Original Article

The Efficiency of Hearing Protective Devices against Occupational Low Frequency Noise in Comparison to the New Subjective Suggested Method

Abstract

Backround: Noise is one of the most important occupational and environmental health hazards. Exposure to loud noise can cause irrevocable hearing damage and loss of hearing. The aim of this study was to determine the efficiency of two samples of earmuff and earplug in low frequency noise reduction in comparison to subjective method. **Methods:** All the procedures of the work were done using the simulated human ear canal and the required microphone in the eardrum. At the octave frequencies, that is 31.5 and 63.5, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz, and intensities of 85-90 dB, one stage was done by using the individual's subjective response relative to the received sound before and after using the ear protector. **Results:** The sound levels before and after the protection were significantly different in both the model and humans ($P < 0.05$). However, at 315 Hz frequency, the rate of attenuation is increased by 4 dB after placing the earplug and 14 dB after placing the earmuff, showing a reduction of 18 dB. **Conclusions:** This study verifies the increasing protection by simultaneous application of earplugs and earmuffs. Because of the laboratory evaluation of ear protectors, it is possible not to justify the proficiency of ear protectors in a subjective method.

Keywords: *Hearing protective devices, low frequency, occupational noise, subjective*

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Introduction

In its broadest sense, sound is defined as the noise, which prevents the performance of individuals in their maximum ability and efficiency. Sound can deprive people of enjoying their leisure time. Sound can increase the stress associated with psychological effects, and it can in particular damage the hearing sensory mechanism and provide early permanent hearing loss.[1] Sound can also affect mood, stress, fatigue, negative effects on memory and increase the error rate,[2] sleep disorder, distress, and high blood pressure.[3] Noise is one of the most important occupational and environmental health hazards. Exposure to loud noise can cause irrevocable hearing damage and loss of hearing. Almost one-third of all the hearing loss cases has been related to exposure to noise, and exposure to occupational noise is the most prevalent reason for noise-induced hearing loss (NIHL). About 10% (22 million) adults between the age of 20 and 69 years in the U.S.A. have permanent hearing loss due to exposure to loud noise in the workplace or during leisure-time activities.[3] An estimation of the existing information indicates that about 2 million workers in Iran are exposed to damaging noise.[4] Noise induced hearing loss (NIHL) is the second prevalent cause of hearing loss after presbycusis (age-associated hearing loss).[5] Exposure to loud noise may cause temporary noise-induced threshold shift (temporary hearing loss - TTS) or permanent noise-induced threshold shift (PTS). Moderate exposure during a short period of time causes temporary hearing loss. Temporary hearing loss (TTS) improves after 24–48 hours.[3] The sound-related hearing loss mechanism involves the destruction of the Corti organ within the cochlea. Loud noise exposures initially damage the hearing cells that are responsible for sounds with high frequency. Over time, continuous exposure to loud noise causes disorders in in the transmission of both high and low frequencies to the brain.[6] Based on a report by the American Conference on Industrial Health, nearly 8% of the US population have occupational hearing loss, and about 10 million workers in the United States suffer the hearing loss of more than 25 dB.[7] Conducted studies show that the sound pressure level of

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95-90 dB (A) can cause above 25 dB (A) of hearing loss, and the sound pressure level of 85-90 dB (A) can lead to hearing loss of less than 2 dB (A). However, in comparison, the sound pressure level with less than 80 dB (A) does not cause a considerable hearing loss.[7] Based on the classification of the National Institute of Standards and the American Academy of Otorhinolaryngology, a hearing loss of 25–40 dB is partial hearing loss, that with 40–55 dB is called mild hearing loss, the hearing loss of 55–70 dB is moderate hearing loss, whereas the condition with 70–90 dB is a severe hearing loss, and the reduction of over 90 dB is referred to as the deafness or permanent hearing loss.[7] According to the report of World Health Organization in 2014, 16% of the hearing loss in adults is due to exposure to occupational noise.[8,9] Human ear and its neural connection to the brain provide a complex and sensitive hearing mechanism that is vulnerable to various diseases, injuries, and exposure to toxic substances. There are two main types of hearing loss: conductive and sensorineural hearing loss. Conductive hearing loss affects the outer and/or middle ear that include auricle, ear canal, eardrum (tympanic membrane), and tympanic cavity. There are different reasons for the conductive hearing loss, the most prevalent of which are infection of middle ear consisting of middle otitis and eardrum rupture. Conductive hearing loss is often temporary and can be cured via complex surgical procedures or medication (for otitis media). Sensorineural hearing loss affects the inner ear (sensory), or the auditory nerve (neural) that connects the inner ear to the auditory organ in the brain.[3] Based on a study by Dr. R. Gholmohammadi *et al*. (2009)[10] on occupational hearing loss in a tractor manufacturing industrial center, it was concluded that hearing loss is increased by age, exposure to noise, and duration of working experience. Furthermore, in increasing the hearing loss by increasing the level of exposure to the equivalent sound level and increasing the work experience, the need to control the exposure and the noise in the work environment are emphasized to reduce the hearing loss of workers. Therefore, a regression model was given for the considered industry that can be used in predicting the hearing loss due to the noise. Noise control can reduce the treatment expenses and compensations for the damaged workers, and thus it can increase the working efficiency in production workshops.[11] The main prevention is important to control the adverse effects of noise, and to achieve this, the effects due to the noise can be reduced by observing specific principles, the most important of which include observing mechanical and engineering principles at the work place, selecting appropriate workers with regards to the working conditions and the environment, fulfilling periodic physical examinations, changing the job, and also using personal protection equipment and devices.[12] Controlling the sound engineering includes three different methods: 1) Sound control in its source, 2) Sound control in its route between the source and the receiver, and 3) Controlling in the receiver, where the worker is located.[1] In general, reducing noise in its generating source by observing, mechanical and engineering principles, is the most effective way of noise control, but the best and most acceptable way to control the effects of noise on human beings is to use personal protective devices. However, as controlling an important part of occupational hazards, including physical factors, especially noise in its generating source and also in its transmission route is sometimes not practical or very difficult,[12] and when engineering and administrative controls cannot reduce the average timing sound time to below 90 dB (according to the OSHA 29 CFR 1910.95 standard), the only remaining solution is to equip personnel with the appropriate and standard personal protective equipment as well as the earmuff standards.[3,12] It has been stated in the article by OiSaeng Hong *et al*.[3] that using ear protection devices is effective in preventing the hearing loss (NIHL). In order to avoid complete hearing loss, workers should constantly use ear protectors, when the sound level is high. Nevertheless, studies have shown that the workers do not constantly use them. Hence, establishing and implementing intervention programs are important to promote the use of ear protectors. Based on the US Department of Health and Human Services (USDHHS), when noise elimination is not possible through engineering controls, the proper use of hearing protection equipment along with audiometric monitoring is effective in preventing NIHL. Effective hearing protection can be achieved through careful selection of different types of hearing devices, proper testing and compliance, proper use, and constant attention to their maintenance. The two main objectives for avoiding occupational NIHL include increasing the use of hearing protection equipment (ENT-VSL-6) and reducing the cases of hearing loss because of the work-related noise (OSH-10).[3] In case of using ear protectors, the rate of received sound by the worker would be reduced in the working environment. The rate of noise attenuation of the ear protectors, developed by the Environmental Protection Agency (EPA), is displayed by the NRR index. Instead of the NRR methodology, the National Institute of Occupational Health and Safety (NIOSH) has three methods for determining the performance of the device's voice impairment. Instead of the NRR methodology, the National Institute of Occupational Health and Safety (NIOSH) has three methods for determining the efficacy regarding noise attenuation by the ear protectors.[8] The NRR index is available on the catalogs of the existing ear protectors. Given that the ear protectors are often used by workers in industrial environments with a high level of sound pressure, and the amount of noise attenuation on the volume of voice received by workers and their hearing system health is very effective; therefore, checking the accuracy and precision of the noise attenuation index for the NRR of the ear protectors is quite important.[13] Hearing protection devices are used to reduce the level of sound pressure to a safe level.[14] When a daily sound level is more than 85 dB, an ear protector is used to prevent the hearing loss.[15] The performance of these devices varies with each other. There are various methods in order to evaluate the reduction of the noise in ear protectors, which are divided into two general subjective and objective categories.[16] One of the most commonly used methods is the subjective method of the "real-ear-at-threshold" (REAT), the objective method of the "real microphone in the real ear" (MIRE - microphone in real ear), and the method of "acoustic test fixture" (ATF - acoustic test fixture).[17] In accordance with ISO4869-1, the REAT method is a method for measuring the reducing potential of earmuff and hearing protection devices in the people's hearing threshold and is referred to as the "golden standard," despite the fact that the rates of noise attenuation is the highest amount by this method, which cannot be achieved in real conditions. In this method, after the deployment of the person and playing the sound, the threshold of hearing is determined via the audiogram. Then, the ear protector is placed on the person's ears, and the threshold is re-determined. The amount of noise attenuation is actually the difference between hearing thresholds when using and not using the ear protector (standard "ISO4869-1"). This method underestimates the amount of sound at low frequencies due to the effects of coating. Hence, it may not show the real results in field conditions. One of the other disadvantages of this method is the high standard deviation of the noise attenuation among the considered individuals.[18] This method is time consuming and is sensitive to the background sounds (Systematic evaluation of the relationship between subjective and objective measurement methods of hearing protectors) devices attenuation.

According to the standard "ISO11904-1," miniature microphones are used in the MIRE method. One of the microphones is placed inside the ear canal and another one is located outside the ear.[19] After playing the sound, the measurement is done once without placement of the earplug and once by placing the earplug in the ears. The main key in the MIRE method is in the placement of the microphone inside the ear canal, in such a way not to have negative effects on the performance of the earplug. In addition to the negative effect of the inappropriate placement of the earplug inside the ear, another concern about this method is that not all the sound that entered in the ear canal is not trapped in this method as in the REAT method, because some of the sound is trapped around the protecting device due to the existing bone conduction. The advantage of this method is testing the noise attenuation of the earplugs in the wide range of sound level. The ATF method is based on the standard "ISO4869-3: 2007. In this method, the insertion loss (IL) is the difference of the sound level in the ear canal by placing the ear protector (earplug) and not placing that for the simulated model of a head for the hearing system of humans. One of the advantages of this method is multiple testing the earplugs in high sound pressure level (Ref.: ISO4869-3:2007).

Various studies are done about sound attenuation of ear protectors. Nelisse *et al*. have done a study regarding the comparison of the rate of sound attenuations of the ear protectors by using the objective and subjective methods.[20] Our aim from this study was to determine the rate of low frequency noise attenuation of at least two ear protector models including earmuffs and earplugs, by using LABVIEW software. Moreover, using the microphone in real ear, the actual reduction and the frequency energy distribution in the received human hearing system before and after the use of protection was evaluated subjectively.

Methods

Sound measurement in a simulated ear canal

All the procedures of the work were done using the simulated human ear and the required microphone in the eardrum on 20 students of Isfahan University of Medical Sciences as the cross-sectional – interventional study. The microphone was connected to the processing card (data acquisition card - DAQ). The DAQ card of the used sound in this project is made by National Instrument Co./USA. At the octave frequencies, that is 31.5 and 63.5, 125, 250, 500, 1000, 2000, 4000, and 8000 Hz, and intensities of 85-90 dB, pink noise was generated by the generator for the model through the sound processor card and played by the loudspeaker in front of the simulated hearing system. After reaching the ears, the sound is taken from the right and left microphones and transmitted to the DAQ card. The LABVIEW software was installed on the computer system and used to plot the results in the form of the frequency analysis curve. Sound measurement was done before and after using the ear protector, and then, the rate of attenuation or the ear protector efficiency was investigated. The change in the sound attenuation in the 1/3-octave frequency spectrum was based on the standard instructions by measuring the sound with using three simultaneous microphones outside the simulated ear at a distance of 1 cm from the auricle, at the place of auricle, and inside the simulated ear canal. The played sound by the microphone mounted on the model was received and the frequency analysis curve was plotted at the frequencies listed on the LABVIEW software. In the next step, an ear protector (earmuff) is placed on the model, the sound was replayed for the model, and the frequency analysis curve is redrawn. Both before and after the use of the ear protector, which is the same as the rate of sound attenuation of the ear protectors, the rate of sound reduction is obtained by subtracting the sound pressure level at any frequency by using the ear protector or not using the device.

Sound measurement by the microphone in real ear

The measuring procedures of before section were repeated in MIRE method. However, at this stage, contrary to the previous stage, work was done on the human ears and 20 people participated in all the measurements. Two different ear protectors (earmuff and earplug) were examined in this descriptive analytic study. The methodology of the study was in accordance with ISO1190401 standard and the MIRE method. Miniature microphones were used for the purpose of this study. Noise reduction changes, in the 1/3-octave frequency spectrum, were based on the standard instructions by measuring the volume using three concurrent microphones outside the ear, at a distance of 1 cm from the ear canal, at the auricle, and inside the ear canal. Sound was played for the person pink or even at octave frequencies (31.5, 125, 250, 500, 1000, 2000, 3000, 4000, and 8000 Hz) by the processor card. The played sound by the microphone mounted on the auricle and inside the ear canal was received and the frequency analysis curve was plotted at the frequencies listed on the LABVIEW software. In the next step, an ear protector was placed on the subject's ear, the sound is replayed, and the frequency analysis curve was redrawn. Both before and after the use of the ear protector, which is the same as the rate of sound attenuation of the ear protectors, the rate of sound reduction is obtained by subtracting the sound pressure level at any frequency by using the ear protector or not using the device. This method indicates the real rate of the attenuation.

A suggested way to develop the subjective method

As the current subjective method of evaluation of the ear protector is not based on industrial noise and in the field, a suggested way to develop the subjective method is recommended by the author. In this way, one stage is done by using the individual's subjective response relative to the received sound before and after using the ear protector. This section is developed by defining the subjective perceptions of individuals and their feelings with respect to the sound comprehension, the score of responses, and then converting them into level amounts of the sound. A number of students between the ages of 18 and 25 were selected. First, a hearing test was performed on their ear to determine their hearing threshold. They were then confronted with a distinct sound level. When using the ear protector and without using it, they were asked how they felt about the amount of sound received. This qualitative feeling was converted into level amounts and compared with a quantitative method. Of course, more candidates are needed to improve the accuracy of the test results.

Results

The results for measuring sound pressure levels inside and outside the ear and also after placing earplugs and earmuffs are hereby presented. The results are also given graphically with using MATLAB simulation to compare the sound levels outside and inside the ear canals and also the energy changes caused by the placement and using the ear protectors. The aim of this study was to determine the efficiency of two samples of earmuff and earplug in low-frequency noise reduction in comparison to subjective method. The results of paired t-test showed that in both samples of the ear protectors, the sound level before and after the protection is significantly different in both the model and the humans ($P < 0.05$). The results of paired t-test on the simulated model and the in-ear microphone did not show a significant difference ($P < 0.05$). Figure 1 shows the levels of sound pressure measured by using ear protectors and the comparison with the levels of sound level in the ear canal after playing 85 dB sound. This graph also depicts the changes of the energy distribution inside the ear canal after using an earplug and earmuff.

By increasing the sound pressure levels, it is possible to see the efficiency of earmuff, which will be better than earplug. For frequencies less than 500 Hz, the reduction of ear plug efficiency is obvious until reaching a frequency of 60 Hz [Figure 2]. The effects of installing and noise reduction of earmuff and earplug simultaneously on the hearing system is demonstrated in Figure 3. As can be seen, a protection of 40 dB is created specially in a frequency of 2500 Hz. Of course, an increase of 20 dB is also seen at low frequencies of 50 Hz.

However, from the Figure 1, as it can be observed, at 315 Hz frequency, the rate of attenuation is increased by 4 dB after placing the earplug and 14 dB after placing the earmuff, showing a reduction of 18 dB. This issue has been maximized at the frequency of 2500 Hz, such that the reduction of 27 dB by the earplug has reached 42 dB by placing the earmuff [Figure 3].

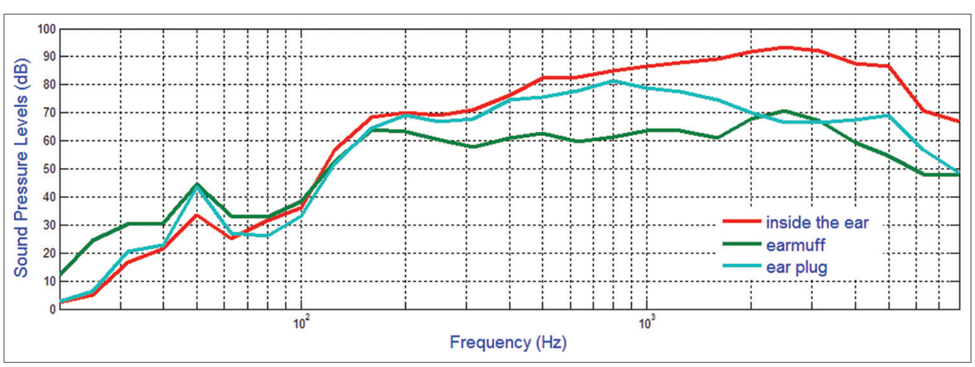

Figure 1: Comparison of the distribution of sound energy inside the ear canal between the earplug and earmuff

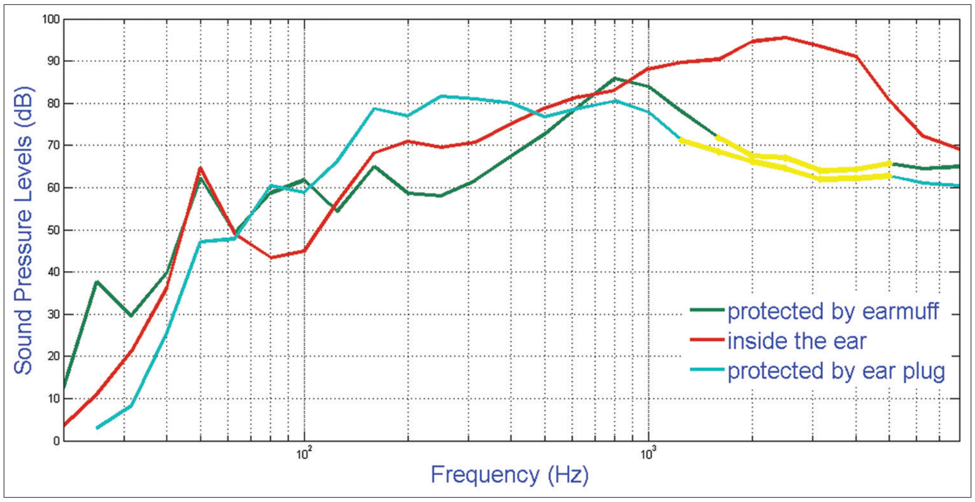

Figure 2: Comparison of the distribution of sound energy inside the ear canal between the earplug and earmuff used in the higher levels

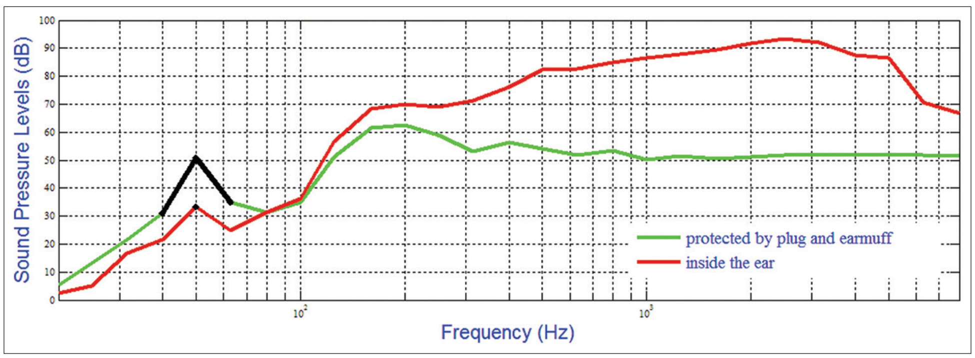

Figure 3: Changes in the distribution of sound energy inside the ear canal and when using both the earplug and earmuff

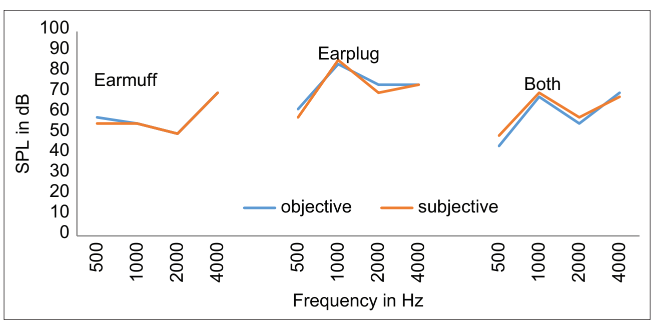

Figure 4: Evaluation of subjective method of hearing protectors in comparison to objective method

Discussion

One of the most important points is the protection of the earplug or the earmuff. According to Figures 1 and 2, on one hand, the protective effect of earplugs is rather higher in low frequencies. Based on European standard, hearing protectors testing physical test methods, the first part of evaluation was the efficiency of earplug in comparison to earmuff. For instance, the protective effect of the earplug in 60 and 80 Hz frequencies is 5 and 7 dB higher than earmuffs, respectively. On the other hand, the protective effect of the earmuffs covers a wider range of higher frequencies, such that in the case of frequencies of 160-800 Hz and higher, the protective effect of the earmuff is quite dominant. For example, at the frequencies higher than 1000 Hz, the protective effect of the earmuff is 14 dB more than the earplug. This was consistent with previous studies.

Of course, Figure 2 is demonstrating that with increasing levels of sound to 90 dB, ear plug protection is declining. As the frequency of 800 Hz to 125 Hz, the ear plug has shown a reduction of efficiency, the earmuff efficiency from the frequency of 1000 to 300 Hz has a rapid decline near to 25 dB. It seems in a higher level of sound, the earmuff protects better hearing system against high frequency noise, whereas the earplug loses its ability to keep protection against low-frequency noise. This suggests that due to changes in the sound releasing environment, the energy distribution of the sound is also different and the frequency spectrum of the received sound is also affected. As the overall sound level is a function of the higher levels of sound, the overall sound level is also increased by increasing the sound level in a specific range. But the most important thing is the reverse effects of putting ear protectors on auricle or inside of ear canal. It leads to changing the acoustical structure of ear canal as well as the sound distribution. Frequency band is affected and the resonance happens. The distribution of acoustic energy goes in the direction that a resonant frequency may appear. Figure 3 shows a 50-Hz resonant frequency when using earmuff simultaneously with the earplug. These are new results in how hearing protectors affect workers' hearing of sound that have not been mentioned in previous studies.

Conclusions

The study shows that the sound levels measured with sound analyzer outside the ear are different and less than the rates received by the ear and inside the ear canal. Hearing protection programs should be reconsidered, in case the matter is verified by more extensive and supplementary studies. Furthermore, this study verifies the increasing protection by simultaneous application of earplugs and earmuffs. It can be observed that in the frequency of 2500 Hz, simultaneous placement of an earplug and an earmuff provides sound attenuation by a maximum rate of 42 dB. According to the results of this study, it is suggested that further studies in this regard, especially in the effectiveness of hearing protection and the effect on changes in the distribution of energy within the ear canal and the state of resonating some frequencies, to be done, in order to provide a better judgment about the process of receiving sound by the ear or the about the effectiveness of hearing protectors. To prove these cases, it may be necessary to perform mental methods to test hearing protectors and compare them with other techniques with a greater number of samples to reach a result as Figure 4. As a result of the laboratory evaluation of ear protectors, it is possible not to justify the proficiency of ear protectors in a subjective method. The method is suggested by using the individual's subjective response before and after using the ear protector. This method is based on the subjective perceptions of individuals and their feelings with respect to the sound comprehension, in an acceptable noise level for occupational and environmental fields.

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Conflicts of interest

There are no conflicts of interest.

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References

1. Aluclu I, Dalgic A, Toprak Z. A fuzzy logic-based model for noise control at industrial workplaces. Appl Ergon 2008;39:368-78.
2. Jang R, Moles worth BR, Burgess M, Estival D. Improving communication in general aviation through the use of noise cancelling headphones. Safety Sci 2014;62:499-504.
3. Hong O, Kerr MJ, Poling GL, Dhār S. Understanding and preventing noise-induced hearing loss. Dis Mon 2013;59:110-8.
4. Golmohamadi R, Amjad Sardrood H, Dormohamadi A, Mousavi S. Occupational hearing loss due to noise exposure in a Tractor industry. J Ooccup Med 2013:4:28-33.
5. Faria CAR, Suzuki FA. Pure tone audiometry with and without specific ear protectors. Braz J Otorhinolaryngol 2008;74:417-22.
6. Daniel E. Noise and hearing loss: A review. J Sch Health 2007;77:225-31.
7. Ebrahimzade M, Darvishi E, The Study Of Hearing Status And Its Influencing Factors In The Workers Of Mines In The Central Region. Med J Zanko 2015;16:33-41.
8. OSHA 29CFR 1910.95 App B. Available from: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.95AppB. [Last accessed on 2015 Dec 17].
9. Protecting workers' health. 2017. Available from: https://www.who.int/news-room/fact-sheets/detail/protecting-workers'-health. [Last accessed on 2015 Dec 17].
10. Gholmohammadi R. NOISE & Vibration Engineering in Indutrial & Enviroment. 4th ed. Hamedan: Student publication; 2011. [In Persian].
11. Mohammadfam I. Personal Protective Equipment. 4th ed. Tehran: Fan avaran; 2013. [In Persian].
12. Tabaraei Y, Ahmadizad S, Heydari H, Kouhpaei A. Study of the effective parameters on the making use of protective devices in Qom province workers community in 2008.
13. National Institute of Occupational Safety and Health. https://www.cdc.gov/niosh/topics/noise/preventhearingloss/hearlosspreventprograms.html. 2015. [Last accessed on 2015 Dec 17].
14. American National Standards Institute. ANSI ASA S122016-Methods for Measuring the Real-Ear Attenuation of Hearing Protectors. American National Standards Institute, New York, NY.
15. American National Standards Institute. American National Standard for the Measurement of Real-Ear Hearing Protectors and Physical Attenuation of Earmuffs. ANSI S3.19-1974, American National Standards Institute, New York, NY.
16. European Standard. Hearing protectors Testing Physical test methods. EN13819-1-2002.
17. International Electrotechnical Commission. Occluded-ear simulator for the measurement of earphones coupled to the ear by ear inserts. IEC60711-1981.
18. ISO 4869-1:2018 Acoustics — Hearing protectors — Part 1: Subjective method for the measurement of sound attenuation.
19. ISO 11904-1:2002 specifies basic framework measurement methods for sound immissions from sound sources placed close to the ear. These measurements are carried out with miniature or probe microphones inserted in the ear canals of human subjects.
20. Nelisse H, Cocq CL, Boutin J, Voix J, Laville F. Comparison of subjective and objective methods for the measurements of hearing protector devices attenuation and occlusion effect. Acoustical Society of America, Acoustics, 2013;19:040004.