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Protection by noise in quarrying activities: test methods comparison of the hearing protection devices efficiency

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Abstract. The work operations in the quarry activities are the source of many physical agents such as dust and vibrations but especially noise. This last can have relevant negative effects they cause serious problems for the worker's health. In order to prevent the hearing loss, the employer must provide to the workers the HPD (Hearing Protection Devices). They are inserted inside the ear following a specific procedure to ensure the maximum protection by the noise. For this reason, the use training represents an essential aspect. Also the material, which the device is made of, can influence strongly the actual noise attenuation. The study is based on tests with different HPD, some made of polyurethane and others by silicone. Two experimental campaigns were carried out under different conditions with the same measurement methodology. The results highlight the importance of the methodology used in the test and the relevant role of the use training.

1 Introduction

In recent centuries, the quarrying activity has been necessary both by industry and construction of new grand buildings and plants. In fact the main commercial purposes are the production quarry dust for the construction of motorways [1], ornamental and building stones [2]. In these work contexts is inevitable the presence of physical agents that can be lead to several health problems for workers, as dust [3], vibration [4] and noise and these are classified under hazards for occupational health of the workers. These physical agents are present simultaneously during the daily mining operations within the quarry, such as the extraction, transport and crushing of the material in the production process [5]. There are many sources of noise, such as screens, crushers, drills, fans and mobile equipment, that generate high noise levels that can lead to dangerous exposure for workers [6], [7]. Also noise sources can be present, such as breakers, bulldozers, and excavators, which are mainly used in many processing stages. European legislation had published a specific law, defined European Directive, due to the magnitude of the exposure noise. It establishes the limits for workers' protection according to their specific activities (time exposure, distance from noise source, ecc.) [8]. In fact it's recognized that excessive exposure to noise from all these sources beyond the levels defined by law is dangerous and could result in Noise-Induced-Hearing-Loss (NIHL). The first consequence of exposure to excess noise is an increase in the hearing threshold (threshold shift), as demonstrated by audiometric studies. This disease is defined as a change in hearing thresholds of 10 dB or more on average at 2000, 3000 and 4000Hz in both ears (worst hearing). NIHL is a biological phenomenon consisting of a particular combination of mechanical and metabolic elements [9]. Many factors can influencing the insurgence of NIHL, for example tobacco [10] and the synergistic effect of smoking, noise exposure and age with biological interaction have a consistent effect on hearing loss [11]. The scientific studies demonstrated that NIHL is subdivided in two types: a permanent threshold shift, which involves a shift in the person's ability to hear soft sounds and a temporary threshold shift, which is a temporary loss of hearing. The permanent shift is a result of long-term exposure to loud sounds, such as factory noise, rock music, blast and drilling operations [12]. It contributes to 16% of adult hearing loss globally in modern countries, from 7% to 21% in various sub-regions and beyond in developing countries [13]. In almost all industry sectors the workers are exposed to dangerous noise, particularly in the large coal and steel industry, about 76% of workers are potentially subjects that can have the development of illness due to exposure noise. For example, in Tanzania, the prevalence of NIHL in mines and steelworks was estimated at 47% and 48% respectively, which is higher than the global average prevalence of NIHL, which ranges from 7% to 21% [14], [15]. Regarding of the mining sector, the noise that occurs during process activities, such as drilling, digging, loading and transport in both open spaces and underground tunnels, is very relevant. In fact considering occupational health and performance, in the mine activities the highest rates of illness and disease continue to be the permanent or temporary loss of the miner's hearing [16]. It is obvious that effective preventive solutions are needed to avoid NIHL (with a permanent shift of the threshold) and its irreversible negative effects [17]. Moreover, many studies point out that noise is the reason for the increase in blood pressure, the acceleration of heart rate and the narrowing of blood vessels. In fact, it has been observed that most workers exposed to high noise levels complain of nervousness, insomnia and

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fatigue [18]. The parameters that describe and quantify the hearing loss due to noise are various and linked by many elements: noise level, frequency spectrum, exposure period, age of workers and their physical condition [19]. Hearing Protection Devices (HPD) are used to protect workers' health. Three main types of common HPDs are currently used, namely headphones and earplugs. Basically, the operation of these HPDs is based on reducing noise by blocking the sound pressure entering in the ear canal [20]. Unfortunately, the use of HPDs has several drawbacks because the effectiveness of hearing protection programs can sometimes be hampered by poor compliance in their use due to communication difficulties, comfort problems, individual attitudes to hearing protection from noise-induced hearing loss, and individual perceptions of how others who do not use hearing protection will see them if they choose to use hearing protection [21]. In addition, one of the major problems is the lack of knowledge of NIHL by many workers, even those who are employed in important work contexts, such as mining, iron and steel factories [22]. Moreover, even when industrial workers are aware of the real health risks, many of them still reject the use of HPDs. From several interviews, it was revealed that the most important reason is the feeling of discomfort [23]. It is the main reason for not using HPDs during work activities. In addition, workers refuse to wear HPDs because it creates a barrier in communication and there is a lack of awareness on the device. Exposure to noise can have consequences on human behaviour ; for this reason the relationship between noise and subjective reactions to it has been studied [24].

2 Materials and methods

Based on the above described, this study compares two methodology for assessing the effective attenuation of HPDs in order to protect workers by exposure to noise. The work consists of two experimental campaigns conducted in different contexts. They are carried out at the same time and are described below.

2.1. First measurement Campaign

The first measurement campaign in anechoic chamber was carried out on 5 different types of HPDs. They were tested on a human mannequin. This phase of the methodology consists in comparing the attenuation of the HPDs, characterized by different characteristics in terms of shape and material. HPDs specific data are reported in the following table 1:

Table 1: the characteristic of the earpieces

HPD	Material	Density	Shape
A	silicone	high	cylindrical - full
B	silicone	medium	cylindrical - full
C	silicone	medium	cylindrical - full
D	silicone	none	cylindrical - empty
E	methacrylate	high	cylindrical - full

The sample considered for this study includes 5 different types of HPDs. As listed in Table 1, the density, and thus the hardness, of HPDs is defined as high or low. Generally, the values are defined in a specific scale, called shore scale, which is used to define the hardness of the material, particularly for elastomers and thermoplastics. For the purposes of this study, all these different types of HPDs are compared and the actual efficiency in terms of attenuation is assessed. All HPDs have a full cylindrical shape, except for case D which is empty inside. All HPDs are made of specific materials, with good adaptability to the human ear.

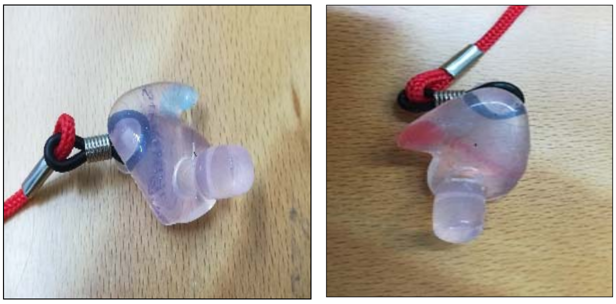

Fig. 1. HPD type A and B

Fig. 2. HPD type C inside the ear of mannequin

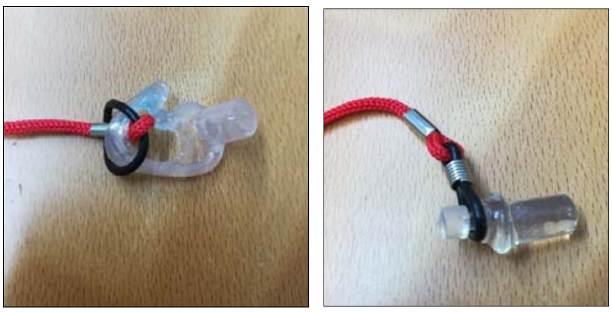

Fig. 2. HPD type D and E

Fig. 4. The microphone n° 3 near the ear of maniquine in the chamber room

The tests were carried out with a noise source that generates a specific signal, called white noise. According to UNI 9432:2011, two microphones replicating the real human ear were placed inside the mannequin's ear and the same mannequin was placed in the centre of the anechoic chamber in front of the noise source. The tests were carried out with three different noise levels, 80, 85 and 87 dBA, defined by law 81/08, respectively lower action value, upper action value and limit value, representing the threshold limit of exposure to noise. For all measurements, the basic measured quantity considered was the sound pressure level (SPL) for a given period of time (10s). All the signal analyzed in flat configuration, without any kind of weight in frequency. The signal was acquired and the level attenuation between the internal and external microphones was calculated on both ears. Level attenuation was calculated for each type of HPD and an average between left and right ear was calculated according to equation 1 below:

$$L_{eq} = 10\log\left[\frac{1}{N}\sum_{n=1}^{N}10^{0.1*L_{eq,n}}\right] \quad (1)$$

According to standardised procedures for measuring noise levels in anechoic chambers, two microphones were placed 0.1m away from each ear of the mannequin to assess the repeatability of measurements while the height of these was set at 1.5m above the ground. Before each measurement, the microphone was calibrated using the B&K 1049 signal source calibrator with a signal of 94 dB and 1 KHz. The signal was acquired through the SAMURAI software and the data were analyzed with Noise Vibration Work software.

2.2 Second measurement Campaign

The earpiece used for this measurement campaign was different from the previous one. The source of the noise signal was characterized by a continuous white noise level and a constant frequency spectrum. It was mounted on a small stand on a table to perform the test, the hearing protection system, model 3M™ 1100 and the measurement system was 3M™ E-A-Rfit™ Dual-Ear Validation System 393-1100. The 3M measurement system consists of a speaker and two microphones connected to a single headset (fig.5). These devices have been modified by the manufacturer to perform this type of test and are made of polyurethane. The modification of the HPDs consists of inserting a small plastic tube with the addition of an electronic support to which two microphones are connected (fig.6). This system can calculate the loss of attenuation of an inner earpiece in the ear by calculating the difference in sound pressure between an outer microphone and an inner microphone in the earpiece. The experimental test was performed and the data was acquired according to the following three-step procedure. Each subject was seated in a chair in front of the noise source: in the first phase the subject wore the headset without any instruction, connected two microphones to the electronic supports of the headset and fixed microphones on the glasses. Finally, the assistant verified the correct position with respect to the noise source, 30 centimeters between the subject's head and the noise source. This method meant that the noise recorded by the microphones was the same as that recorded inside the headset, so that the distance between the subject and the noise source was the same in all tests. After this phase, the attenuation levels at the noise source were recorded for each headset. The time acquisition signal was 5 seconds long. After the measurement, the subject had to see a short video provided by 3M explaining the operating instructions for proper insertion of the headset. It was made with the aim of providing the most standardized training possible for all subjects. At this point, the measurement was repeated again and the new data was recorded using the same procedure. In this measurement campaign, for post-processing, the software package used was the 3M software that acquired the levels and spectra obtained by the microphones. It provided graphs and tables based on the acquired data and provides the results with a tolerance not exceeding 5dB.

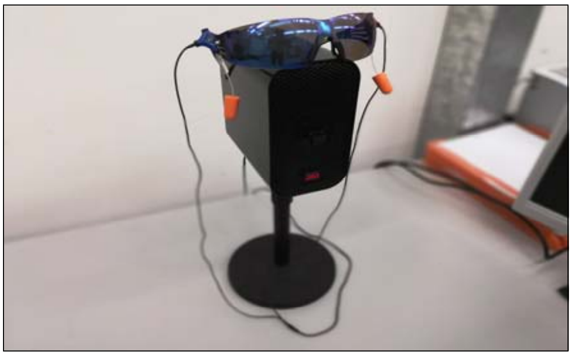

Fig. 5. The noise source and the glasses

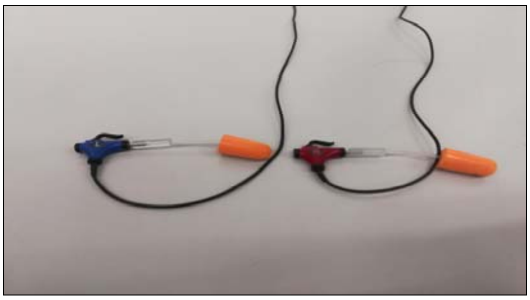

Fig. 6. The HPDs devices for both ears

3 Results

3.1 First measurement campaign

The first measurement campaign was carried out with different types of HPDs with the purpose of study the effective attenuation. The following graphs show the results of each HPD. On the y-axis the level attenuation for each frequency, expressed in terms of dB, while on the x-axis all the frequency components are reported. Each line is referred to a specific HPD and represent the trend attenuation. The blue line represents the hard silicone device, the light blue line the methacrylate earpiece, while the red and green lines describe the silicone HPD with a different shore scale. Finally the purple line point outs the global attenuation for the empty HPD. It should be noted that the values attenuation are calculated as an average between the two ears. The actual effectiveness of HPDs for the purpose of protecting health of workers can be analyzed by analyzing this data

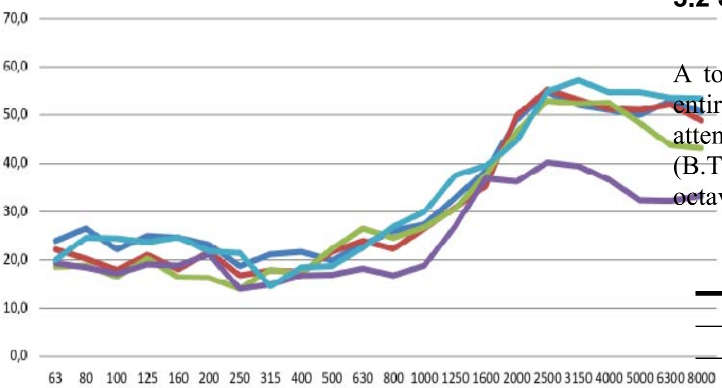

Fig. 7. Data carried out in test 1

The above graph (fig. 7) is shown for test 1 with the noise source level set to 80 dB as described above while the following figure (fig.8) shows the results of test 2 carried out at 85 dB.

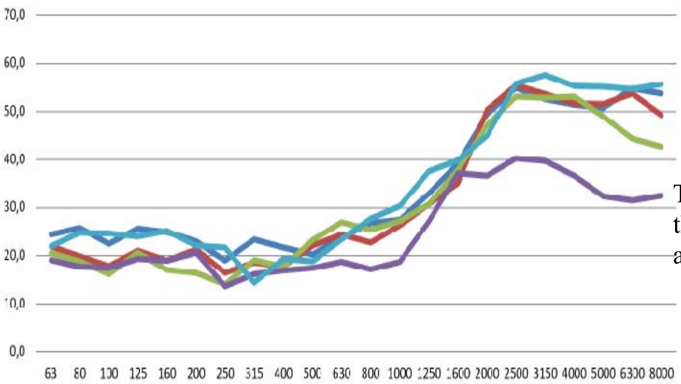

Fig. 8. The attenuation levels for test 2

The following figure (fig.9) shows the attenuation level of the HPDs in the test with the highest 87dB noise level.

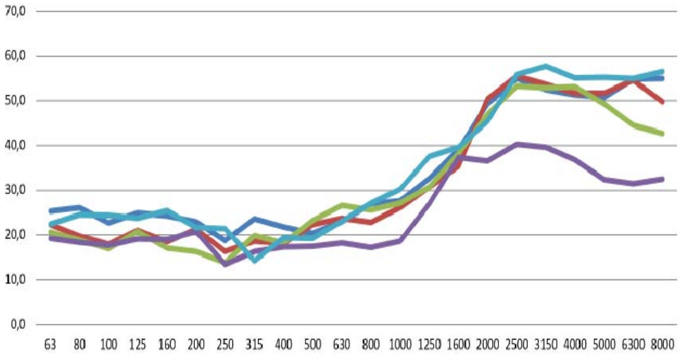

Fig. 9. Data obtained in test 3

The analysis of this configuration plays a relevant role because is the noise level represents the limit value established by the Italian law in terms of maximum exposure for the workers

3.2 Second measurement campaign

A total of 100 subjects participated and completed the entire test required in this experimental campaign. The attenuation of the level before the use of the training (B.T.U.) and after the use of the training (A.T.U.) for octave band for each ear are reported in table 2.

Table 2: the results before and after the training use

Hz	EAR	B.T.U.	A.T.U.
125	Left	13	29
125	Right	14	31
250	Left	12	32
250	Right	13	33
500	Left	10	32
500	Right	11	33
1000	Left	16	36
1000	Right	17	36
2000	Left	18	31
2000	Right	19	31
4000	Left	29	39
4000	Right	31	40
8000	Left	33	45
8000	Right	34	44

The global attenuation levels for each ear are analyzed in the following graphs. The first graph compares the level attenuation between left and right ear.

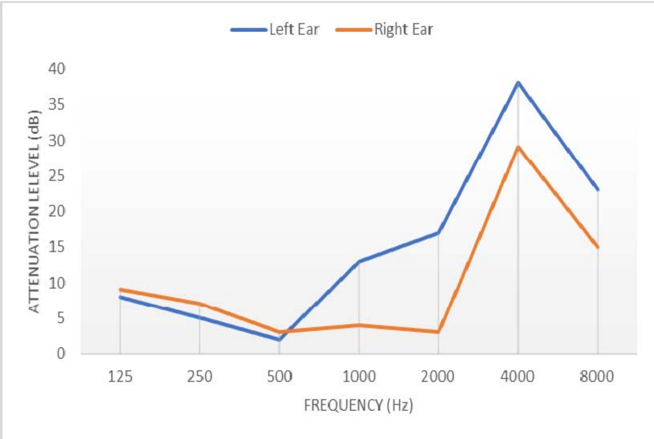

Fig. 10. Comparison of data between right and left

The graph in fig.11 shows the level of attenuation before and after use when subjects have seen the training video that explains the correct way to insert the headset in the ear.

Fig. 11. comparison of data obtained before and after traing use

4 Results and discussion

The results of the measurement campaigns were analysed. The study of the octave band was carried out in order to identify the range of frequencies in which the greatest attenuation of noise is obtained. In general, from the data obtained in the first measurement campaign, it can be said that the level attenuation increases with the highest frequencies. This result is clear for each test with different noise sources (fig.7). From this frequency value all lines grow up to 8000Hz. These frequency values have been defined because they represent the spectrum of the best human audibility where a worker is most exposed to noise. It is possible to verify that the attenuation is similar for all HDPs characterized by the same geometric shape and filled with material while the cylindrical but empty HPD shows a lower effective attenuation. The data carried out with microphone n° 3 and n°4 have shown similar values with a difference between one measurement and the other not exceeding 0.1 dB in all tests. This result shows a good repeatability of the measurement technique with different noise levels. The second measurement campaign aims to highlight the relevant role of user training for workers and how their position can influence noise damping and consequently the worker's noise exposure dose. The first graph (fig.10) shows the difference between the left and right ear. Differences in attenuation level are minimal up to 500Hz and are most relevant from 1000Hz. The most important result is the difference between the frequency spectrum before and after viewing the video (fig.11). When the operator uses the HPD after instructions for proper insertion into the ear, the headset is able to attenuate approximately equally in all frequencies of the spectrum in a attenuation range of 30 dB to 45 dB. When the HPD is used directly without any instruction, attenuation is maintained in a range from 5dBa to 20dB at low frequencies. At 4000 Hz, the maximum peak was measured for both the left and right ear configurations.

5 Conclusions

Noise is one of the occupational risks and environmental pollutants in mining activities that cause many health problems for workers. NIHL is an incurable but preventable work-related hazard to human health. In order to prevent NIHL for workers, the use of HPDs seems to be the best way. The study revealed that the strategy to reduce noise exposure is based on two main elements: the choice of specific materials for HPDs and training for proper use by workers. The first measurement campaign focuses on the effectiveness of the hearing protector material, while the second tests aim to analyze how the proper use of these elements plays an important role. The results of the first measurement campaign highlight the importance of the material of which the HPD is composed. It is a key parameter for two reasons: the effective attenuation of noise during the worker's work and comfort during use. The latter can be decisive in prevention strategies because it can contribute positively to the use of HPDs by workers in all work contexts. The second measurement campaign is based on tests carried out under real conditions. Measurements were made on participants who have no experience in mining and never use HPDs. The results obtained with the same type of headset, allow different considerations. The first interesting result is a significant difference between the values made before the training to use and after watching the video for the correct procedure of insertion of the ear. The second consideration concerns the type of material; the type of HPD used in this test is different from the earphones used in the previous campaign because they are malleable and have a lower hardness. A limitation in these experimental campaigns may be the fact that the largest number of selected subjects were males but this is because all workers in mining and those exposed to noise are generally males. Another limitation of this work is the type of source; the type of sound source is similar in the two different measurement campaigns with a constant noise level. The effective noise source can include many worker exposure variables that could contribute to induced hearing loss. It should be noted that the use of HPDs is not the only method to prevent NIHL. Preventive strategies that aim to reduce noise source levels in the workplace, planned health surveliance prevention for workers exposed to excessive noise, regular education for all employers and employees on these issues can certainly help prevent possible damage to the hearing system. Further future research may be based on other experimental campaigns with the same HPD but under real conditions. Also it would be interesting to analyze the actual attenuation for a group of workers in defined times with specific tests. Repeat the same test after a long period of exposure to assess the performance of the material during the long period of work. This can lead to an understanding of when HPDs can no longer protect the worker from noise. The authors of this article hope that the results obtained will help develop HPDs research to reduce the risk of hearing loss among mine workers.

Keywords

Prevention, Hearing Protection Devices (HPDs), risk assessment, noise, quarrying activities, human health, noise-induced hearing loss (NIHL).

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References

[1] T. G. Soosan, A. Sridharan, B.T. Jose, B. M. Abraham, Utilization of quarry dust to improve the geotechnical properties of soils in highway construction, Geot. Test. J., **28(4)**, pp.391-400, (2005)

[2] M. Galetakis, A. Soultana, A review on the utilisation of quarry and ornamental stone industry fine by-products in the construction sector, Constr. and Build. Mat., **102**, pp.769-781. (2016)

[3] G. Alfaro Degan, D. Lippiello, M. Pinzari, Effectiveness of airborne dust control strategies in opencast quarrying activities: A case study near Rome, GEAM, Geoingegneria Ambientale Mineraria, **139 (2)**, pp. 5-12 (2013)

[4] G. Alfaro Degan, G. Coltrinari, D. Lippiello, M. Pinzari, A comparison between methods for assessment of whole-body vibration exposure: a case study in a limestone quarry. International J. of Safety and Security Engineering, **8(1)**, pp.90-97. (2018)

[5] R. Ciccu, V. Dentoni, G. Massacci, I. Mulas, Personal noise exposure in dimension stone quarries: the role of quarrying technology and quarry design. *In 11th International symposium on Mine Planning and Equipment Selection*, pp. 87-92. (2002)

[6] K. Raisian, J. Yahaya, A. Deraman, A. Hamdan, I. Rais, N. Yahaya, A Model for Environmental Quarry System based on Particles Vibration and Noise Components. J. of Adv. Res. in Manag., **7(2)**, pp.185-193.(2016)

[7] E. R. Bauer, Avoiding noise overexposure at underground and surface coal mines, preparation plants and surface drilling, *Mining Hearing Loss Prevention Workshop.* (June 2015)

[8] European Parliament - EP, In: EC (Ed.), European Directive 2003/10/EC on the Minimum Health and Safety Requirements Regarding the Exposure of Workers to the Risks Arising from Physical Agents (Noise). (2003)

[9] W. W. Clark, B. A. Bohne, Effects of noise on hearing. Jama, **281(17)**, pp.1658-1659. (1999)

[10] G. Maffei, P. Miani, Experimental tobacco poisoning. Resultant structural modifications of the cochlea and tuba acustica. Arch Otolaryngol;**75**, pp.386–396. (1962)

[11] S. Ferrite, V. Santana, Joint effects of smoking, noise exposure and age on hearing loss, Occ. Med., **55(1)**, pp. 48-53. (2005)

[12] National Institute for Occupational, Safety and Health: Criteria for a recommended standard: occupational noise exposure, *Revised criteria*. (1998)

[13] D.I. Nelson, R.Y. Nelson, M. Concha-Barrientos, M. Fingerhut, The global burden of occupational noise-induced hearing loss. Am J Ind Med ;**48(6)**, pp.446- 458. (2005 Dec)

[14] I.P. Nyarubeli, A.M. Tungu, M. Bratveit, E. Sunde, A.V. Kayumba, B.E. Moen, Variability and determinants of occupational noise exposure among iron and steel factory workers in Tanzania. Ann Work Expo Health.;**62(9)**, pp.1109–1122. (2018)

[15] I. P. Nyarubeli, A. M. Tungu, M. Bråtveit, B. Moen, Occupational noise exposure and hearing loss: A study of knowledge, attitude and practice among Tanzanian iron and steel workers. Archives of env. & occ. Hea., pp.1-10. (2019)

[16] D. F. Scott, R. L. Grayson, A. Edward, Disease and Illness in U.S. Mining, J. of Occup. & Env. Medicine, **46 (12)**, pp.1983-2001. (Dec. 2004)

[17] M. Basner, W. Babisch, A. Davis, et al., Auditory and non-auditory effects of noise on health. Lancet; **383**, pp.1325–1332. (2014)

[18] S. Ferrite, V. Santana, Joint effects of smoking, noise exposure and age on hearing loss, Occup. Med. (Lond), **55(1)**, pp.48-53. (Jan. 2005)

[19] B. Unver, A study on the effects of noise experienced during mining activities on the health of labour. *Conference on Safety in Mines and*

Environmental Protection, ISGUM, Ankara [In Turkish], pp. 83-98, (1995)

[20] R.R. Davis, What Do We Know about Hearing Protector Comfort? Noise Health, **10(40)**: pp.83-89. (2008)

[21] C. Sensogut, Occupational noise in mines and its control-A case study. Polish J. of Environmental Studies, **16(6)**, pp. 939. (2007)

[22] S. N. Yahya, N. A. A. Rahman, A. Razali, N. I. A. Rahman, M. Haque, Satisfaction study of using hearing protection device among sawmill workers in Kuantan, Malaysia. Inter. J. of Pharmaceutical Research, **8(1)**, pp.50-56, (2016)

[23] Center for Disease Control and Prevention, Mining Topic: *Hearing Loss Prevention Overview*. (2015)

[24] R. F. S. Job, Community response to noise: A review of factors influencing the relationship between noise exposure and reaction. The J. of the Ac. Soc. of Am., **83(3)**, pp.991-1001. (1988)