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ANALYSIS OF NOISE SOURCES AND SELECTION OF EAR PROTECTOR IN A COAL MINE

In this study, the noise sources to which a coal miner, who works at the Kurul panel of Kilimli Colliery, Zonguldak, was exposed were investigated. These sources were positioned at different points from the surface to the workface. Noise levels were measured according to the working periods of the coal miners around the machines. The results were evaluated under the Turkish Noise Regulation. The critical exposure times in which the coal miners could work without the use of personal protective equipment were examined according to the noise values to which they were exposed. In addition, the personal noise exposure values of the machine operators (boring machine, electro-hydraulic drill, and pick hammer) were determined during the development works. Two different types of noise measurements, with a microphone at the ear level and inside the ear protector, were conducted. The results obtained when the microphone of the personal dosimeter was at ear level, were found to be 15 dBA higher than those when the microphone was inside the ear protector. As a result, the selection methods of ear protectors were analyzed. Recommendations were given for those working on the risky tasks at the panel.

Keywords: Coal Mine; Noise; Sound Meter; Dosimeter; Hearing Protection Device

1. Introduction

Noise exists at all stage of mining, especially during operations such as drilling and blasting, crushing, transportation, ventilation, ore dressing, excavation etc. [1]. Various types of mining equipment generate noise at dangerous level, which can create long-term damage to human hearing. The most serious noise sources for underground mining equipment are the development and production machines such as boring machines, roadheaders, shearers, pick hammers and chain conveyors used for transportation, and also fans for ventilation. Thus, the underground miners

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spend too much time in noisy environments at their workplaces. Prolonged exposure to noise causes occupational health problems such as hearing loss. It is a very well-known fact that the coal miners working underground are subjected to higher levels of hearing loss when compared to those working in other industries. This results in depression amongst coal miners, a decrease in their productivity and the occurrence of occupational accidents. For this reason, noise sources and levels in the workplace environment should be determined accurately. There should also be a legal obligation to ensure the coal miners work with appropriate safety equipment.

Noise-induced hearing loss can be prevented by avoiding excessive exposure to noise and using hearing protectors [2,3] Protectors reduce noise to a level where the risk of hearing damage is minimised. To accurately select a hearing protector, it should be known what type of noise the workers are exposed to, their exposure levels and whether or not the hearing protector is compatible with the work environment. High noise reduction protects against hazardous noise while at the same time allowing the user to hear desirable sounds (e.g., conversation, warning sounds).

Various studies concerning the effect of noise in coal mines, natural stone quarries, and mineral processing plants have been performed. Tripathy and Rao [4] examined the noise level changes between 1 and 10 meters on different machines (dozer, crusher, hopper, grader, digger, boring machine, etc.) located in the fully-mechanized opencast bauxite mine in India. Pandey et al. [5] developed a statistical model for the prediction of occupational noise exposures of operators using loaders in Indian underground coal mines. McBride [6] reported that noise and noise-induced hearing loss occurs from pneumatic rock drills (117 dBA), which make the highest level of noise in mining. Çınar and Şensöğüt [7] evaluated the noise measurement survey conducted on the coal miners at three different mining sites. They emphasised that coal miners would be physically affected while working at high noise levels, encouraging them to use earplugs as a precaution. Nandi and Dhatrak (2008) [8] studied the coal miners exposed to high noise levels throughout their working life. They stated that noise pollution is an invisible danger in industry, causing severe hearing loss. Matetic [9] assessed the noise levels of roof bolting equipment. Vardhan and Murthy [10] attempted to investigate the influence of the sound level of jackhammer drills due to drilling in rocks with different physical properties. Roy and Adhikari [11] compared the noise levels and dose values (8 hours) of electrical and diesel mining machines in the coal mine. Sharma et al. [12] made noise measurements on various machines in open pit mines, underground coal mines and coal processing plant in India. Fişne and Ökten [13] grouped the miners according to their homogenous noise exposure levels and made noise measurements. Erol and Su [14] reported the noise levels of some excavation and transportation machines used in an underground coal mine. Sorin et al. [15] stated the effects of some underground noise sources on human health. Bonnet et al. [16] also carried out personal noise measurements by placing a microphone under the earplug. Parnell [17] conducted a noise analysis of heavy construction machinery and equipment used for open pit mines in England, Scotland, and Wales. Erdem et al. [18] measured the noise levels of 67 different types and models of heavy construction machines used in mining. Şensöğüt [19] conducted noise measurements in TKİ Tunçbilek colliery, open pit mine and coal preparation plant. Erdem et al. [20] determined noise sources in open pit mines and repair-maintenance laboratories. Kosala and Bartłomiej [21] took noise measurements on machines in a crushing-screening plant in an andesite quarry. Engel and Kosala [22] measured the noise levels generated during various activities in andesite, chalk and dolomite mines. Ergün et al. [23] created a noise map of a quarry where three stone crushers work. Akbay et al. [24] measured the noise levels generated during different operational activities in tunnel construction and determined whether they were within the limit values permitted in the regulation.

The main aim of this study is to determine the minimum, maximum, average, and equivalent noise levels based on the working time of the noise sources from the shaft access of Karadon Colliery to the production face of the Kurul panel at the –360/–160 levels. The results were evaluated within the context of occupational health and safety in accordance with regulations. Finally, some recommendations to minimise the hearing loss of employees and selection of hearing protector are given.

2. Selection of hearing protectors

Occupational exposure to noise causes hearing loss which can be prevented by using a hearing protector. There are many types of hearing protectors. They can be generally classified as earmuffs and earplugs. Each type of protector has advantages and disadvantages. The earplugs can be produced in small, medium and large sizes. Disposable earplugs are designed for single use and lose their noise reduction capabilities with each usage. If the noise exposure is intermittent, earmuffs are more desirable since it may be inconvenient to remove and reinsert earplugs. The earmuffs are also easier to use and fit the ear quickly. The choice of a proper hearing-protector depends on various factors such as level of noise, comfort, and the suitability of the hearing protector for both the worker and the environment. However, CE mark, sound attenuation feature (SNR value), and compatibility with other personal protective equipment are also taken into account.

Before the selection of a hearing protector, it is necessary to evaluate the working area of the employees in terms of machine use, the level of noise exposure and the period of exposure. In addition, the difference between the protection levels of earmuffs or earplugs should be examined. Paakkonen et al. [25] pointed out that the attenuation is 16-23 dB for earplugs, 10-20 dB for earmuffs, and 24-34 dB for the combined use of plugs and muffs. Berger et al. [26] stated that the most effective ear protective device that prevents noise is the earmuff. It should be considered whether the selected hearing protector is suitable for the employee and is comfortable enough for long-term use. Hearing protective equipment standards in Europe and Turkey agreed to be EN 352 [27]. Several studies have shown that the attenuation of Hearing Protection Devices (HPD) depends on their continuous use [28-30]. Even a very short break without wearing ear protectors significantly decreases the effective noise reduction and protection. Thus, hearing protectors should be used continuously and properly. Table 1 shows the active protection periods without hearing protectors during the 8-hour working day.

TABLE 1

Active protection of ear protector with elapsed time without ear protectors

Time without ear protector (min)	Effective protection of the ear protector (dBA)
—	30
5	20
24	13
48	10
96	7
144	5
192	4
240	3

If an employee uses ear protective device for 8 hours, they will have a maximum protection level of 30 dBA. A break of one hour without using it causes a drop in the maximum protection level of 9 dBA [31]. In the calculation of the effective sound pressure level of ear protectors, Table 2 should be taken into account. According to Table 2, if the effective noise level in the ear is within the range of 75-80 dBA, the worker is assumed to be well protected. If the range is between 70-75 dBA and 80-85 dBA, it falls within the acceptable limits. When it is less than 70 dBA, the worker is overprotected.

TABLE 2

Effective noise level in the ear [43]

Sound level at the ear while using the protector (dBA)	Protection outcome
More than 85	Insufficient
80-85	Acceptable
75-80	Optimal
70-75	Acceptable
Less than 70	Overprotection

2.1. Methods for selection of hearing protectors

Hearing protectors are selected according to their insulating properties. The sound level and spectrum of the noise to which the worker is exposed are matched. The most suitable ear protection ensures that the noise level at the worker's eardrum is 10 to 15 dB below the impact level. The minimum acceptable attenuation for a protector is a function of the noise exposure level of the workers that have to use it and of the criterion level (CL) usually set by the existing legislation, which is usually between 85 and 90 dBA [32].

The noise level exposure by hearing protectors can be estimated by two standards (BS EN ISO 4869-2 and BS EN 458). The BS EN ISO 4869 estimates weighted sound pressure levels on workers wearing attenuation devices in noisy environments. This standard compares different hearing protectors. It checks the suitable conditions of hearing protectors and identifies the sound characteristics of the work environment [33]. There are several methods for assessing the A-weighted sound pressure level under hearing protection. The octave band method is assumed a reference method due to producing more reliable results. The HML method considers both A and C-weighted sound pressure levels, while the SNR method takes into account the C-weighted sound pressure level. These methods are generally utilised for comparative purposes. On the other hand, the noise reduction rating (NRR) method is the oldest valid method which is based on acoustical attenuation. In general, the higher NRR, the better the protector.

2.1.1. The octave band method

The octave band method is based on octave band sound pressure levels of ear protection, sound insulation and workplace noise by using an octave band sound level meter. This method is considered to be the most accurate way to measure the effectiveness of hearing protectors since the actual noise frequencies are considered [34]. The octave band method requires the most detailed noise measurement and involves the most complicated method of calculating the L_{Aeq} at the ear. The A-weighted value at the ear can be calculated by Eq. (1).

$$L_{Aeq} = \left(10\log \sum_{f=63}^{8000} 10^{\left(L_f + A_f - APV_f\right)/10} \right) \tag{1}$$

L_{Aeq} — the effective A-weighted sound level at the ear;
f — the octave band centre frequency in Hz;
L_f — the measured octave band sound level in band f;
A_f — the frequency weighting for octave band f;
APV_f — the assumed protection value of the hearing protector for octave band f.

Some regulations (such as those used in the UK and Europe) recommend adding 4 dB to the final result to account for real-world factors, such as the poor fitting of protectors [34]. If there are no levels for octave bands, HML and SNR would be valid as an alternative method nowadays [33].

2.1.2. The HML method

The HML method is evaluated based on the high (H), medium, (M) and low (L) frequency insulation of ear protectors in addition to the A and C weighted sound pressure levels of the workplace noise. In the calculations related to the HML method, the low frequency noises (L) are 63, 125, 250 and 500 Hz, the mid-frequency noises are 500, 1000 and 2000 Hz, and high frequency noises (H) are 2000, 4000 and 8000 Hz. The calculations are carried out with the formulas given in the EN 458 standard (Eq. (2) and Eq. (3)), and then it is decided whether the selected ear protective equipment is suitable or not [35].

A-weighted sound pressure level under hearing protectors $L_{A'}$ is determined by Eq. (2)

$$L_{A'} = L_A - PNR \tag{2}$$

where:

L_A — the A-weighted sound pressure level of noise;
PNR — the predicted noise level reduction provided by the hearing protector.

If $L_C - L_A$ is ≤2, then PNR is calculated by Eq. (3). However, if $L_C - L_A > 2$, it is calculated using Eq. (4)

$$PNR = M - \left((H - M)/4\right) \cdot (L_C - L_A - 2) \tag{3}$$

$$PNR = M - \left((M - L)/8\right) \cdot (L_C - L_A - 2) \tag{4}$$

where H, M, and L are the high, medium, and low-frequency attenuation values, respectively. They are described in ISO 4869-2 standard and provided by the PPE catalogue. HSE [34] recommends allowing 4 dB for real-world factors, and this value should be added to the result of $L_{A'}$. Whether the selected ear protector is appropriate or not should be evaluated according to Table 2.

2.1.3. The SNR method

The SNR method is a method based on the Single Number Rating of the ear protective device in addition to the A and C-weighted sound pressure level of the workplace noise. It is considered to be the least accurate method. In this method, the SNR value is based on the 'C' weighted sound pressure level that needs to be measured at the workplace. Characterisation of properties of the hearing protector is carried out using one parameter. The sound pressure level (dBA) under the ear ($L_{A'}$) is calculated by Eq. (5).

$$L_{A'} = L_C - SNR \tag{5}$$

where L_C is the measured value of the sound pressure level, SNR is the attenuation parameter of the hearing protector described in ISO 4869. HSE [34] recommends allowing 4 dB for real world factors. For this reason, this value should be added to $L_{A'}$. Whether the selected ear protector is sufficient or not should be evaluated according to Table 2.

2.1.4. The noise reduction rating (NRR) method

A single number that describes the sound level reduction in decibels is provided by HPD. The NRR, which is obtained in laboratory testing, has been recognised to overestimate the attenuation that can be achieved in real-word conditions. Additionally, the NRR is reported in C-weighted sound measurements, whereas measurements made in the workplace typically use A-weighting. To account for these factors, the NRR must be de-rated. The standard recommendations for the de-rating scheme are given in Table 3. Whether the selected ear protector is sufficient or not is evaluated according to Table 2.

TABLE 3

Noise Reduction Rating (NRR) and De-Rating [42]

Device Type	Predicted dBA Effective at the Ear
Earplugs	For use with dBA: L_{eq} – [NRR (0.5) – 3]
Earmuffs	For use with dBA: L_{eq} – [NRR (0.7) – 3]
Dual Protection	For use with dBA: L_{eq} – [(NRR + 5) * (0.65) – 3]

2.1.5. CSA Class method

The CSA recommends a class system for the selection of hearing protectors. This method uses classes A, B or C to describe the range of reduction in sound level provided by an HPD. Table 4 presents the ranges of noise exposure in line with the classes for proper selection of HPDs. Class A protection is not recommended for workers whose noise exposure is less than 95 dBA.

TABLE 4

Guidelines for selecting HPDs [42]

Level of noise exposure, $L_{EX,8h}$ (dBA)	Class
<90	C
91 to 95	B or BL*
96 to 105	A or AL*
>105	Dual†

* AL or BL class HPDs meet the requirements for either Class A or Class B and have a minimum attenuation of 20 dB at 125 Hz; † Dual hearing protection is required (Class B earmuff and Class A earplug); Limit exposure duration.

Class B protection or specialised hearing protection devices are often more acceptable and more likely to be consistently worn. This method is used to select the hearing protector in Canada.

2.2. Selection of hearing protectors in different countries

2.2.1. Turkey

In Turkey, if daily noise exposure exceeds the lowest exposure action value (80 dBA) in accordance with regulation concerning the "Protection of Employees from Noise-Induced Risks", employers should provide personal ear protectors to employees. However, employees must use personal ear protectors when daily noise exposure reaches or goes beyond the highest exposure action value (85 dBA). When selecting an ear protector in Turkey, the SNR value, which is calculated according to the logarithmic average of all frequencies using the formulations in EN 458 (2016), is considered.

An error margin of +9 dBA for earplugs +5 dBA for ear muffs should be added due to deviations in real-world environment conditions and usage errors [35]. If an ear plug is used at a workplace with an L_c value of 97 dBC as a protective device and its protective effect is desired to be in a good class, the SNR should be between 31 dBA (97-75+9) and 26 dBA (97-80+9). If an ear muff is to be used as a protective device and if the protection effect is desired to be in a good class, it is more appropriate to select a protective device whose SNR value is between 27 dBA (97-25+5) and 22dBA (97-80+5).

2.2.2. USA

NIOSH recommends that workers shall be required to wear hearing protectors when engaged in work that exposes them to noise that is ≥85 dBA. In addition, when the noise exposure is higher than 100 dBA, workers should wear double hearing protection devices [36]. The noise reduction rating (NRR) is a single number rating method. This method is adopted in the United States [37]. Tak et al. (2009) states that 22 million workers are exposed to noise loud enough to harm their ears every year [38]. Despite the use of HPD, when noise-induced hearing loss (NIHL) remains common, all HPDs have to be evaluated in a test laboratory and labeled with a Noise Reduction Rating (NRR) in the U.S. The National Institute for Occupational Safety and Health (NIOSH) developed the HPD Well-Fit™ system to reduce the incidence of hearing loss among noise-exposed workers who must still use HPDs. HPD Well-Fit™ measures the amount of sound reduction an individual worker receives from their HPD and identifies workers who are not sufficiently protected. NHCA-NIOSH-OSHA Alliance (2008) recommends fit-testing as a best practice in hearing loss prevention programs [39]. HPD Well-Fit™ (2015) can test the noise reduction of any earplug [40]. It is inexpensive, fast and portable. It can be used to test any type/brand of HPD and provides results within 7 to 10 minutes.

2.2.3. England

When the $L_{EX,8h}$ is over 85 dBA or $L_{C\,peak}$ of 137 dBC, employees must wear the hearing protection device in England. Employers should also enable them to take training courses about its correct use. The octave band is widely applied in predicting the attenuation while the SNR method is used rarely.

2.2.4. Canada

Employers provide hearing protection devices, and workers wear single hearing protection devices, when noise levels are ≥85 dBA. When the noise exposure is >105 dBA $L_{EX,8h}$, workers wear double hearing protection devices [41]. Hearing protection must be selected according to CSA Standard Z94.2-14. NRR and CSA Classes are the most common methods used to select the hearing protector in Canada [42].

3. Noise level measurements at the Kurul panel

3.1. Site description

This study was carried out at the Kurul panel of Kilimli colliery in TTK. The Kurul panel has been established between –360/–160 altitudes, with the coal being extracted by longwall mining methods. The average seam thickness is between 2.5 and 3.0 m, and the slope angle is around 45°. It is a panel where the mechanised method is applied in steep seams. Due to the faults and discontinuities at the face, classical production is carried out. It is one of the most intense workplaces among the panels since the number of the coal miners is high. For this reason, Kurul panel was preferred for the field tests. There are three shifts in a day at the Kurul panel. In the P1 (00:00-08:00) and P3 (16:00-00:00) shifts, production-intensive works are carried out, while in the P2 (08:00-16:00) shifts, ground support works are conducted. In this panel, coal miners have three field of professions such as supervisor, production worker and transportation worker. During the noise measurements, the total number of the coal miners working in three shifts was determined to be roughly 140. The highest number of the miners was working in the P2 shift. For this reason, noise measurement tests were conducted there. The number of the coal miners working in three shifts according to their fields of profession is listed in Table 5. The noise levels of the machines were measured based on their mobility and locations. For this purpose, it was aimed to measure the noise of mobile machines having operators and stationary machines. Additionally, some of the tests were performed at points where there were no noise sources. Types and locations of noise sources in the colliery from the surface to the faces in the underground are shown in Fig. 1.

TABLE 5

Number of workers by the field of professions

Shifts	Supervisor	Production	Transportation	Total
P1	2	23	5	30
P2	5	61	8	74
P3	2	27	6	35
Total	9	111	19	139

3.2. Noise levels of machines

PCE-322 type sound meter, which is a portable and professional Class II noise meter was used for noise levels of machines measurements. It was connected to a computer via the USB port, as shown in Fig. 2. and the data was recorded. Then, the detailed readings were analysed using

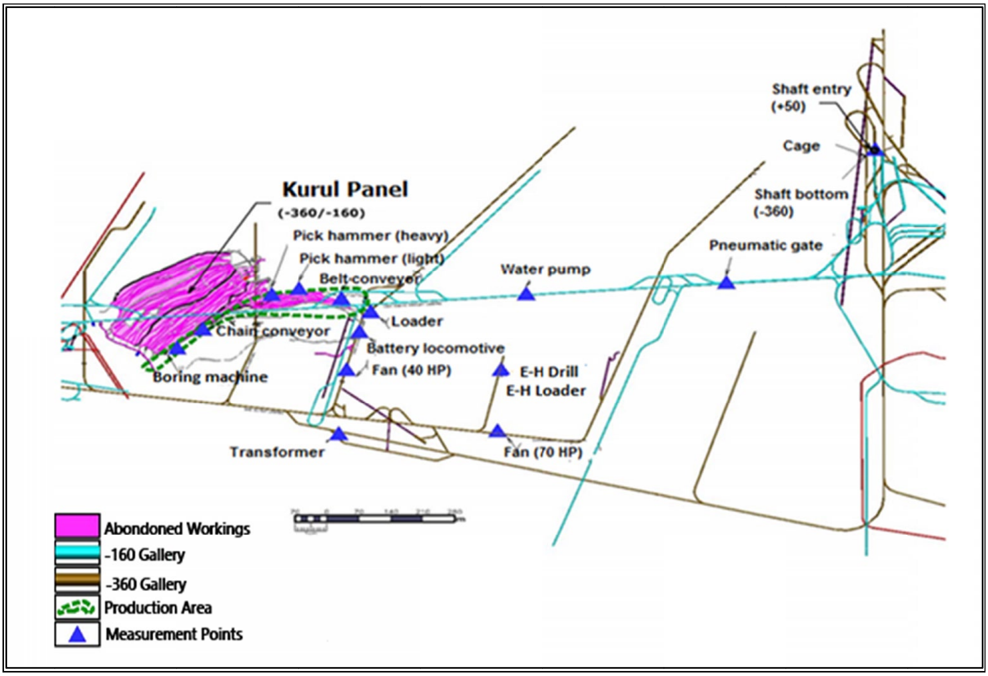

Fig. 1. Noise measurement route at the Kurul panel

the proprietary software. The sound meter was calibrated with a PCE-SC 42 acoustic calibrator to test the accuracy before the field measurements. It is also able to calibrate microphones and other noise measuring devices. The technical specifications of the sound meter and calibrator are shown in Table 6. The sound meter device was set to a slow response time during the tests. Noise measurements were carried out 1 m from the stationary machines and nearby the mobile machines. Minimum and maximum A-level sounds were measured. The entire noise sources that are subjected to field tests are listed in Table 7. Following the field measurements, the equivalent noise level (L_{Aeq}) was calculated by Eq. (6). In addition, the noise levels to which coal miners were exposed while working around the machines and operators during the 8-hour working shift were determined by Eq. (7).

$$L_{Aeq} = 10 \times \log\left[\left(\frac{1}{n}\right) \times \sum_{i=1}^{n} 10^{L_i/10}\right] \tag{6}$$

where L_{Aeq} is the equivalent noise level (dBA), n is the number of measurements, L_i is the measurement values (dBA).

$$L_{EX,8h} = L_{Aeq} + 10 \times \log\left[\frac{T_e}{T_0}\right] \tag{7}$$

where $L_{EX,8h}$ is the daily noise exposure level (dBA), T_e is the period of active exposure on the working day, T_0 is the reference exposure period (8 hours).

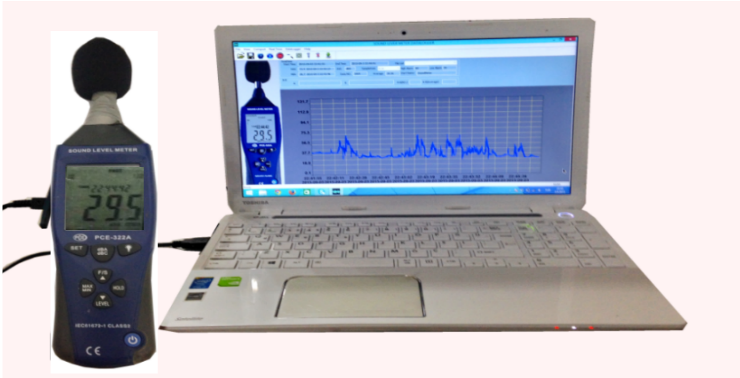

Fig. 2. The sound meter employed during the measurements

TABLE 6

Technical specifications of PCE-322A digital sound meter and PCE-SC 42 acoustic calibrator

PCE-322A	
Noise levels	Low 30 ... 80 dB Medium 50 ... 100 dB High 80 ... 130 dB Auto 30 ... 130 dB
Dynamic range	50 dB
Sampling rate	2 x per second
Frequency	31.5 Hz ... 8 kHz
Storage capacity	32,700 readings
Frequency weighting	A and C
Time weighting	Fast (125 ms) Slow (1 sec.)
Functions	Min, Max, Hold, Alarm
Operating conditions	0 ... 40°C / 32 ... 104°F, < 90% RH
Standards	IEC 61672-1 Class II
PCE-SC 42	
Frequency	1 kHz / ± 0.1%
Sound pressure levels	94 dB and 114 dB
Accuracy	± 0.5 dB (at 20°C / 68°F and 760 mm Hg / 101325 Pa
Hole opening	13 mm or 1/2” for sound meter microphone

The minimum, maximum, average, equivalent noise levels, C weighted peak noise level and exposure values of the machines having an operator are listed in Table 8. Moreover, the test results of the stationary machines are shown in Table 9. The noise measurement was conducted for machines located on the inbound and outbound routes of the coal miners’ workplace and in stable locations. These machines have been used for ventilation, electrical wiring, water disposal, belt conveying, pneumatic gate interfaces. However, no remarkable results were obtained during the tests except for electric fans, pneumatic fans and pneumatic water pumps.

TABLE 7

Noise sources and tasks

Machine Type	Task
Battery Locomotive	Personnel, material muck and coal transportation
Pick Hammer (Heavy)	Drilling blasting and ceiling holes
Belt Conveyor Pick Hammer (Light) Loader Boring Machine Electro-Hydraulic Drill Electro-Hydraulic Loader	Muck transportation Coal excavation Muck loading Pilot exploration, degassing, sampling Drilling rocks Muck loading
Transformer	Electricity supplying
Cage	Personnel and muck transportation
Chain Conveyor	Coal/Muck transportation
Pneumatic Air Gate	Ventilation
Electrical Fan	Ventilation
Pneumatic Fan	Ventilation
Pneumatic Water Pump	Dewatering
Shaft Bottom	
Roadway	

TABLE 8

Test results of mobile machines (with operators)

	$L_{\min}$, (dBA)	$L_{\max}$, (dBA)	L_{ave}, (dBA)	L_{Aeq}, (dBA)	$L_{C,\max}$, (dBC)	$L_{EX,8h}$, (dBA)
Battery Locomotive	61.2	76.4	69.8	72.4	79.5	68.2
Pick Hammer (Heavy)	84.3	85.7	85.1	85.2	92.9	79.1
Belt Conveyor	74.1	76.7	75.3	75.4	82.0	71.1
Electro-Hydraulic Drill	81.1	114.2	96.4	106.7	115.6	100.7
Pick Hammer (Light)	93.6	96.7	95.3	95.4	101.5	89.4
Loader	90.2	96.1	93.6	94.1	100.2	88.1
Boring Machine	101	107.8	104.5	105	113.2	102
Electro-Hydraulic Loader	82	95.4	85.9	88.4	95.5	82.4

TABLE 9

Test results of stationary machines

	$L_{\min}$, (dBA)	$L_{\max}$, (dBA)	L_{ave}, (dBA)	L_{Aeq}, (dBA)	$L_{EX,8h}$, (dBA)
Transformer	49.1	51.4	50.2	50.3	28.3
Cage	45.1	56.6	51.1	52.7	30.7
Pneumatic Air Gate	30.7	55.4	44.3	50.2	28.2
Electric Fan	101.3	102.9	102	102	80
Pneumatic Fan (40 HP)	92.3	97.7	95.6	95.9	73.9
Pneumatic Fan (70 HP)	102.1	107	105.5	105.7	83.6
Pneumatic Water Pump	93.2	103.8	98.1	99.7	77.7
Shaft Bottom (-360)	71.9	72.6	72.2	72.2	50.1
Inside the gallery	29.1	34.1	31.3	31.7	22.6

3.3. Personal noise exposure of operators

Personal noise exposure of the operators was measured by collecting the data of an A-weighted equivalent noise levels using Extech SL355 model noise dosimeter (Fig. 3). The reliability and safety of the ear protectors were analyzed by using it. The technical specifications of the dosimeter are given in Table 10. The noise levels that the operators were exposed to personally using a boring machine, electro-hydraulic drill, and pick hammer (heavy) were measured. In this context, it was determined how much noise the same operators were exposed to while the microphone of the personal dosimeter device was inside the ear protective equipment. In addition, the microphone of the personal dosimeter was attached to the collar of the clothes, at the level of the operator's ears. Based on the position of the microphone, the personal noise exposure of the operator of the electro-hydraulic drill with and without earmuff is shown in Fig. 4. The average A-weighted equivalent noise values of the machines are summarized in Table 11, where the importance of using ear protective equipment can be seen.

Fig. 3. Extech SL355 noise dosimeter

TABLE 10

Technical specifications of Extech SL355 noise dosimeter

Sound Level Range	A/C Weighting: 60-130dB and 70-140dB; C or Z (Linear) Peak: 93-133dB (for 60-130dB range); 103-143dB (for 70-140dB range)
Digital Display	LCD 0.01-9999%
Criterion / Threshold Level	80, 84, 85 or 90dB / 70-90 (1db steps)
Response Rate / Exchange Rate	Fast or Slow / 3, 4, 5 or 6 dB
High Level Detector / Peak Flag	115dB / 130dB (for 60-130dB range); 140dB (for 70-140dB range)
Event Storage	20 surveys

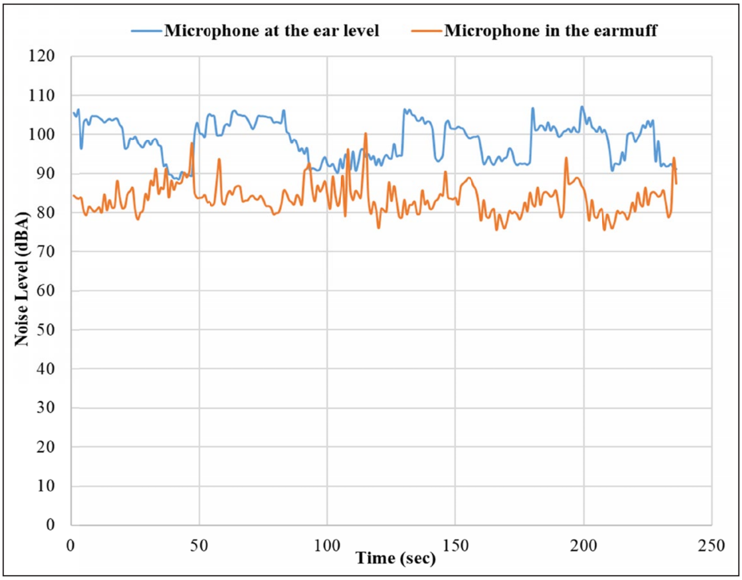

Fig. 4. Personal noise exposure measurement of the electro-hydraulic drill operator

TABLE 11

The effect of wearing ear protection on noise exposure

Noise measurement	Microphone outside the earmuff, L_{Aeq}, dBA	Microphone inside the earmuff, L_{Aeq}, dBA	Difference L_{Aeq}, dBA
Boring Machine	105.77	89.99	15.78
Electro-Hydraulic drill	100.79	86.03	14.76
Pick Hammer (Heavy)	109.75	95.51	14.24

4. Results and discussion

4.1. Noise levels of mobile and stationary machines

The sound levels of the machines were measured from the surface entrance of the shaft to the workplace underground. The results were evaluated according to the "Turkish Regulation on the Protection of Employees from Noise-Induced Risks". In this context, the daily noise exposure level ($L_{EX,8h}$); is the time-weighted average of all A-weighted exposure levels, including impact noise, as defined in the TS2607-ISO1999 standard, for an 8-hour working shift. The lowest exposure action values are reported to be 80 dBA and 135 dBC while the highest exposure action values are 85 dBA and 137 dBC and the exposure limit values are 87 dBA and 140 dBC [44]. A comparison was made between the results based on the noise exposure times of the machine operators and coal miners working in the field according to the limit values specified in the regulation. The equivalent noise levels to which machine operators are exposed are shown in Fig. 5. A comparison between the equivalent noise levels of the stationary machinery and equipment is shown in Fig. 6.

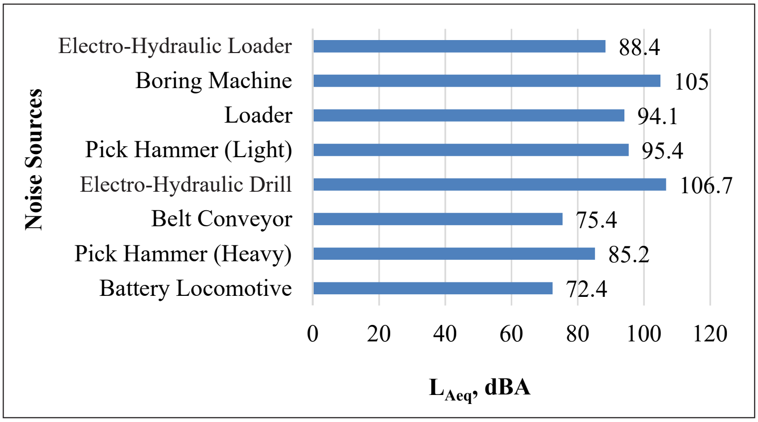

Fig. 5. The corrected version of this figure is in the attached file

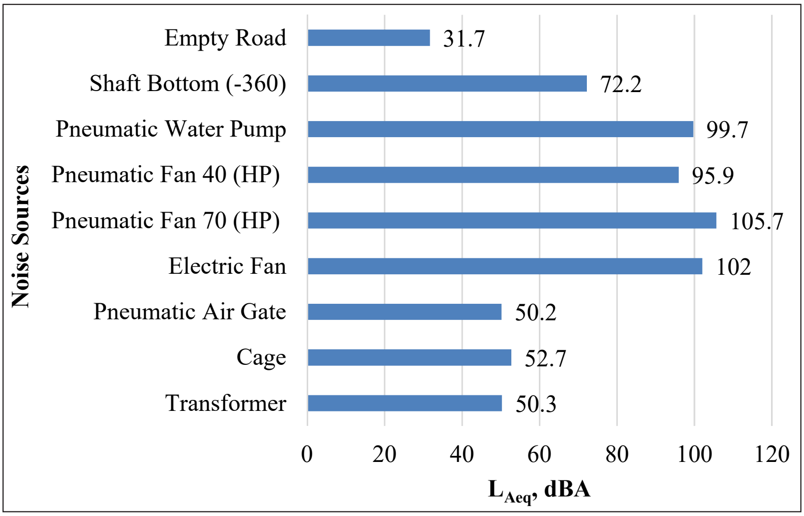

Fig. 6. The corrected version of this figure is in the attached file

Önder et al. [45] stated that there was a risk of occupational disease (hearing loss due to noise), especially, in the development works in coal mining. The study also found that the daily noise exposure values of the operators using the pick hammer (light), loader, boring machine and electro hydraulic drilling machines used in the development works in coal mines exceeded the limit value specified in the regulation. If they keep working in such noisy environments without using personal protective equipment, the risk of hearing loss is imminent. The equivalent noise levels to which the machine operators were exposed are shown in Fig. 7. As seen, the operator using the boring machine will be exposed to the highest noise. In addition, the operators using boring machines, electro-hydraulic drills, pick hammer (light) and loader appear to exceed the $L_{EX,8h}$ = 87 dBA exposure limit value specified in the regulation for an 8-hour shift.

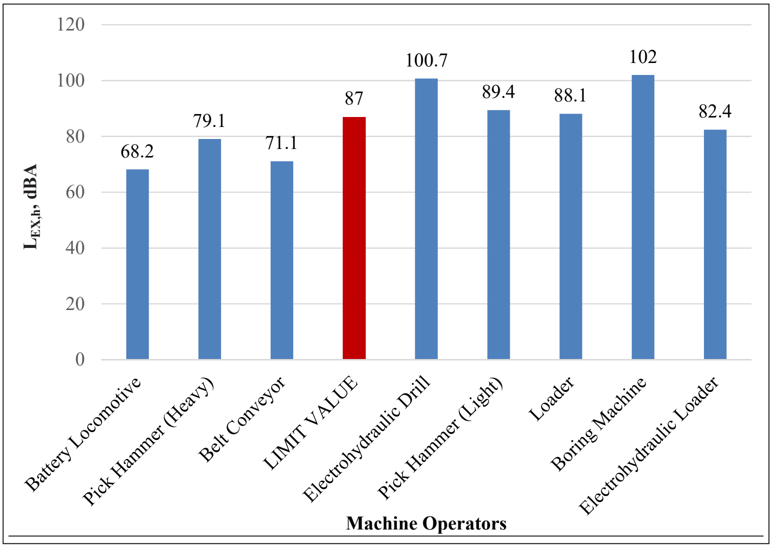

Fig. 7. The corrected version of this figure is in the attached file

According to the results given in Fig. 6, The equivalent noise values (L_{Aeq}) are higher near the electric fans, pneumatic water pumps and pneumatic fans that run continuously in a stable position without an operator. These fans are installed at least 2 m above the ground and on the left or right internal heading wall. Considering the locations of the fans on the roadway, it is clear that these values are below the limits since a coal miner would not be able to get close to these machines, and the coal miners who pass through these areas do not need to use any protectors, providing that the coal miners are not working for a long time nearby the stationary noise sources. They are not affected by the noise and this does not pose any risk in terms of exposure. However, it should considered that operators working with mobile machines are exposed to more noise at long intervals. Hearing loss does not occur immediately, and it takes an average of 10 years to develop. Therefore, necessary health precautions must be taken by the coal miners. According to Fig. 7, it is thought that the pick hammer (heavy) measurement results were so close to the lowest exposure action value since the pick hammer (heavy) may have stumbled upon a fault zone or argilliferous minerals. In addition, if the 2-hour working time is exceeded, so will the lowest exposure action values.

4.2. The effect of hearing protectors

According to the Noise Regulation, the daily noise exposure level and a time-weighted average of all noise exposure levels for an 8-hour long shift ($L_{EX,8h}$) should not exceed 85 dBA, including sudden impact noise. When the lowest exposure value ($L_{EX,8h} \geq 80$ dBA) is exceeded, the employer must provide suitable ear protectors for the coal miners. When the highest exposure value ($L_{EX,8h} = 85$ dBA) is reached, employers must ensure that workers use ear protectors compulsorily. The critical periods in which the coal miners could work without ear protectors, were calculated by using Eq. (7). In the equation, $L_{EX,8h}$ was assumed to be 80 dBA, which is the minimum exposure value in the regulation. L_{Aeq} value was taken from Table 8-9, the T_o value was accepted as an 8-hour working day, and the T_e value was calculated accordingly. The results shown in Table 12 indicate that the coal miners working for the Kurul panel are exposed to noise during travelling in the cage to the bottom of the shaft, when passing through the pneumatic air gates, near the transformers that exist along the way and when boarding the electrical locomotive by which they travel to their workplace. Besides, the noise of the pick hammer (heavy), electro-hydraulic loader and belt conveyor that are active in the workplaces affects both coal miners and operators. The critical periods of using ear protection were indicated, based on the lowest exposure action value mentioned in the noise regulation. Furthermore, miners must use ear protectors continuously in the area with electric fans, pneumatic fans (40 HP and 70 HP) and a pneumatic water pump. In addition, operators using pick hammers (light), loaders, boring machines and electro-hydraulic drills must always wear ear protectors.

TABLE 12

Critical times that coal miners or machine operators can work without using ear protector

	L_{Aeq} (dBA)	Critical period (hour)
Empty Road	31.7	544017
Pneumatic Air Gate	50.2	7619
Transformer	50.3	7447
Cage	52.7	4302
Shaft Bottom (-360)	72.2	48
Battery Locomotive	72.4	46
Belt Conveyor	75.4	23
Pick Hammer (Heavy)	85.2	2
Electro-Hydraulic Loader	88.4	1
Electric Fan	102	0
Pneumatic Fan (40 HP)	95.9	0
Pneumatic Fan (70 HP)	105.7	0
Pneumatic Water Pump	99.7	0
Pick Hammer (Light)	95.4	0
Loader	94.1	0
Boring Machine	105	0
Electro-Hydraulic Drill	106.7	0

On the other hand, the noise values for the workers, according to their occupational groups in the development works, were found to be above the highest exposure action value specified in the regulation. Based on the noise regulations in Turkey, it is mandatory to wear an ear protector for these occupational groups. The employer should insist the workers comply regarding the protective equipment worn. In this context, personal ear protectors with suitable SNR values should be used, according to the noise level in the environment. In addition, the noise levels that the operators are exposed to using the boring machine, pick hammer (heavy) and electro-hydraulic drills were determined by holding the microphone of the personal noise dosimeter at ear level and also placing it inside the earmuffs (Fig. 8.) The difference between the results obtained from both practices clearly shows the importance of using ear protective equipment for the miners working in the development works.

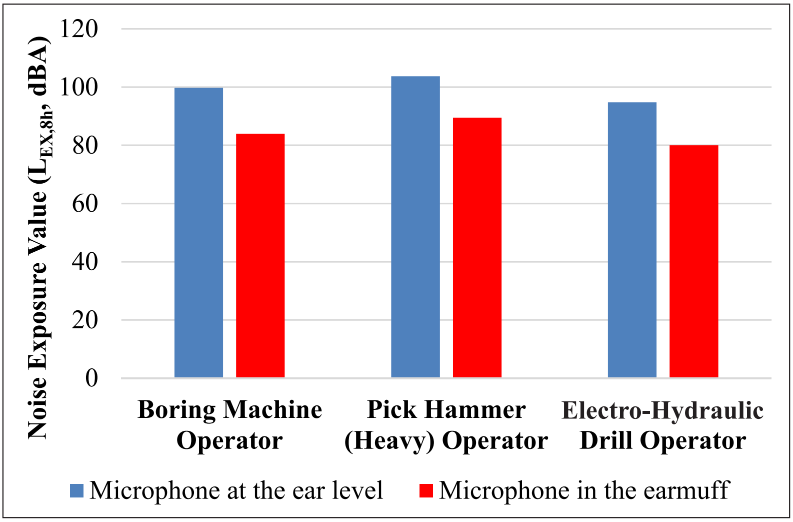

Fig. 8. PThe corrected version of this figure is in the attached file

While the microphone of the personal noise dosimeter is inside the earmuff, the noise values to which the operators using the boring machine and electro-hydraulic drill are exposed do not exceed the limit value defined in the regulation. However, the situation is different for the operator of the pick hammer (heavy) since the noise level is above the limit value. For operators to be exposed to less noise, earmuffs and earplugs should be used together, similar to the Canadian practice. In addition, ear protection equipment should be tested with software similar to the HPD Well-Fit system applied in the USA. When selecting an ear protective equipment, none of the users must use or wear devices providing unnecessary high attenuation. Such ear protective equipment can cause difficulties in hearing warning signals and communication problems with users not feeling comfortable using them. The most important point in the selection of ear protectors is that these protectors keep the effective pressure level in the ear between 75 dBA and 80 dBA. On the other hand, using ear protectors with a high SNR value may prevent hearing verbal warnings from other miners [42].

In this sense, ear protector selection methods were examined, and practices for selecting these devices in Turkey, England, America and Canada were evaluated. Calculations based on the methods used in these four countries for those working in the development part of coal mines and appropriate earmuff and earplug models were determined (Table 13-14). In Table 13, if the ear protector that a pick hammer (light) operator has an L_c value of 101.5 dBC, which is desired to be in a good class, it is commonly approved that they should use an earmuff with values of SNR32 (101.5 – 75 + 5) and SNR 27 (101.5 – 80 + 5) or an earplug with values of SNR36 (101.5 – 75 + 9) and SNR31 (101.5 – 80 + 9). However, the SNR method used in the selection of ear protectors in England is calculated differently from the one applied in Turkey. In England, the main point of selecting a good quality ear protector is to maintain effective pressure levels in the ear between 75 dBA and 80 dBA (EN 458, 2016). For instance, if a pick hammer (light) operator is required to wear a good quality ear protector at a workplace, with an L_c value of 101.5 dBC, they should select an earmuff or earplug with values of SNR 31 (101.5 – 75 + 4 = 31) and SNR 26

(101.5 – 80 + 4 = 26). Whereas, a loader operator should select a value between SNR 29 and SNR 24 and a boring machine operator between SNR 42 and SNR37. The electro-hydraulic drill operator can also use an earplug or earmuff with an SNR45 to SNR 40. Furthermore, there are similarities in the SNR values of ear protectors determined based on occupational groups for both countries. While separate calculations are made for earplugs and earmuffs in Turkey, there is no such difference in England. In fact, the method of selecting an ear protective device in both countries is similar, and the difference is due to the correction factor in the equations. The ear protective equipment that was determined based on the ear protective selection methods applied in the USA and Canada are shown in Table 14.

TABLE 13

Recommended ear protectors according to SNR methods

Art Branches	L_{Aeq}	$L_{EX,8h}$	L_c	Turkey		England
				Earplug	Earmuffs	Earplugs/ Earmuffs
Pick hHammer	95.4	89.4	101.5	SNR36-**SNR31**	SNR32-SNR27	**SNR31**-SNR26
Loader	94.1	88.1	100.2	SNR34-**SNR29**	SNR30-SNR25	**SNR29**-SNR24
Boring Machine	105	102	113.2	SNR37-**SNR42**	SNR43-SNR38	**SNR42**-SNR37
Electro-Hydraulic Drill	106.7	100.7	115.6	SNR50-**SNR45**	SNR46-SNR41	**SNR45**-SNR40

TABLE 14

Recommended ear protectors according to the NRR method applied in the USA and Canada

Art Branches	L_{Aeq}	$L_{EX,8h}$	Recommended Ear Protector		
			Earplug	Earmuffs	Dual Protection
Pick Hammer (Light)	95.4	89.4	NRR36	NRR 26	—
Loader	94.1	88.1	NRR34	NRR 24	—
Boring Machine	105	102	—	—	NRR36
Electro-Hydraulic Drill	106.7	100.7	—	—	NRR40

The operator using the pick hammer (light) can wear an earplug with a damping value of NRR26 or an earplug with a damping value of NRR36 so that the ear protectors provide a good quality protection. If it is for a loader operator, it is more appropriate to wear an earmuff with NRR24 or an earplug with NRR34. The boring machine operator can also use the NRR36, and the electro-hydraulic drill operator can use earmuff and earplugs at the same time together with a damping value of NRR40 (dual protection). In all four countries, employees must wear a protector when the $L_{EX,8h}$ exceeds 85 dBA. The NRR method is used in the United States and both the NRR and Class methods are applied in Canada. However, the SNR method is widely preferred in Turkey. On the contrary, ear protectors are selected by the octave band method based on available data in the UK. In some cases, the HML method and the SNR methods are also used. Applications of octave band and HML methods are similar in Turkey and England. The results from the SNR method in Turkey and the results of the NRR method in USA and Canada were found to be compatible. For example, if the pick hammer (light) operator wears an NRR36 earplug or an NRR26 earmuff according to the NRR method, it would provide effective protection.

If the same operator uses earplugs in the range of SNR36-SNR31 or earmuffs in the range of SNR32-SNR27 according to the SNR method, it means that he has selected a good quality ear protector. SNR is calculated following ISO 48692 Standard [46]. It is similar to the NRR in terms of the calculation method but with some exceptions. In addition, the NRR is reported in C-weighted sound measurements, whereas measurements made in the workplace typically use A-weighting. Additional –3 dBA adjustment is applied to NRR to calculate effective dBA sound levels at the ear from measured ambient noise levels in dBA. There is no such application in the SNR method. When the equivalent noise level in the environment exceeds 105 dBA in Canada and 100 dBA in America, employees use earmuffs and earplugs together. This may be a positive method to prevent employees from hearing loss due to noise in Turkey and England.

5. Conclusions

This study mainly aims at determining the type of noise sources to which a coal miner is exposed working in an underground mine until he arrives at the site. For this purpose, noise sources were determined along the route of miner from surface to the workplace in the Kurul panel. These consist of machines with operators, i.e., mobile machines and machines in stable position. The workers are exposed to noise while either working nearby these machines or walking around these machines.

Among the machines with an operator, the highest noise level came from the electro-hydraulic drill, boring machine, pick hammer (light), loader and electro-hydraulic loader. The noise values of these machines exceed the lowest and highest exposure limit value specified in the regulation. According to the Turkish Noise Regulation, there are cases when exposure limit values are exceed. The management is responsible for taking necessary precautions, discovering the reasons, and preventing recurrence so that the noise level always stays below the limit value. Based on the noise values to which the employees using these machines are exposed, the critical times in which they could work without ear protectors were calculated. It is obligatory for all states to wear ear protectors when working beyond these critical times. In this context, it was determined that operators using pick hammers (light), loaders, boring machines and electro-hydraulic drills should always wear ear protectors. The measurements of noise levels from stationary machines such as electric fans, pneumatic fans, and the pneumatic water pumps were found to be relatively high. However, there is no risky situation in terms of noise exposure since the workers are not present for a long time in the areas where these machines are positioned. In this study, it was observed that the noise exposure values of coal miners, especially those working in development galleries, exceeded the highest exposure action value defined in the regulation. Precautions aren't taken in this regard, and the workers here may suffer from noise-induced hearing loss. For this reason, especially those working in these occupational groups should wear ear protectors under all circumstances and their effectiveness should be checked. Wearing ear protective devices with excess SNR value for employees may prevent verbal warnings that may come from the other miners around. It can cause dangerous consequences.

Hearing protectors reduce the noise exposure level and the risk of hearing loss, so employees must use appropriate hearing protectors. Employers must provide hearing protection devices for workers who are exposed to sound levels ≥85 dBA $L_{EX,8h}$. They are responsible for workers who are overexposed to noise and who require hearing protection. They should organize education seminars about the use of ear-protectors for those who are responsible for these machines and raise their awareness in this regard. In addition, all the employees should go through routine physical tests. They should also be monitored frequently when underground on whether they require ear protectors. To avoid noise-induced hearing loss for workers, noise sources should be determined before, and noise maps of all workplaces should be created. The devices should be maintained properly, and the machines that have expired should be replaced. Risky occupational groups in terms of hearing loss should be determined in advance. Employees' personal protective equipment usage should be controlled, and if necessary, there should be penal sanctions. Since machine operators are always exposed to high noise levels during work, workplace changes or alternate working organisation arrangements should be made. Employees should be ensured that they work in less noisy workplaces, and their routine health checks should not be neglected.

In addition to ambient noise in workplaces, personal exposure measurements should also be performed regularly. According to the results of personal noise exposure measurement, it was determined that there was a clear difference at ear level between the measured values inside and outside the earmuff. For this reason, devices that can measure in-ear noise should be used while making personal noise exposure measurements of employees. According to the in-ear measurement results, the use of earmuffs or earplugs alone may not be sufficient as personal protective equipment for exposures above the limit value. In such a case, the combination of earmuffs and earplugs should be used together. In addition, if there is a software program that can select ear protective equipment in personal dosimeters by which noise level is measured, employees will be able to select reliable ear protectors. Within the use of fit-testing system programs similar to the HPD Well-Fit system applied in the USA, it will be possible to test the effectiveness and reliability of ear protectors used by employees in noisy environments. Noise measurements and audiograms should be recorded frequently, and the results should be correlated. The coal miners, who will work in the risky and noisy workplaces, should undergo a full audiometric examination when they first start the job.

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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