An Animal Model for Underwater (UW) High Intensity High Frequency and Impulse Sound Exposures

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Abstract

Background: Deleterious effects of continuous wave (CW) UW high intensity, LFA (Low Frequency Active) sound on auditory and vestibular function and histology has been previously shown in a guinea pig model. When UW, LFA sound at 190 dB was delivered at frequencies of between 750 and 2500 Hz, a decrement in the horizontal vestibulo-ocular reflex (VOR) gain, off-vertical axis rotation bias, and auditory brainstem response threshold was noted. Although testing was carried out at 160, 180 and 190 dB, the most significant loss of auditory and vestibular function occurred at 750Hz frequency, especially with the 190 dB exposed group. Findings suggested that the threshold for auditory and vestibular damage is greater than 180 dB at the frequencies tested. This study investigated the damaging effects of waterborne high intensity, high frequency, CW and impulse sound on hearing and balance measures.

Methods: Guinea pigs were anesthetized, intubated, immersed and exposed to 180 or 190 dB CW noise for 10 seconds at a frequency of 50 kHz. Another group was exposed to 5 sound impulse waves(each impulse lasting 2 seconds). Control groups were anesthetized and immersed for the same time period but received no sound exposure. Subjects were tested for vestibular and auditory measures both before and 48 hours after immersion/sound exposure.

Results: Our data suggest that for continuous wave exposure significant auditory effects occur primarily at 22kHz for 180db SPL. Significant effects are seen at 8kHz and 22kHz for the impulse exposure . Upon review of HVOR and OVAR data, there did not appear to be any significant effect on vestibular function as measured by VOR.

Conclusions: UW high frequency sound exposure at 50 kHz appears to produce damaging effects to high frequency auditory function, primarily around 22kHz.

Introduction

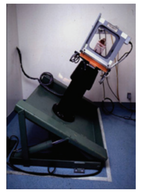
Underwater (UW) sound was been proposed as a possible non-lethal deterrent which may act on the vestibular system of hostile divers. Exposures to loud, acute and long-term impulse or continuous underwater noise can result in dysfunction of both auditory and vestibular systems. Studies where divers were exposed to prolonged continuous, intense, pure tone UW sounds demonstrated significant auditory temporary threshold shifts (TTS), as well as "non-auditory" effects, such as head vibration, tickling and ringing in the ear and watering of the eyes. A number of diver studies were performed at the NSMRL investigating the thresholds for UW hearing, sound tolerance, and vestibular responses. These reported varying subjective effects (lightheadedness, head vibration and tingling, unsteadiness)

Several other studies noted auditory or neurological abnormalities after underwater noise exposure.The purpose of this study is to elucidate the effects of continuous wave (CW) sound and impulse sound on the auditory, vestibular, and central nervous systems of guinea pigs.

Methods

Subjects were female guinea pigs (Harlan Sprague Dawley) weighing 300 – 500 grams with good hearing. Controls were anesthetized & submersed for same duration but no sound (control for anesthesia and immersion effects). All animals were surgically prepared for VOR measures with scleral search coil and head fixation bolt (10 days recovery). Prior to UW immersion, animals were anesthetized with Telazol/xylazine mixture. Stabilization period for UW immersion was at least 3 minutes. Sound exposures consisted of high Frequency continuous @ 50khz for 10sec or impulse (5 impulses at 1 per 2 sec). Sound was delivered @180 and 190 dB re:1µPa. Metrics included: Hearing using Auditory Brainstem Response & balance or vestibular ocular reflex (VOR) determined pre + 48 hrs post UW. ABR were assessed @ pure tone frequencies between 4-28 kHz; Horizontal VOR @ angular freqs 0.05 -2.0Hz + Off-Vertical Axis Rotation (OVAR) response to changing gravity vectors between 20 and100 deg/s. Analyses: performed repeated measures 2-way ANOVA; Newman Keuls Post Hoc for significance at 0.05 level.

Rotation Table for testing Earth-vertical Axis Rotation (EVAR) which tests Lateral Semi-circular Canal Output or HVOR



Position of table to test Off-vertical Axis Rotation (OVAR) (tests Otolithic Sensor Output or changing gravity vector

Methods

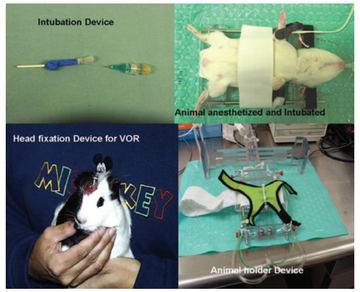
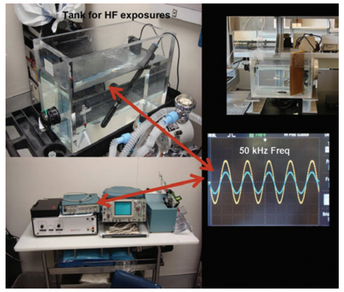
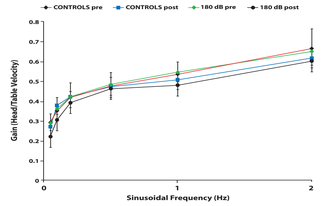


Figure 1A & B. The left panel shows the high frequency sound set up. The sound source is a fish finder transducer that emits a 50kHz signal (see inset). The right panel shows the intubation device and an anesthetized guinea pig on the holder. The lower left of this panel depicts an animal with the head fixation device implanted for performing balance measurements.

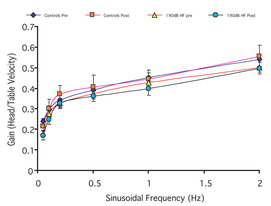


Results

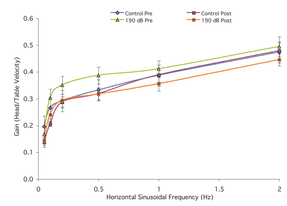
HVOR Gain for Pre-Post Controls & 180dB Exposed (50kHz Continuous Wave)



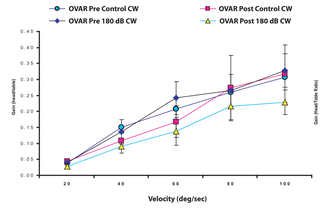
HVOR Gain for Pre-Post Controls & 190dB Exposed (50kHz Continuous Wave)



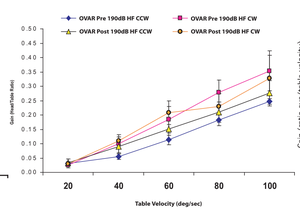
HVOR Gain for Pre-Post Controls & 190 dB Exposed (Impulse Sound)



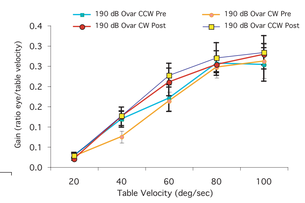
Off-Vertical Axis Rotation for Pre-Post Controls & 180dB Exposed (50kHz Continuous Wave)



CCW ^ CW Off-Vertical Axis Rotation for Pre-Post Controls & 190dB Exposed (50kHz Continuous Wave)

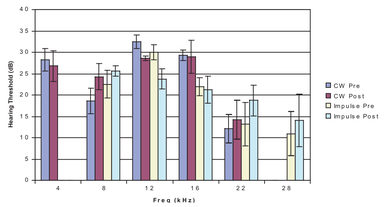


Pre-Post CCW & CW OVAR Gain for 190 dB Impulse Sound Exposures

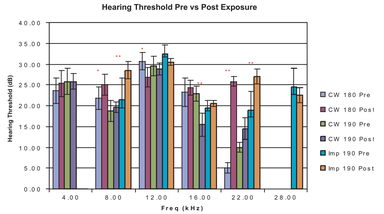


Results

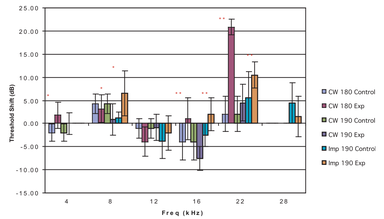
Controls Pre vs Post Exposure



Hearing Threshold Pre vs Post Exposure

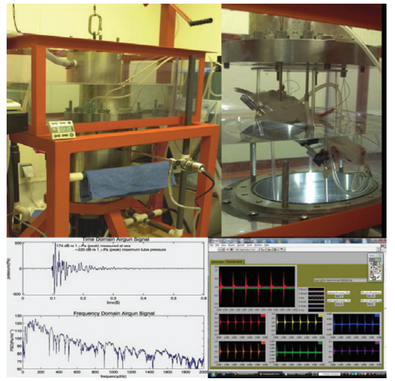


Threshold Shifts Control vs Exposure



* Significant for p<0.05 ** Significant for p<0.01

Figure 2



Conclusions

- All animals that were exposed to UW sounds did not show outward signs of inner ear or neurological damage (no head tilt, circling, etc)
- Short-term exposure to high frequency CW underwater sound produced no significant functional effects on the vestibular system as measured by HVOR and OVAR 48 hours after the exposure
- 180 dB CW UW sound produced significant auditory effects at 48 hrs primarily at 22 kHz. 190dB CW UW sound showed effects at 8kHz and 16kHz. 190dB Impulse sound produced significant auditory effects at 8KHz and 22kHz
- UW impulse sound delivered at 5 pulses over 10 seconds at 190 dB intensity was not significantly damaging to the vestibular system but appears to cause some auditory TS at higher frequencies measure
- ABR threshold shifts of this magnitude at 48 hrs post exposure do not represent physiological conditions at exposure (threshold changes most likely greater) may have recovered as much as 25-50% or more and may not be completely recovered (still TTS)
- Auditory threshold shifts at 22 kHz ranged from 4 – 20 dB. ABR threshold shifts of this magnitude may not greatly affect hearing especially if the TS occur at such high freqenciess 22 and 28 kHz (above the sensitivity range for humans)
- Although a few effects demonstrated for both HF and impulse, these may not have significant physiological or clinical meaning

Acknowledgements

Thanks to Naval Submarine Medical Research Lab for their guidance and support. Also our gratitude to the Naval Medical Center San Diego Otolaryngology Department, Veterinarian and staff of the Animal Research Facility for their help with this project and to Ms. Judy Christiansen for producing this poster presentation.