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Effects of Diving on Auditory Sensitivity of California sea lions (Zalophus californianus)

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13. ABSTRACT *(Maximum 200 words)*

We obtained underwater hearing thresholds from a male California sea lion at frequencies of 2.5, 6, 10, and 35 kHz, and at depths of 10, 50, and 100m. Results showed systematic changes in response bias with changes in depth; false alarm probabilities decreased significantly with depth, indicating that the sea lion adopted a more conservative response criterion in deeper water. Sensitivity at frequencies below 35 kHz decreased with depth, while sensitivity at 35 kHz increased with depth. Increasing pressure with depth probably affects the size of the middle ear air space due to the expansion of cavernous tissue into the middle ear cavity. Our findings are consistent with the idea that the middle ear impedance changes with depth, altering the frequency response and sensitivity of the ear. Thus, the sea lion middle ear plays a functional role in underwater sound detection. However, the presence of cavernous tissue in the sea lion middle ear does not appear to enhance sensitivity at depth except at high frequencies.

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PRINCIPAL INVESTIGATOR: Dr. Ronald J. Schusterman

INSTITUTION: University of California, Santa Cruz

GRANT TITLE: Effects of diving on the auditory sensitivity of California sea lions

AWARD PERIOD: 1 July 1997 - 31 December 1999

OBJECTIVE: To resolve the role of pressure on auditory sensitivity at depth and to provide the first open water audiometric data from a California sea lion (*Zalophus californianus*).

APPROACH: A 12-year old male California sea lion was trained to respond to acoustic pure tones in a go/no-go psychophysical procedure. The signal detection experiments were conducted at depths of 10, 50, and 100 m in the Pacific Ocean, 4-6 miles west of Point Loma, San Diego, California.

ACCOMPLISHMENTS: Auditory thresholds were obtained at frequencies of 2.5, 6, 10, and 35 kHz, at depths of 10 and 50 m. Additionally, several thresholds were obtained at frequencies of 2.5 and 6 kHz at a depth of 100 m. Two significant findings were observed. First, false alarm rates were greater at 10 m than at 50 and 100 m, indicating a change in the subject's response bias related to depth (or one of its correlates, such as ambient light level, temperature, or pressure). Second, there was a significant effect of depth on thresholds and a significant interaction between depth and frequency. Low frequency thresholds (up to 10 kHz)were lower near the surface, while high frequency thresholds (35 kHz) were lower at depth. Thresholds compared between depths of 10 and 50 m (holding frequency constant) showed significant differences at all frequencies except 2.5 kHz. Data obtained from a single sea lion in a shallow tank (Schusterman et al., 1972) are similar to the 10 m data obtained in the present study.

CONCLUSIONS: The results of this study suggest that comparisons between hearing thresholds obtained in tanks and the hearing capabilities of free ranging animals may only be valid for shallow water. The reasons for the loss in sensitivity with depth may be related in some way to the changes in response bias. However, controls using a signal detection approach showed that response bias only partially influenced threshold estimates. Conventional thinking, that the air-water interface at the tympanic membrane acts as a reflective barrier to the transmission of sound, may be incorrect, especially at low frequencies, where the sound wavelengths are many times larger than the structures of the ear. At these frequencies, the middle ear space may act as a highly damped resonant bubble, similar in action to the swim bladder of a fish. Changes in pressure, density and volume would then be expected to have frequency-dependent effects on hearing sensitivity. The interface between the environment and the middle ear space might only become important as a barrier to sound transmission at high frequencies where the wavelengths are similar in size to the middle ear, external meatus, and other tissue and bony structures surrounding the ear. Thus, in shallow water, high frequency sensitivity would be relatively poor, because of the reflection of sound energy at the middle ear. In deeper water, sensitivity may improve because of better impedance matching due to the expansion of cavernous tissue on both sides of the tympanic membrane. This line of thinking leads to two separate types of change in the middle ear to account for patterns of sensitivity change occurring with depth. At low frequencies, changes in the resonance properties of the middle ear space affect sound transmission in a frequency dependent manner. At high frequencies, expansion of cavernous tissue increases the efficiency of sound transmission through the ossicular pathway, also leading to frequency-dependent alterations in sound transmission with depth (but possibly in the opposite direction).

<u>SIGNIFICANCE</u>: This study shows that underwater hearing sensitivity varies as a function of depth in *Zalophus californianus*. Although apparently less sensitive to low frequency sounds at depths corresponding to typical dives

than near the surface, these animals might be much more sensitive to high frequency sounds at such depths.

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1. Kastak, D., and Schusterman, R.J. (1999). Loss of hearing sensitivity with depth in a free diving California sea lion (*Zalophus californianus*). Abstract presented 1 December 1999, 13th Biennial Conference on the Biology of Marine Mammals, Maui, Hawaii.

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Loss of hearing sensitivity with depth in a free diving California sea lion (*Zalophus californianus*)
D. Kastak and R.J. Schusterman

All current knowledge of underwater hearing in most marine mammals, including pinnipeds, is based on data obtained in small tanks and shallow water. These data may not accurately represent the auditory functioning of free-ranging animals if hearing sensitivity changes with increasing depth. In order to compare hearing ability in shallow water and at depth, we trained a 12-year-old male California sea lion to report detection of pure tones (2.5, 6, and 10 kHz) at three depths (10, 50, and 100m). A go/no-go psychophysical procedure was used, in which the subject pressed a paddle upon detection of a 500-ms tone. Initial results showed systematic changes in response bias with changes in depth; false alarm probabilities (responding in the absence of a signal) decreased significantly with depth, indicating that the sea lion adopted a more conservative response criterion in deeper water. Because of changes in response bias we defined auditory thresholds as signal levels corresponding to a d-prime value of 1.0 (rather than the traditional 50% correct detections). Thresholds increased significantly with increasing depth. There was also a significant interaction between depth and frequency—the depth effect was least pronounced at 2.5 kHz and most pronounced at 10 kHz. Increasing pressure probably alters the impedance characteristics of the pinniped ear, in particular affecting the size of the middle ear air space due to the expansion of cavernous tissue into the middle ear cavity. Our findings are consistent with middle ear impedance changes, which should alter the frequency response and sensitivity of the ear. Therefore we conclude that the middle ear plays a functional role in underwater sound detection in California sea lions. However, contrary to previous speculation, the presence of cavernous tissue in the sea lion middle ear does not appear to enhance sensitivity at depth.