HELMET NOISE AND DIVERS' HEARING

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ABSTRACT

The effects of diving helmet noise on the hearing of divers were assessed during two helium-oxygen saturation dives to simulated depths of 650 and 850 feet of sea water. Twelve male U.S. Navy divers in excellent health and possessing good hearing underwent a series of exposures to deep-sea diving helmet noise for periods up to 4 hours per day. Audiograms were conducted before and after each noise exposure. Noise from inside the manned helmet was recorded while the diver was exercising and resting. Noise levels actually recorded from inside two helmets at depth would normally have limited diver exposure to one hour or less by present U.S. Navy airborne noise standards. However, close monitoring of divers' hearing indicated that dives up to 4 hours in duration could be accomplished in these diving helmets. Moderate threshold shifts were observed in all divers after 4-hour helmet noise exposures; however, these shifts were temporary and divers' hearing returned to within 5 dB of pre-noise exposure levels by 24 hours post-exposure. Follow-up studies indicated no permanent hearing loss was incurred.

1. INTRODUCTION

According to tradition and occasional reports in the diving literature, diving can lead to auditory impairment¹. However, if one accounts for prior noise exposure and age differences, there is some evidence that the hearing threshold levels (HTLs) of divers and non-divers are not significantly different^{2,3}. A comprehensive review of the literature was recently conducted by Molvaer and Lehmann⁴, who found it difficult to conclude whether the hearing threshold is higher in divers than non-divers. However, their own study of 164 professional divers found that the divers' hearing thresholds were elevated in the high frequencies in all age groups as compared to ISO normality curves. This result suggested that professional diving can lead to accelerated high-frequency hearing impairment.

The effects of dry helmet noise on diver audition have only recently received attention. Noise was measured in Superlite 17 and Siebe-Gorman helmets with and without the concurrent use of underwater tools at shallow depths with the diver breathing air⁵. Auditory temporary threshold shifts were assessed, and the authors concluded that lengthy

exposures to combined helmet and tool noise could be hazardous to the divers' hearing.

At present, there is no general hearing conservation standard for dry helmet noise, with or without the use of underwater tools. The literature suggests that the sensitivity of the ear is reduced under dry hyperbaric conditions, with the most common explanation centering on increased acoustical impedance in the external ear canal and middle ear mechanism^{6,7}. Nevertheless, current directions by the U.S. Navy state that the hearing conservation standards set forth for use in 1.0 ATA air environments be applied to the use of dry helmets under hyperbaric conditions with different gas mixtures.

Initial studies conducted at the Navy Experimental Diving Unit (NEDU) suggested that the present U.S. Navy limits for airborne noise exposure may be conservative for application in a high-pressure helium-oxygen environment. The purpose of this paper is to present our findings on the effects of prolonged exposure to helmet noise on diver hearing.

2. METHOD

Subjects

Twelve male U.S. Navy divers, aged 24 to 33, served as diver-subjects. All men were volunteers in excellent health and in superior physical condition as a result of rigorous physical training regimens completed before the saturation dives. All divers underwent extensive screening, including auditory evaluations before final selection. The hearing threshold levels (HTLs) of all subjects were 20 dB or below in both ears at frequencies of 3000 and 4000 Hertz (Hz) as assessed by standard audiogram techniques. Further, these men demonstrated reliable, systematic threshold shifts and recovery at 4 kHz following exposure to a 100 dB, 3 kHz fatiguing stimulus for 3 min during training sessions. Otoscopic examination and auditory history revealed no significant abnormalities or contraindications to participation in the auditory studies.

Apparatus

Acoustic studies were conducted during two helium-oxygen dives to simulated depths of 650

and 850 feet of sea water (FSW) in NEDU's Ocean Simulation Facility (OSF), a hyperbaric living and working complex. Divers lived in the dry portion of the complex, and worked under water in the OSF's 55,000 gallon wet chamber. Two bicycle ergometers were modified locally for use in the wet chamber. Two prototype deep-sea mixed-gas diving systems, similar in design, were installed in the OSF and used during the studies. Divers wore hot water suits with liners.

To assess helmet noise, Bruel and Kjaer (B&K) pressure response condensor microphones (#4134), dehumidifiers and preamplifiers were used. The helmet microphone was attached inside the diving helmet near the diver's right ear. A B&K 2807 microphone power supply was used to obtain the microphone signal. A water-blocked sound cable penetrated the helmet, ran through the water, and penetrated the pressure hull. Coaxial cable carried the microphone signal from the pressure hull to a B&K digital frequency analyzer (DFA; 2131). A Hewlett Packard 9845 calculator was connected to the DFA using a IEEE interface buss. B&K 4144 pressure response condensor microphones were used to measure noise levels in the hyperbaric chambers, and to calibrate earphones used in audiogram testing. Calibration of both 4134 and 4144 microphones was accomplished by using appropriate sized electrostatic actuators (B&K UA 0033; UA 0023). The signal to the actuator was provided by a Wavetech 273 signal generator, and amplified by a B&K 2713 high voltage power amplifier. A Tracor RA 400 microprocessor audiometer with matched Telephonics TDH-39P 10 ohm earphones were used to administer audiograms. A 1000 pound sound-attenuating audio booth was custom designed and fabricated to fit inside the OSF living chamber. This booth met ANSI standard S3.1 criteria for noise attenuation at 1.0 ATA in an air environment.

Procedure

Acoustic testing was conducted at pressures of 1.0, 20.7 and 26.8 atmospheres absolute (ATA), pressures equivalent to those found at 0, 650 and 850 FSW. At pressures greater than 1.0 ATA, the partial pressure of oxygen was maintained between 0.40 and 0.45 ATA in a 97% helium environment. Water temperature was maintained at 2°C.

All sound equipment was calibrated before and after each saturation dive at 1.0 ATA. Daily calibrations during the dive were conducted to detect instrumentation drift. Helmet microphones were calibrated before and after each wet exposure. Other microphones and the earphones were calibrated at the start and completion of each day's testing. Before each wet dive, the diver underwent an audiogram test (500 → 8000 Hz, both ears) in the audio booth. He was then dressed and the helmet placed on his head. The diver then descended into the wet chamber and began pedalling the bicycle ergometer at 60 rpm on a 6 min work/4 min rest cycle for the duration of the dive. Resistance was set at 50 watts. Helmet noise data was recorded continuously

during 10 minutes of each hour of the dive when the diver was exercising and resting. That is, four 10-minute samples were taken during a 240-minute dive. Mean third octave band levels were then corrected for microphone sensitivity attenuation and impedance of the medium. The corrected octave bands were then combined using the formula $L_{comb} = 10 \log_{10} (\sum 10^{L_i/10})$, where L_i = corrected octave band level center frequency. This yielded an overall sound intensity level.

Within 3 minutes after completion of the dive, the diver began a post-dive audiogram in the audio booth. Follow-up audiograms were routinely conducted that evening and twice the next day to assess the magnitude of the remaining threshold shifts. In all cases, a minimum of 48 hours was observed between helmet noise exposures.

3. RESULTS

20.7 ATA/650 FSW

The average overall noise recorded from inside the helmet during 12 dives of four hours duration was 96.3 dB(A)/97.9 dB. Standard deviation was 1.4 dB(A). Peak noise levels were associated with the frequencies of 1000 Hz (93.3 dB) and 2000 Hz (91.1 dB). By present U.S. Navy guidelines, the overall noise level would only allow exposure for 60 minutes per day. Audiograms conducted immediately post-dive revealed moderate temporary threshold shifts due to helmet noise exposure when compared to the pre-dive reference audiogram. As can be seen in Table 1, temporary threshold shifts averaged 10.8 and 9.2 dB in the left and right ears at 2000 Hz. No individual shifts greater than 15 dB were observed. The hearing threshold levels of all divers recovered to within 5 dB of their pre-noise exposure levels within 24 hours.

Table 1. Temporary auditory shifts (in dB) immediately after 4-hour helmet noise exposure at 650 FSW (20.7 ATA). Numbers indicate the magnitude of the shift from pre-dive hearing threshold levels.

Diver	LEFT EAR (Hz)						
	500	1000	2000	3000	4000	6000	8000
A	0	-5	10	5	0	0	0
A	5	0	5	0	-5	0	0
B	10	0	10	5	5	0	0
B	0	0	10	5	0	5	0
C	0	5	10	10	5	0	0
C	5	-5	15	5	5	0	0
D	5	0	15	10	0	0	0
D	5	0	15	5	5	0	0
E	0	-5	15	5	0	0	0
E	10	5	10	15	5	0	0
F	5	5	10	5	5	0	0
F	0	-5	5	5	5	0	0
X Shift	3.8	-0.4	10.8	6.2	2.5	0.8	0.0

RIGHT EAR (Hz)								
Diver	500	1000	2000	3000	4000	6000	8000	
A	5	5	10	5	0	5	0	
A	0	0	5	5	0	5	5	
B	0	-5	0	0	0	0	-5	
B	5	5	0	0	0	0	0	
C	10	5	5	0	5	-5	-5	
C	5	5	10	0	0	0	0	
D	0	0	15	5	0	0	5	
D	5	0	10	5	0	0	0	
E	0	0	15	5	5	5	0	
E	0	5	15	0	0	0	0	
F	5	5	10	5	10	5	-5	
F	0	0	15	10	0	-5	-5	

X Shift 2.9 2.1 9.2 3.3 1.7 0.8 -0.8

26.7 ATA/850 FSW

Five dives of four hours' duration were accomplished at this simulated depth, yielding an average overall noise level of 97.3 dB(A)/99.3 dB. Noise was concentrated at frequencies of 125, 1000 and 2000 Hz (i.e. above 92 dB). Based upon present USN criteria, the Permissible Exposure Time for this overall noise level would be 50 minutes in every 24 hours. Audiograms were again administered immediately post-dive with the results presented in Table 2. As seen previously at 650 FSW, the greatest shifts were observed at frequencies of 2000 and 3000 Hz. A threshold shift of 25 dB was seen in Diver J at 2 kHz, and a shift of 20 dB at 2 kHz in Diver K. Diver J had substantial auditory shifts across the spectrum. The other 3 divers showed a shift of 15 dB at one or more frequencies. Yet all divers returned to within 5 dB of their pre-dive reference baseline within 24 hours post-noise exposure.

Table 2. Temporary auditory shifts (in dB) immediately after 4-hour helmet noise exposures at 850 FSW (26.7 ATA). Numbers indicate shifts from pre-dive hearing levels.

LEFT EAR (Hz)								
Diver	500	1000	2000	3000	4000	6000	8000	
G	0	0	15	5	10	0	-5	
H	-5	0	15	0	5	5	0	
I	-5	5	15	15	5	-5	0	
J	5	5	20	20	10	10	15	
K	10	5	20	15	10	0	5	

X Shift 1.0 3.0 17.0 11.0 8.0 2.0 3.0

RIGHT EAR (Hz)								
Diver	500	1000	2000	3000	4000	6000	8000	
G	5	5	5	0	0	0	0	
H	0	0	10	5	5	0	0	
I	0	10	0	5	0	0	-10	
J	0	10	25	10	10	5	10	
K	15	5	15	10	10	5	5	

X Shift 4.0 6.0 11.0 6.0 5.0 2.0 1.0

At both test depths, noise averaged 70-75 dB inside the living chambers during the daily routine with the environmental conditioning system in a normal set up. At night, with the complex in a quiet mode, sound levels dropped to ~65 dB. Overall corrected noise levels in the audio booth at both test depths were 46-48 dB. Noise levels at the specific frequencies associated with audiogram testing were much lower. For example, at 26.7 ATA/850 FSW, the following noise levels were recorded during an actual audiogram test: 500 Hz, 33.6 dB; 1000 Hz, 26.0 dB; 2000 Hz, 19.5 dB; 3150 Hz, 19.5 dB; 4000 Hz, 16.4 dB. Analysis of the audiogram data with background audio booth data indicated auditory masking probably did not take place.

4. DISCUSSION

Manned helmet noise exposures of up to 4 hours duration were undertaken at simulated depths of 650 and 850 FSW. Helmet noise was approximately 96 dB(A) at 20.7 ATA/650 FSW and 97 dB(A) at 26.7 ATA/850 FSW. By U.S. Navy criteria, divers would normally be allowed exposure to noise of these magnitudes for 50-60 minutes in every 24 hours in a 1.0 ATA air environment. We exceeded this criteria in this study. The magnitude of the average temporary threshold shifts from our divers was moderate given noise exposure of this type. Within 24 hours post-noise exposure the hearing threshold levels of all divers recovered to within 5 dB of their pre-dive reference audiogram at all tested frequencies. This finding suggests that the application of airborne noise criteria to a dry hyperbaric helium-oxygen environment may be inappropriate. Indeed, our evidence suggests that airborne noise criteria is overly conservative in this situation. No permanent shifts in auditory acuity were observed once the divers had returned to the 1.0 ATA/0 FSW air environment.

Throughout the acoustic testing, divers were rotated sequentially. Each diver had a minimum 48 hour interval after completing one dive before again being exposed to helmet noise. This procedure allowed the tracking of hearing recovery and auditory rest [defined as exposure to less than 84 dB(A)] before the next noise insult. The potential problem of repeated helmet noise exposures in a short interval of time (e.g. eight hours of noise exposure every 24 hours) was

not addressed. The hearing data obtained are based upon (a) a quiet recovery environment and (b) a minimum of 48 hours between helmet noise exposures. The generalization of these results to an operational environment depends in part upon these criteria being met.

5. REFERENCES

1. Molvaer, O.I. Acoustical exposure in diving. Norwegian Underwater Institute Report No. 15-81, September, 1981.
2. Coles, R.R.A. Ears and their after effects. Royal Navy Diving Magazine, 1963, 10(3), 5-11.
3. Brady, J.I., Summit, J.K., and Berghage, T.E. An Audiometric Survey of Navy Divers. Navy Experimental Diving Unit Report No. 4-77, 1977.
4. Molvaer, O.I. and Lehmann, E.H. Hearing acuity in professional divers. Undersea Biomedical Research, 1985, 12(3), 333-349.
5. Molvaer, O.I. and Gjestland, T. Hearing damage risk to divers operating noisy tools underwater. Scandinavian Journal of Work and Environmental Health, 1981, 7, 263-270.
6. Molvaer, O.I. and Vestrheim, M. Noise in a standard dive helmet. Norwegian Underwater Technology Center Report No. 28-82, April, 1982.
7. Smith, P.F. Noise exposure in hyperbaric environments. Proceedings of Oceans 84, IEEE/Marine Technology Society, 1984, 521-526.