soc. Am. 118, 1820-1829, 2005), the most sensitive thresholds are found in air, regardless of whether sound pressure or sound intensity is used as the relevant metric. This finding suggests that hearing in otariid pinnipeds is primarily adapted for hearing in air; an unsurprising result in light of the important roles that aerial vocalizations play in Steller sea lion reproductive behavior. The fact that more sensitive thresholds were found in air in this study and not in previous studies is most likely a result of the extremely quiet aerial testing environment in which this experiment took place.

The frequency range of best auditory sensitivity as determined in this experiment is well above the frequency range of Steller sea lion vocalizations, which typically have dominant energy below 3 kHz. This is contrary to the assumption that hearing sensitivity of a given vocal species is precisely tuned to the frequency range of their vocalizations. Based on our findings, knowledge of the frequency range of vocalizations is not sufficient to accurately predict the range of best hearing sensitivity in the Steller sea lion.