World Academy of Science, Engineering and Technology
International Journal of Medical and Health Sciences
Vol:12, No:7, 2018

Ear Protectors and Their Action in Protecting Hearing System of Workers against Occupational Noise

F. Forouharmajd, S. Pourabdian, N. Ziayi Ghahnavieh

Open Science Index, Medical and Health Sciences Vol:12, No:7, 2018 publications.waset.org/10009272/pdf

Abstract**—**For many years, the ear protectors have been used to preventing the audio and non-audio effects of received noise from occupation environments. Despite performing hearing protection programs, there are many people which still suffer from noise-induced hearing loss. This study was conducted with the aim of determination of human hearing system response to received noise and the effectiveness of ear protectors on preventing of noise-induced hearing loss. Sound pressure microphones were placed in a simulated ear canal. The severity of noise measured inside and outside of ear canal. The noise reduction values due to installing ear protectors were calculated in the octave band frequencies and LabVIEW programmer. The results of noise measurement inside and outside of ear canal showed a different in received sound levels by ear canal. The effectiveness of ear protectors has been considerably reduced for the low frequency limits. A change in resonance frequency also was observed after using ear protectors. The study indicated the ear canal structure may affect the received noise and it may lead a difference between the received sound from the measured sound by a sound level meter, and hearing system. It means the human hearing system may probably respond different from a sound level meter. Hearing protectors' efficiency declines by increasing the noise levels, and thus, they are not suitable to protect workers against industrial noise particularly low frequency noise. Hearing protectors may be solely a reason to damaging of hearing system in a special frequency via changing of human hearing system acoustical structure. We need developing the subjective method of hearing protectors testing, because their evaluation is not designed based on industrial noise or in the field.

Keywords**—**Ear protector, hearing system, occupational noise, workers.

I. Introduction

HUMAN hearing system, including outer ear, middle ear, inner ear, and related nerves, depends on sound. Outer ear has the duty to collect the sounds and transfer them to the middle ear via the ear canal and to the tympanic membrane (eardrum). Sound waves pass through malleus, incus, and stapes, reaching to the inner ear. Inner ear includes cochlea, and semi-circular canals. Cochlea includes thousands of very thin hair cells in the spiral organ (organ of Corti). When the sound waves enter the inner ear, the hair cell helps in stimulating the sound waves. Hair cells transform the vibrations into electric signals, and waves are transferred to the brain via hearing nerves. Brain transforms the signals into understandable sounds. Confronting with sound damages spiral organ cells. The sensing hair cells are vibrated by acoustic input signals, and then the mechanical vibrations are transformed to electric form to reach to the 8th brain nerve. Confronting with intense sounds (over 85 dBA), primarily damages outer hair cells that are responsible for the sounds with high frequencies (3-6 kHz) [1]. When sound passes from ear canal and reaches eardrum, most of the sound is reflected and reaches to the end of the ear and reflects again. Thus, the waves go under resonance in a frequency that depends on the length of the ear canal. Ear canal is a tube that is open at one end and close at the other. Resonance frequency in the ear canal is calculated by:

$$F_n=\frac{nc}{4L} \quad (1)$$

where n is an odd number (1, 3, 5…), L is the length of ear canal, and c is the sound velocity.

When ear canal is covered by earplug, the resonance frequency will be calculated by:

$$F_n=\frac{nc}{2L} \quad (2)$$

where n=1, 2, 3…, and L is the length of ear canal [2]. Ear canal performs like a resonator, turning up the sound. Ear canal resonance depends on its length. The shape and size of ear lobes and the curvature of ear canal affect frequency reactions of the eardrum [3]. Different parts of the base membrane have different widths. High frequencies signals are affected by resonance near the oval window and low frequencies are so affected near cochlea [4]. Generally, 16% of hearing loss in adults is due to noise at working places. Noise induced hearing loss (NIHL) is bilateral and symmetrical, and it usually affects high frequencies (3, 4, and 6 kHz), extending then to lower frequencies (0.5, 1, or 2 kHz) [5]. Hearing damage due to confronting with noise for some years is extended to both high and low frequencies [1]. According to the U.S. Health and Human Services Ministry, when eliminating noise is not possible by engineering controls, proper use of hearing protection devices together with audiometric monitoring is effective in preventing NIHL. Effective hearing protection can be achieved by proper selection of different types of hearing aids, appropriate tests and compatibility, proper use, and continuous attention to maintaining them [1]. Despite the fact that hearing system protecting devices are not considered as the first protective

Forouharmajd. F. is with the Department of Occupational Health Engineering, School of Public Health, Isfahan University of Medical Sciences, Isfahan, Iran (e-mail: forouhar@hlth.mui.ac.ir).

Ahmadvand M. was with Fars Shasi company, a producer of chassis of motorcycle, Isfahan, Iran (e-mail: masi834@yahoo.com).

Pourabdian S. is with the Department of Occupational Health Engineering, School of Public Health, Isfahan University of Medical Sciences, Isfahan, Iran (corresponding author, phone: +98 31 37923261; e-mail: pourabdian@hlth.mui.ac.ir).

Open Science Index, Medical and Health Sciences Vol:12, No:7, 2018 publications.waset.org/10009272/pdf

action, but they are regarded as a main measure for preventing hearing loss due to their low costs, availability, and effects [6]. Hearing protection devices are divided into two categories, namely earmuffs and earplugs. Earplugs are placed inside the ear to block the ear canal, and they are produced either in molds or by ductile foams. Earmuffs are in the form of cup-shape pads with reducing noise materials that are placed around ears. The results of the study dealing with analysis of noise damping rates by earplugs and earmuffs showed that in low frequencies and high frequencies (8, 12 kHz), earplugs have higher rate of damping as compared to earmuffs, while earmuffs had more rate of damping in 1, 2, and 4 kHz frequencies [7]. The performances of hearing protection devices differ from each other in reducing and attenuating the noise. There are various methods for evaluating the performance of hearing protection devices in reducing noise. These methods are categorized into subjective and objective aspects. According to standard no. 4869, the golden standard in measuring the reduction is real ear attenuation at threshold (REAT), this is a subjective method. In this method, hearing tests are done in different frequencies with or without the protective earphone. The attenuation index is obtained out of the difference between open and blocked ears thresholds [8], [9]. Hence, since sound is one of the most important problems in industrial environments causing hearing loss in the workforce, by simulating a model of ear canal in this study and evaluating the rate of attenuation in different distances between the earplug and the microphone that is located in an ear as the simulator for receiving the sound, in different materials of Teflon and cast iron, the effective frequencies on hearing loss and variations of the sound level in different frequencies after placing the earplug are determined.

II. Materials and Methods

A. Modeling and Preparation of Setup

A model of ear canal was primarily prepared. Since the diameter of human ear canal is about 7 mm [10], This dimension was considered in the modeling. By default and in two changeable conditions, the ear canal structure was designed with different material of Teflon and cast iron. Sound pressure sensors (1/4") were placed in the ear canal. The microphones were connected to the sound processing card (DAQ- made by the company National instrument, USA), and the sound card was connected to the computer. LabVIEW software was installed in the computer, which was used for drawing the frequency analysis curves.

B. Simulation of Sound Attenuation by LabVIEW

LabVIEW software was used for simulation of sound attenuation in octave band frequencies. The software is a graphic programming software with capabilities such as noise measurement, frequency analysis, and controlling the sound [11]. Response network was adjusted on network "A", and also, the bandwidth of one octave band was set on the work page of the software.

C. Sound Play

The microphone was first calibrated by the calibrator (Model: 4230). Pink noise with 90 dB in octave frequencies was played by the 80-W loud speakers. The played sound was received by the microphone placed in the ear canal, and the frequency analysis curves were drawn according to the stated frequencies in LabVIEW software. The earplug (Model: ELVEX NRR25) was placed on the model, the played sound with the same intensity was replayed in the mentioned frequencies, and the required graphs were drawn. The rate of attenuation of the earplug sound was obtained by subtracting the sound pressure level at each frequency in two stages. The rates of sound reduction in octave frequencies were calculated for the simulated canal of Teflon material, in different distances between the microphone and the earplug (12.8 mm, 17.5 mm. and 25.5 mm). For more investigations, the rates of sound attenuation in octave frequencies were determined for the distance of 22.8 mm for the canal of cast iron material, and for the distance of 25.5 mm for the canal of the combined Teflon and cast iron materials

III. Results

The results of sound attenuation in octave frequencies signals showed that by increasing the frequency, the rates of sound reduction in different conditions had also an increasing trend. By increasing the frequency, the rate of attenuation on the used earplug also showed an increasing trend. By increasing the distance of the microphone from the earplug, the sound level had an increasing trend from the distance of 12.8 mm to 25.5 mm, but it had a decreasing trend at the distance of 31.1 mm. As can be seen from Fig. 1, this decreasing trend was quite prominent in frequencies under 500 Hz. The sound level in Teflon showed increasing and decreasing trends for different frequencies at the distance of 25.5 mm, reaching to its maximum rate at the frequency of about 4000 Hz. The peak frequency of 4000 Hz was observed in most of the existing states regarding the material, including metal at the distance of 22.8 mm, Teflon at 17.5 mm, Teflon at 25.5 mm, and combination of metal and Teflon at 25.5 mm. Among different conditions, the required rate reached to its maximum value, i.e. 59 dB, in the metal canal at the related distance of 22.8 mm and in the frequency of 4000 Hz.

The obtained peak rates for all the situations were coincided on each other at fixed frequencies signals. The sound level in the Teflon canal at the distance of 25.5 mm was higher in comparison with other distances, for the low frequencies of 16, 31.5, 63, and 125 Hz (23.941, 27.257, 29.487, and 37.308 dB, respectively), being closer to the rate of sound attenuation of the protective earphone. At the frequency of 250 Hz, the sound level in the canal with combination of metal and Teflon was the highest at the distance of 25.5 mm (30.967). At frequencies of 500, 1000, and 2000 Hz, the rates of sound attenuation in the Teflon canal were higher at the distance of 31.5 mm as compared to other distances (39.777, 41.54, and 54.346 dB, respectively). The rate of the attenuated sound level in 4000 Hz frequency at the distance of 22.8 mm was

higher in comparison with other distances (59.031 dB). Finally, in the Teflon canal, the sound level obtained the maximum rate at the distance of 12.8 mm in 8000 Hz frequency (48.989 dB).

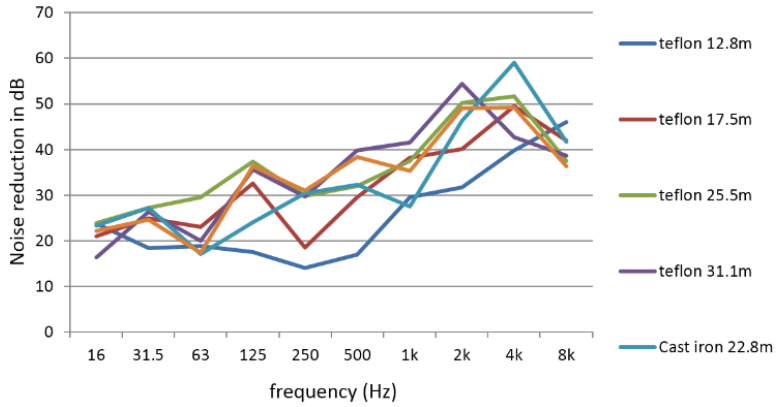


Fig. 1 The results of noise reduction in a simulated ear canal with Teflon, and cast iron

The results of the calculations for resonance frequency in different conditions are calculated. Sound resonance frequencies at different distances regarding the ear canal are calculated as in Table I.

TABLE I
CALCULATION OF SOUND RESONANCE FREQUENCIES AT DIFFERENT DISTANCES IN THE SIMULATED EAR CANAL

The length of the ear canal	The resonant frequency (Hz)	
	Open ear canal ($F_n=\frac{nc}{4L}$)	Blocked ear canal with earplug ($F_n=\frac{nc}{2L}$)
Teflon 12.8	6703.12	13406.25
Teflon17.5	4902.85	9805.7
25.5Teflon	3364.7	6729.4
Teflon31.1	2758.84	5517.68
Cast iron22.8	3763.15	7526.3
Teflon& Iron25.5Cast	3364.7	6729.4

IV. CONCLUSION

The aim of the present study is determining effective frequencies on hearing loss in human beings. Firstly, the study has showed a difference in receiving noise between the microphone located in eardrum and what the microphone of sound level meter is taken. It means the microphone in eardrum situation has been presented a noise level of 5 dB more than the microphone of sound level meter. This issue may be important to measure the hearing system exposure to noise. The fact is that, based on the results gotten from the present study, the people may be exposed to more values of noise in comparison to the presented noise by a sound level meter. Secondly, the results also showed that the rates of sound level in Teflon canal at the distances of 12.8 mm, 17.5 mm, and 25.5 mm, and cast iron canal at the distance of 22.7 mm, and the canal with combination of Teflon and cast iron at the distance of 25.5 mm reached their maximum at the frequency of 4000 Hz. The study by Mala Agarwal showed that hearing loss had its highest rate due to confrontation with traffic noise at the frequency of 4000 Hz [12]. According to the studies by Mirzakhani et al. regarding confrontation with noise and hearing loss among the key makers in the city of Tehran, hearing loss was observed mainly in the people at the frequencies of 1000 Hz and 2000 Hz, with higher rates at 4000 Hz and 8000 Hz frequencies [13]. Audiometric studies have shown hearing loss in frequencies of 3, 4 or 6 kHz can be related to occupational noise [14]. The base membrane at 4 kHz is usually affected by noise due to sound conduction from the ear bones [12]. Receptor of Corti is more sensitive in specific frequencies, and according to experience, the 4096 Hz frequency region is the vulnerable region in the ear, and this region tolerates the highest hearing damage in confrontation with noise. There are various reasons for that, which are stated in audiology books, the most important of which are deficiency in vascular flows in this region and reflection of sound wave energy in the canal [15].

Thirdly, the results of the studies dealt with analysis of the damping rate of earplug in different distances of its placement in the ear canal, so that, by decreasing the distance of the earplug in the ear, the rate of sound attenuation also decreases. This reduction has been more for the frequencies of 1000 Hz and less than that in comparison with higher frequencies than 2000 Hz [3].

The sound levels at different distances showed lower values at low frequencies. According to Lewis, the sounds with low frequencies (e.g. the sound made by heavy artilleries) are less harmful than sounds with frequencies over 1-6 kHz. The other reason for the problems of noise in different frequencies can be in the point that hearing loss almost occurs primarily in the frequency range of 4-6 Hz, as observed in audiogram [16]. Due to the shape of human outer ear canal and other reasons, human sensitivity is more in 1000 Hz to 5000 Hz frequencies. The worker confronting with 90 dB noise in that frequency range is exposed to more harm as compared to the person who is confronting with 90 dB sound in the frequency of 250 Hz [17]. According to this study, the rates of sound attenuation were higher in all the distances in high frequencies. The results show that sound is stimulated in ear canals for about 10-15 dB in frequency range of 2-4 Hz, which is dangerous.

Open Science Index, Medical and Health Sciences Vol:12, No:7, 2018 publications.waset.org/10009272/pdf

Open Science Index, Medical and Health Sciences Vol:12, No:7, 2018 publications.waset.org/10009272/pdf

Middle ear has two muscles connected to the bones that become stiff at the presence of sounds with high frequencies and transfer the sounds with frequency of 1500 Hz and lower. The activity of middle ear manages protections against loud noise existing in the environment. Moreover, ear lobe and ear canal improve sound frequencies [18]. Thus, human hearing system weakens some sound frequencies, having protecting role, and resonates the sound in some frequencies, having a destructive role.

Damages to cochlea starts at the beginning at frequencies ranging from 3000 to 4000 Hz. This is fixed in the first 10 years of confrontation, but it changes afterwards. The next region exposed to affection is 6000 Hz, continued after 8000 and 2000 Hz, where the damage develops with slower speed [17]. Different sound frequencies cause various movements of the base membrane. Hence, different frequencies stimulate different parts of the base membrane. Sounds with frequencies lower than 1 kHz are not affected by the ear lobe. Sounds with frequencies higher than 1 kHz, especially vocal frequencies (2-3 kHz) are stimulated considerably [4].

Sound attenuation will show an ascending trend by increasing sound frequency. The rate of reduction stated on earplugs also increases by increasing the frequency, and this increasing trend is observed in the two models of earplugs.

Hearing protection devices dampen the sounds with high frequencies more than the sounds with low frequencies. The reason for it is that the energy of sounds with low frequencies freely enters into the space between the ear canal wall and the earplug. There are three reasons for the dependency of the frequencies. The first reason is that all the frequencies are dampened with half of the wavelength lower than the blocking diameter (e.g. ear protection devices). Thus, the sounds with low frequencies that have higher wavelengths easily pass from the blockage, while the sounds with high frequencies having lower wavelengths are dampened easier. The second reason is mass and weight. By heavier ear mass, the damping rate becomes more. The third reason is the resonance characteristic of the ear canal [5].

The results of the calculations for resonance frequency in different conditions showed that resonance frequency in the blocked canal by the earplug was twice the open canal. This result causes that during using hearing protection devices, the sound frequencies to leave the range of harming frequencies to the human hearing system and have protecting role for humans. Hence, the type and material for the earplugs to be used are of great importance, for the resonance frequency of the hearing protection to be removed from the range of harming frequencies for human hearing system (about 4000 Hz), to minimize the hearing damages during using such devices. Since the sensitivity of hearing system differs in different people and this can affect sound reduction during using protective earphones, thus, investigations in this regard is recommended for future studies. Finally, the developed subjective method in hearing system evaluation against occupational noise may be needed. We need a method to evaluate the hearing system with and without protection in situ. The people should be in a real situation exposing to noise coming from real sources. In this case, it is possible to conclude the correct response of using ear protectors.

REFERENCES

[1] Alam N, Sinha V, Jalvi R, Suryanarayan A, Gurnani D, Barot DA. Comparative study of attenuation measurement of hearing protection devices by real ear attenuation at threshold method. Indian Journal of Otology. 2013;19(3):127.

[2] Lokki T, Huhtakallio I. Measurements on active earplugs and effect of ear canal resonance on spectral balance. EuroNoise 2015. 2015:21.

[3] Tufts JB, Chen S, Marshall L. Attenuation as a function of the canal length of custom-molded earplugs: A pilot study. The Journal of the Acoustical Society of America. 2013;133(6):EL446-EL51.

[4] Hiipakka M. Measurement apparatus and modelling techniques of ear canal acoustics: Helsinki University Of Technology; 2008.

[5] Hong O, Kerr MJ, Poling GL, Dhar S. Understanding and preventing noise-induced hearing loss. Dis Mon. 2013;59(4):110-8.

[6] Nodoushan MS, Mehrparvar A, Jahromi MT, Safaei S, Mollasadeghi A. Training in using earplugs or using earplugs with a higher than necessary noise reduction rating? A randomized clinical trial. The international journal of occupational and environmental medicine. 2014;5(4 October):479-187-93.

[7] Kabe I, Kochi T, Tsuruoka H, Tonegawa T, Denda I, Nonogi M, et al. Noise attenuation of earplugs as measured by hREAT and F-MIRE methods in a Japanese metal manufacturing plant. Journal of occupational health. 2012;54(4):310-5.

[8] Nélisse H, Le Cocq C, Boutin J, Voix J, Laville F. Systematic evaluation of the relationship between subjective and objective measurement methods of hearing protector devices attenuation. 2015

[9] ISO4869-1. Acoustics -hearing protectors -part 1: subjective method for the measurement of sound attenuation. Switzerland: Geneva; 1990.

[10] Cheng JT, Ravicz M, Guignard J, Furlong C, Rosowski JJ. The effect of ear canal orientation on tympanic membrane motion and the sound field near the tympanic membrane. Journal of the Association for Research in Otolaryngology. 2015;16(4):413-32.

[11] Forouharmajd F, Mohammadi Z, Ahmadvand M, Forouharmajd F. Sound pressure level tools design used in occupational health by means of Labview software. International Journal of Environmental Health Engineering. 2015;4(1):41.(in persian).

[12] Agarwal M. International Journal of Chemical, Environmental and. Pharmaceutical Research. 2014;5(1):1-7.

[13] Mirzakhani A, Monazzam M, Monazzam M. Noise Exposure and Hearing Status among the Registered Locksmiths in Tehran, Iran. International Journal of Occupational Hygiene. 2015;6(2):56-60.

[14] Chang T-Y, Liu C-S, Huang K-H, Chen R-Y, Lai J-S, Bao B-Y. High-frequency hearing loss, occupational noise exposure and hypertension: a cross-sectional study in male workers. Environmental Health. 2011;10(1):35.

[15] R G. Noise and vibration engineering. Medical university of Hamedan: student; 2015(in persian).

[16] Hohmann BW, editor. Assessment of impulse noise regarding harmfulness to hearing. PACS; 2015.

[17] May JJ. Occupational hearing loss. American Journal of Industrial Medicine. 2000;37(1):112-20.

[18] Lehtomaki K. Noise attenuation of hearing protectors against heavy weapon noise. Military medicine. 2000;165(9):678.