Research Note

Impact of Underwater Acoustic Degradation on Health of Divers

Aarohi Kapadia, Dr. (Cdr) Arnab Das

Introduction

In recent years there has been a growing interest in the marine industry and at the heart of it, are the different kinds of diving activities that are carried out for occupational as well as recreational purposes. Diving can be defined as the immersion of the body into water and can be partial immersion, complete immersion (submersion) and submersion with auxiliary breathing apparatus [1]. Occupational diving can be further classified into scientific diving, military diving and maintenance diving. While diving continues to be an increasingly popular activity amongst tourists and a necessity for industries to source materials, maintain equipment, conduct research etc., there are hazards associated with it that must be acknowledged and should be accounted for via regulatory measures.

There are several risks associated with diving however, a primary area of concern is the exposure of divers to the rising levels of underwater noise. As stated in the Review of Diver Noise Exposure by Health and Safety Executive, UK, "There is a growing body of evidence that divers are exposed to noise levels that put them at risk of hearing damage" [2] – case study references of which can be found in "*Review of published safety thresholds for human divers exposed to underwater sound*" [3], Fothergill et al (2002) [4] and the "*Underwater Noise And The Conservation Of Divers' Hearing: A Review. Volume 1*" [5]. Divers are exposed to various types of noise including ambient noise of the underwater environment, self-generated breathing noise, noise from operation of equipment, sonar, etc. and beyond certain thresholds these noises can have damaging effects on the auditory system of the divers as well as have subsequent effects on other physiological systems due to the increased pressure. Despite legislations that provide guidelines on occupational noise levels, there are no standard thresholds of noise exposure defined for underwater use [6]. Several previous research works have also established that sound level reference values used to form conclusions of diver exposure to noise vary depending on the investigator which makes the review of existing evidence challenging [5]. In addition to this, lack of publicly available computations of human audiograms in water are another obstacle [7]. Nevertheless, a number of studies have postulated on the adverse physiological as well as occupational effects of increased noise exposure of divers.

Underwater Acoustic Degradation

Sound is a vibration or acoustic wave that can travel solid, liquid or gas. The pitch of the sound is described by its frequency which is the rate of vibration in Hertz (Hz). [8]. The sound pressure is defined as the change in ambient pressure due to the vibrations and is measured in Pascals (Pa). However, noise is expressed in Sound Pressure Level (SPL) and its unit is the decibel (dB) which is always represented along with the reference pressure level (Pa). [2]. For a constant SPL, noise can be characterized via Sound Exposure Level (SEL) which is a value that "captures both the level (magnitude) and the duration of a sound event in a single numerical quantity" [9] by condensing the entire event into one second which "provides a uniform way to make comparisons among noise events of various durations" [9].

The term "ambient noise" is widely used to refer to the cumulative noise present in a water body. It is essentially the background sound which includes varying types known as well as unknown independent sources of sound. Ambient noise is dependent on many factors and does not necessarily remain constant however, certain natural phenomena such as wind, earthquakes, turbulence, etc. can influence the ambient noise [8].

Recent trends have shown that anthropogenic activities have become a huge contributor to the ambient noise levels of water bodies leading to acoustic habitat degradation. Sound from human activities can either occur as a consequence of other actions or, because sound signals are often used underwater for research purposes. Man-made noises can be in general classified as follows:

- Shipping noises
- Navigation and military sonars
- Research/Conservation Sites, ex. Seismic Survey Sites
- Explosions (Chemical/Nuclear)
- Operation of maintenance equipment
- Offshore drilling and industrial activity
- Noise generated by breathing apparatus of divers

Each of these sources of noise occur at different sound pressure levels and have varying bandwidths and directionality [8]. Irrespective of whether a type of noise is independent or distributed with other sources of noise, a common approach to analyze the propagation of sound and its effects is to make use of the Source-Path-Receiver model. In such a type of modelling, the source emits a noise that is eventually received by the receiver but whether this noise is hazardous to the receiver or not depends on several factors with the primary factor being the path through which the noise travels i.e., whether the noise gets distorted before reaching the receiver or the length of the path. A source-path-receiver model can be useful in controlling noise levels and thereby reducing any adverse effects on the other species present in an environment. [3].

The rising levels of sound in the underwater domain have always been a cause of concern for marine mammals [8] however, several lines of evidence have shown that

humans in the marine industry, especially divers are also at risk of auditory damage due to their exposure to these noise levels. [2].

Human Auditory System

The human ear is divided into three parts – outer ear, middle ear and the inner ear. Each part serves a specific purpose and all three work together in synchrony to transmit the mechanical sound signal from a source that reaches the ear and convert it to an electric signal so that it can be processed by the brain. Briefly, the function of each section of the ear can be described as:

- Outer Ear: It consists of the pinna which assists in focusing the incoming sound to the auditory canal and the eardrum [10]. The ear drum is also known as the tympanic membrane and the sound signals cause this membrane to vibrate which enables the transmission of the signals to the middle ear [2].
- Middle Ear: It is an air-filled cavity, very small in size and surrounded by bones, through which the sound signals pass onto three bones which are collectively called the ossicles – malleus, incus and stapes. The chain of these barely visible bones is crucial to transmitting the sound from the eardrum to the inner ear [10]. The stapes bone is connected further to a membrane that interfaces with the cochlea present in the inner ear [2].
- Inner Ear: It is a fluid filled portion of the ear, and consists of the cochlea, the hearing organ, which is a spiral tube that contains hair cells [10]. “It is where sound is converted, via pressure-induced movement of hair cells, into electrical activity in neurons of the auditory nerve producing hearing.” [2]. Different frequencies of sound resonate in different parts of the cochlea which allows varying pitches of sound to be heard [2].

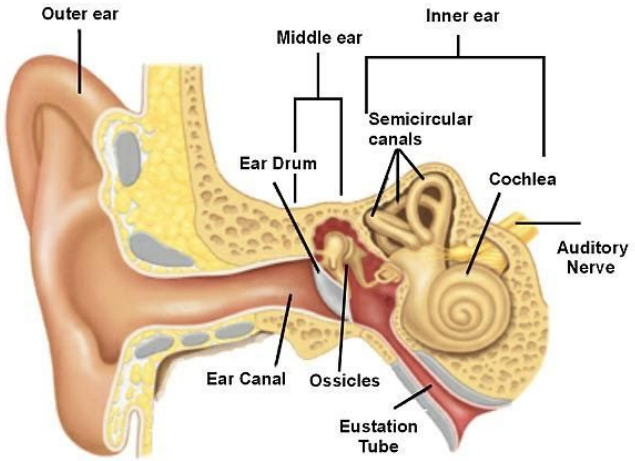

Figure obtained from A. Ear, "Anatomy of the Ear | Professional Hearing Services", Professional Hearing Services [Online]. Available: https://www.heardakota.com/anatomy-of-the-ear/. [Accessed: 30- Nov- 2020].

The above-described propagation of sound is referred to as tympanic conduction and for further reference of the mechanical functioning of the ear, the following reference can be used – “Auditory System: Structure and Function (Section 2, Chapter 12) Neuroscience Online: An Electronic Textbook for the Neurosciences | Department of Neurobiology and Anatomy - The University of Texas Medical School at Houston” [11].

Apart from this, a different type of conduction that takes place is the bone conduction. Here, the sound propagates to the inner ear via the bones of the skull. [2]. Tympanic conduction is considered predominant for air-borne sound hearing while for water-borne sound, it is widely assumed that bone conduction occurs.

Diver Hearing & Exposure to Noise

A sound that is audible to humans is the one whose ‘frequency components of the vibrations can be detected by the human hear’ [2]. In air, human ear can detect frequencies in the range of 20Hz to 20 kHz.

Sound, however, functions differently in air and water. There is a lot of debate on the mechanism of hearing of humans underwater [12], however, a common assumption is that bone conduction is a pivotal factor at high frequencies while tympanic conduction contributes more at low frequencies. [2].

Along with this, an important aspect of underwater hearing in humans is the type of headgear worn by the divers – it can limit or further expose a diver to noise. The use of headgear can be classified in three ways depending on design:

- ***Bare Head***: This implies that no head gear has been worn and the ears are in direct contact with the water. This is more common in recreational divers that intend to dive up to limited depths. While the presence of water in the ear canal reduces the sensitivity to noise due to the fact that mass of water weighs down the tympanic membrane [2], bare headed divers remain at high risk in situations of explosions or high intensity sound signals which can cause several physiological impacts [13].
- ***Hood***: These are generally made of neoprene material and are part of wet suits. Hoods, with the exception of tight-fitting hoods, allow for water to be in contact with the ear canal which is known as the wet ear effect [2], and therefore provide some protection from the noise present in the environment. However, the cumulative noise in the underwater environment can still be significant enough to pose a threat to the diver. Hoods provide substantial protection from high frequency sounds [13].
- ***Helmet***: This type of headgear encloses the head due to which the ears are surrounded by air and this is termed as the dry ear effect. Under these conditions, noise exposure is perceived in the same way as it would be in air and therefore the sensitivity of the ears to noise underwater is considered to be greater for helmet wearing divers than hooded divers which suggests that overall, there is a greater potential of hazard in dry ear situations [2, 13].

It is important to note that along with the above-mentioned factors, several other parameters such as changes in pressure & density, breathing gases, temperature, depth of diving, etc. can also affect hearing sensitivity.

Physiological & Occupational Impact of Noise Exposure

The biological effects of noise on divers depend on the frequency bandwidth and the sound pressure level to which the diver is exposed along with the level of protection provided by the headgear worn. Outlined below is a summary of generalized physiological effects from different studies in ascending order of hazard and discomfort:

- Annoyance and aversion [14, 15]
- Temporary dizziness and similar symptoms [7]
- Blurred vision, tremors, lightheadedness, disorientation [16]
- Vibrations in forearms and thighs [7]
- Visual field shifts [13]
- Tingling and numbness due to over-stimulation of the nervous system [15]
- Temporary or permanent hearing loss [5]
- Mechanical injuries to various parts of the ear [5]
- Abdominal discomfort due to “vibrations of gas pockets in the gastrointestinal tract” [15]
- Tissue/arterial resonance and lung hemorrhage [15]

Many of these effects such as slight discomfort might seem harmless however, may cause panic and anxiety in unsuspecting divers. In case of inexperienced divers, there is a likelihood of failure to handle such occurrences which can lead to greater damage. In addition to this, fogging of face masks and erratic behavior of equipment [13] can cause added stress to the diver.

The by-product of physiological and psychological impacts on divers due to noise is an adverse effect on performance and increased probability of accidents. Physical impairments can reduce efficiency of a diver and increased noise levels can influence a diver to abort the mission. Furthermore, poor efficiency and inability to cope with the physiological changes can lead to accidents and unfortunate mishaps.

Overall, there is significant evidence of harmful effects of increased noise exposure to divers and appropriate regulatory measures should be instituted to ensure safe diving practices.

Regulatory Framework on Underwater Noise Exposure

The provision of guidelines and regulations for exposure of divers to underwater noise is essential in ensuring safe workplace practices, reducing likelihood of accidents and avoiding loss of resources from prematurely aborted for failed diving missions. While there are legislations in many countries that limit occupational noise exposure, guidelines provided by these laws only account for air-borne sound

perception to the best of our knowledge. Several studies outline important aspects to consider when designing regulations for underwater noise, some of which are summarized below:

- Specific auditory threshold values should be defined for recreational and occupational divers as well as for different types of headgear worn.
- In areas where acoustic habitat degradation is well known, use of appropriate headgears should be mandated.
- Diving near research sites should require appropriate communication of diving vessels with the research and survey vessel.
- Pre-diving procedures should include ear examinations and baseline audiometry analysis [10]
- Diving certifications and instructional course content should include outlines on management of any unexpected physiological occurrences.
- Legislations limiting anthropogenic activities around marine environments should be introduced to control rising ambient noise levels.

Research Directions

- Marine spatio-temporal mapping to enable safe diving practices and support proposal for requirement of sound level thresholding in areas with high ambient noise. This will be additionally supported by simulation of effects of acoustic degradation on the auditory system of divers.
- Proposal of a regulatory framework that mandates necessary medical examinations pre-diving and post-diving to ensure no adverse effects on the diver's physiology have occurred.
- Recommendation for creating SOPs to reduce acoustic pollution in underwater environments and establishment of a regulatory authority to corroborate compliance from different industries operating in the marine domain.

References

[1] Bosco, G., Rizzato, A., Moon, R. and Camporesi, E., 2018. Environmental Physiology and Diving Medicine. *Frontiers in Psychology*, 9.

[2] Health and Safety Executive,UK, 2009. *Review Of Diver Noise Exposure*. [online] Available at: <https://www.hse.gov.uk/research/rrpdf/rr735.pdf> [Accessed 17 November 2020]

[3] "What are the principles of controlling noise?", Epd.gov.hk. [Online]. Available: https://www.epd.gov.hk/epd/noise_education/young/eng_young_html/m3/m3.html. [Accessed: 26- Nov- 2020].

[4] Fothergill, David & Schwaller, Derek & Forsythe, S. & Cudahy, Edward. (2002). Recreational Diver Responses to 600-2500 Hz Waterborne Sound. 61.

[5] DEFENSE TECHNICAL INFORMATION CENTER, 1989. *Underwater Noise And The Conservation Of Divers' Hearing: A Review. Volume 1*.

[6] Al-Masri, M., Martin, A., & Nedwell, J. (1993, January 1). Underwater Hearing Thresholds And Proposed Noise Exposure Limits. Society of Underwater Technology.
[7] M. Ainsie, "Review of published safety thresholds for human divers exposed to underwater sound", TNO, 2007.
[8] J. Hildebrand, "Impacts of Anthropogenic Sound", Marine Mammal Research: Conservation beyond crisis, Book, 2005.
[9] "Fundamentals of Noise and Sound", 2020. [Online]. Available: https://www.faa.gov/regulations_policies/policy_guidance/noise/basics/. [Accessed: 26- Nov- 2020].
[10] C. Edmonds, B. McKenzie, R. Thomas and J. Pennefather, Diving Medicine for SCUBA Divers, 5th ed. 2013.
[11] "Auditory System: Structure and Function (Section 2, Chapter 12) Neuroscience Online: An Electronic Textbook for the Neurosciences | Department of Neurobiology and Anatomy - The University of Texas Medical School at Houston", Nba.uth.tmc.edu. [Online]. Available: https://nba.uth.tmc.edu/neuroscience/m/s2/chapter12.html. [Accessed: 26- Nov- 2020].
[12] S. Chordekar, L. Kishon-Rabin, L. Kriksunov, C. Adelman and H. Sohmer, "Experimental Analysis of the Mechanism of Hearing under Water", 2015. Available: https://doi.org/10.1155/2015/526708.
[13] United States Navy, 2016. *U.S. Navy Diving Manual, Revision 7*. DIRECTION OF COMMANDER, NAVAL SEA SYSTEMS COMMAND.
[14] S. Parvin, Limits for underwater noise exposure of human divers and swimmers. Subacoustech.
[15] "NATO Undersea Research Centre Human Diver and Marine Mammal Risk Mitigation Rules and Procedures", NURC, 2006.
[16] "The Effect of Sonar Transmission on Commercial Diving Activities", Dmac-diving.org, 2020. [Online]. Available: http://www.dmac-diving.org/guidance/DMAC06.pdf . [Accessed: 26- Nov- 2020].
[17] Fothergill, David & Sims, John & Curley, Michael. (2004). Neoprene Wet-Suit Hood Affects Low-Frequency Underwater Hearing Thresholds. Aviation, space, and environmental medicine. 75. 397-404.
[18] A. Ear, "Anatomy of the Ear | Professional Hearing Services", Professional Hearing Services. [Online]. Available: https://www.heardakota.com/anatomy-of-the-ear/. [Accessed: 30- Nov- 2020].
[19] "Safe Diving Distance from Seismic Surveying Operations", Dmac-diving.org, 2020. [Online]. Available: https://www.dmac-diving.org/guidance/DMAC12.pdf.[Accessed: 26- Nov- 2020].
[20] J. Nedwell et al., "A validation of the dBht as a measure of the behavioural and auditory effects of underwater noise", 2007.