Celal Bayar University Journal of Science

Statistical Analysis of Noise-induced Brain Electrical Activity of Employees in the Underground Mining Sector in the Soma Basin

Ayla Tekin[1], Mustafa Oğuz Nalbant[1*], Mustafa Orhan[1], Fırat Tekin[1], Fatih Suvaydan[1], Kemal Berki[1], Aslı Aydın Savran[2], Sami Gümüş[2]

[1] Manisa Celal Bayar University, Soma Vocational School
[2] Soma Medigün Hospital
[*] mustafa.nalbant@cbu.edu.tr
[*] Orcid: 0000-0002-9311-2241

Received: 9 May 2022
Accepted: 6 September 2022
DOI: 10.18466/cbayarfbe.1114348

Abstract

In the mining sector, which requires a lot of attention, excessive noise pollution is encountered during the works due to the use of mining machines, and this is observed as one of the most important factors causing various problems for the personnel working in underground mining. The present study investigated the neurological effects of instantaneous noise exposure and exposure to noise on workers' health in the underground mining sector using electroencephalography (EEG) device. Firstly, the noises that underground workers are exposed to in different working areas were determined. One hundred people working or working in the mining industry were included in the study. Brain electrical activities of these people were measured at periodic intervals under the noise that occurred in the underground mine. Their relationship with occupational noise exposure was analyzed statistically. As a result of these measurements, the values collected in noise-free and noisy environments were compared.

Keywords: Noise Effect, Underground Mining, Occupational Health, Statistical Analysis, EEG.

1. Introduction

Today, rapidly developing technology includes many positive developments that will make life easier. However, these developments also have aspects that negatively affect human health. One such negative problem is noise. Noise is an important problem in all workplaces and is one of the effective parameters in the occurrence of occupational accidents [1]. The most important effect of noise on human health is on the hearing system [2]. In addition to negatively impacting hearing loss and verbal communication, noise can also lead to distress, cardiovascular disease, sleep disturbance, and even cognitive performance. Many studies have confirmed a direct relationship between increased noise levels and decreased cognitive performance [3-6]. As noted in the study of Rostam Golmohammadi et al., noise caused people to react more quickly due to higher stress levels compared to silence, and the noise was found to be a distraction for cognitive performance in occupational settings [7]. Distraction on employees is quite common. However, the issue of distraction at worksites has not yet been adequately explored. Since distraction occurs due to reasons such as noise, moving vehicles, body discomfort, fatigue, depression, a wearable physiological device has been proposed to monitor the distraction of employees. It has been conducted a research to improve hazard identification performance by analyzing people's physical and physiological responses through wearable sensors. The basic logic in this research is that employees show unusual or abnormal reactions when faced with a danger [8-9]. Physical responses (eg walking and stepping) have been studied using wearable sensors and the relationship between the presence of hazards and changes in physical responses has been demonstrated [10-12]. Similarly, physiological responses (eg, eye movement, brain activity) derived from wearable sensors have also been investigated to elicit and identify hazards in the environment [13-14]. Electroencephalogram (EEG) is a diagnostic imaging technique used to obtain information about brain activities by detecting voltage changes created by neurons on the scalp cortical surface, and new technologies have made it possible to obtain EEG data without any problems [15]. Because the brain activity is directly linked to people's cognitive processes [16], some studies have also analyzed patterns of brain electrical activity measured using EEG to predict cognitive states such as stress, attention, mental workload, and alertness [17-19]. A different study suggested using EEG to detect a person's mind wandering. The findings showed that EEG data from several electrodes could predict the intensity of mind wandering and contributed to the development of neurofeedback studies [20]. Jeon and Cai [21] investigated the feasibility of identifying construction hazards by developing an EEG classifier based on wearable experiments that can classify EEG signals associated with perceived hazards in a virtual reality (VR) environment. At the work of You Bo et al; investigated the effects of underground mining conditions (high temperature, high humidity, noise, etc.) on human health and safety. They used a memory test before and after exercise to examine the effects of mining conditions on the brain nerve activity of workers. However, to analyze the effect of temperature and humidity on workers' body blood pressure (including systolic pressure, diastolic pressure, and mean pressure), heart rate, respiratory rate, body temperature, body weight, typing speed, and memory level, a bedside monitor, and EEG device have been used. As a result of the study, it has been quantitatively and accurately analyzed that high temperature and high humidity in the mine have a detrimental effect on body physiology and labor productivity and that occupational health standards should be taken as a reference [22]. Önder, and Önder [23] in their study, they made statistical noise analysis in three main mining areas including lavavar, open pit and underground mine.

In summary, noise exposure is dangerous for occupational health, harms the perception of risk, and increases the psychophysiological burden. Since the noise of the machines in the mining industry is harmful, the focus of the present research is to evaluate the noise levels and analyze the physiological responses of the machines with a wearable EEG that can classify the EEG signals in the noise environment in which they operate.

2. Materials and Methods

In this study, an Electroencephalography (EEG) device was used to measure and analyze the electrical activities in the brain during exposure to noise of people who work or will work in the underground mining sector. Measurements were made on 100 people. Selected 100 people work in the mining company with 5500 personnel. Factors such as the fact that the people are male and working in the underground area were taken into consideration during the selection.

2.1. Location of Measurements

Measurements were made in the underground mine training pit, where chain conveyor, belt conveyor, water discharge systems, and ventilation systems, which are constant source of noise in underground mining enterprises, are located. The underground training colliery where measurements were made is shown in Figure 1.

Figure 1. Underground Training Colliery where the study was carried out.

The noise levels of each noise source were measured with a calibrated PCE-430 brand noise measuring device as listed in Table 1 and the noise intensity was observed to vary between 84 -94 dBA.

Table 1. Noise Intensities of Underground Training Machines.

Noise Source	Noise Intensity (dB)
Chain Conveyor	94
Belt Conveyor	86
Water Disposal System	84
Ventilation	88

2.2. Participants

One hundred male volunteers who work and will work in mining enterprises in Soma, which has the highest quality lignite reserves in Turkey, were studied. In the light of the information obtained as a

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Doi: 10.18466/cbayarfbe.1114348

result of the survey conducted with the workers, the characteristics of the workers were formed as in Table 2. In addition, all volunteer employees were subjected to audiometric tests with the AMPLIVOX 240 brand audiometer device and audiometric tests were applied to all-volunteer employees. As seen in Figure 2, workers whose hearing limit is below the sound produced by noise sources were not included in the experiment.

Table 2. Characteristics of the Worker Population.

		Worker (N:100)	
Old (year)			
Mean ± SD	Min-Max	23,95 ± 5,26	19 - 49
Weight (kg)			
Mean ± SD	Min-Max	76,46 ± 16,85	55 - 115
Height (cm)			
Mean ± SD	Min-Max	176,68 ± 5,80	166 - 186

All volunteers accepted the use of personal data in academic studies and accepted that these data are sensitive data and they were informed that the results obtained are handled collectively with methods and purposes in accordance with scientific principles. Also, before the experiment, all participants were fully informed about the general experimental procedure and signed a consent form.

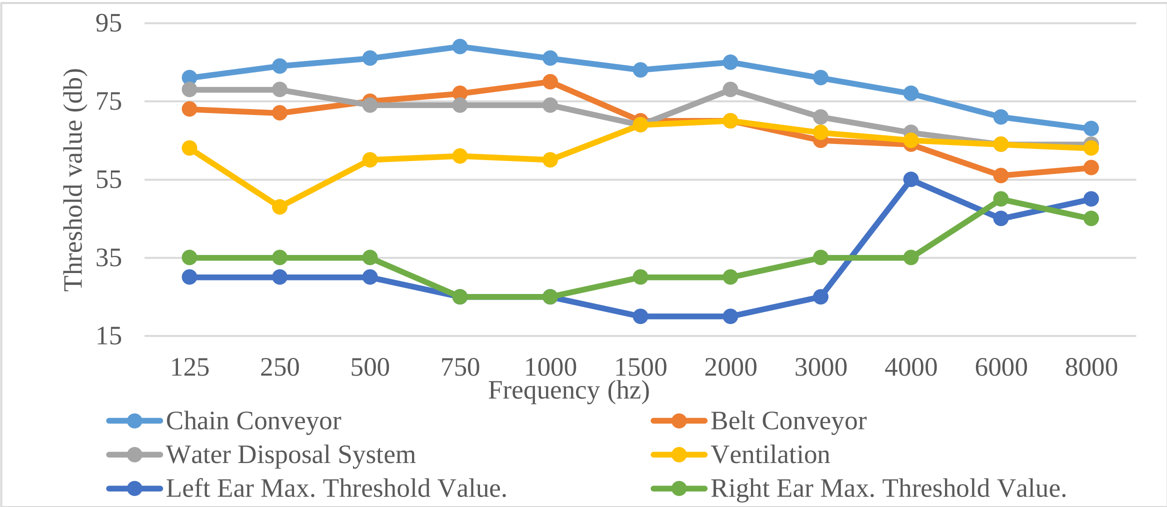

Figure 2. Comparison of noise intensity per frequency of noise sources and minimum hearing thresholds per frequency of participants.

2.3. Equipment and Measurements

A wearable physiological device has been proposed to monitor employee distractions. Instead of transmitting events between a single neuron, EEG records the total activity of thousands or millions of neurons as oscillatory activity [24]. EEG signals are mostly between 0.5-4 Hz Delta (δ), 4-8 Hz signals Theta (θ), 8-16 Hz signals Alpha (α), 16-32 Hz signals Beta (β), 32 Hz and The signals above are divided into five frequency bands as Gamma (γ). The band gaps of the EEG signals cause different success rates depending on the classification target. Thanks to the research in this field, the band gaps in which emotional states are active and the brain activities that are generally active can be grouped [25].

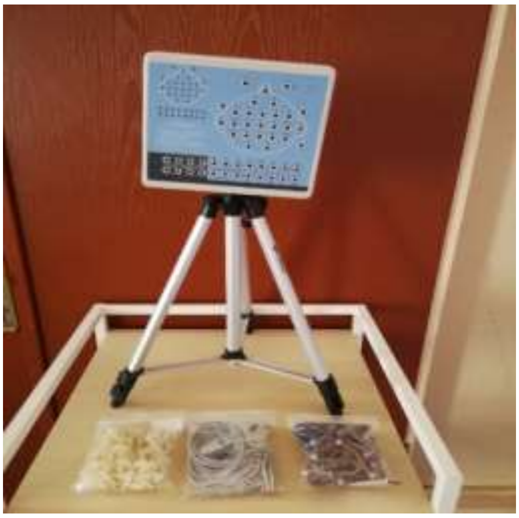

Figure 3. Electroencephalography Device

With the Contec KT88-3200 brand electroencephalography device shown in Figure 3, the brain electrical activities of the individuals were recorded separately before and after the operation of the machines that are the source of noise in the underground training colliery.

In the study, in order to examine the effect of noise on mine workers, measurements were taken from 100 people (males) who are working or will work in mining companies in the Soma basin, with the algorithm drawn in Figure 4.

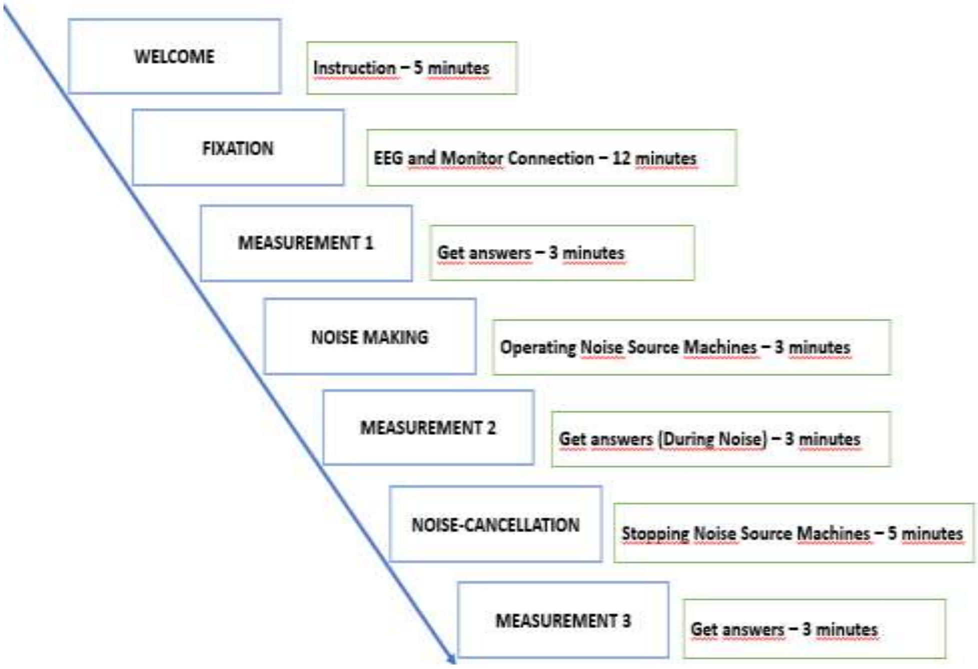

Figure 4. The procedure of each experimental personnel.

In order to examine the electrical activities of the brain in the measurement area prepared in the Underground Training Colliery, 16 EEG electrodes were connected to the places included in the box in the diagram given in Figure 4. In the first place, the signals of the person were recorded under the conditions when the systems called the 1st state were turned off. Then the person was exposed to the noise of the machines for a while. After the noise, the person was measured after the noise as the 2nd situation, and the data were recorded. After these measurements, the person rested for 5 minutes outside the Underground Training Colliery.

The rested person was taken back to the Underground Training Colliery to take the final measurements. The person was connected to the bedside monitor and EEG in the sitting position and the last measurements were taken. The following values were recorded in three cases.

- **1.Case:** In a noise-free environment, SYS, DIA, MEAN, HR, PR, SPO2, RR, and body temperature values were obtained with a bedside monitor, and Brain Electrical Activity Mapping with EEG.
- **2.Case:** SYS, DIA, MEAN, HR, PR, SPO2, RR, and body temperature values were recorded in a noisy environment.
- **3.Case**: After the noise, SYS, DIA, MEAN, HR, PR, SPO2, RR, and body temperature values were recorded and Brain Electrical Activity Mapping was performed with EEG.

2.4. Monitoring the Electrical Activities of the Brain with Electroencephalography Device

In this study, the positions of the measurement and reference electrodes on the skull were predetermined. Figure 5 shows this arrangement. For signal recording, 18 channels of 32-channel Electroencephalography (EEG) device, 2 of which are references, were used. EEG data were recorded by placing electrodes on the scalp. The electrodes are placed symmetrically to the brain regions. Before the measurement was taken, the electrodes were checked for wear. Then the electrodes were washed and disinfected with alcohol. Here, "Nasion" defines the front part of the head and "Inion" defines the back part. In the 10-20 system, odd-numbered electrodes identify the left side of the brain, and even-numbered electrodes identify the right side of the brain. The letters in front of the numbers are the abbreviations of the names of the relevant regions of the brain. (Fp = frontopolar; F = frontal; C = central; P = parietal; O = occipital; T = temporal). The brain regions where they are located

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Doi: 10.18466/cbayarfbe.1114348

and their electrode nomenclature are as follows; on the frontal lobe (Fp1, Fp2), (F3, F4, Fz, F7, F8), on the temporal lobe (T7, C3, C4, T8), on the occipital lobe (O1, O2), on the parietal lobe (P7, P3, P4, P8) and on the central region (C3, C4). Electrical activity was recorded by reference to the ear reference electrodes (A1 and A2). 500 Hz as the sampling frequency for each channel. value is used.

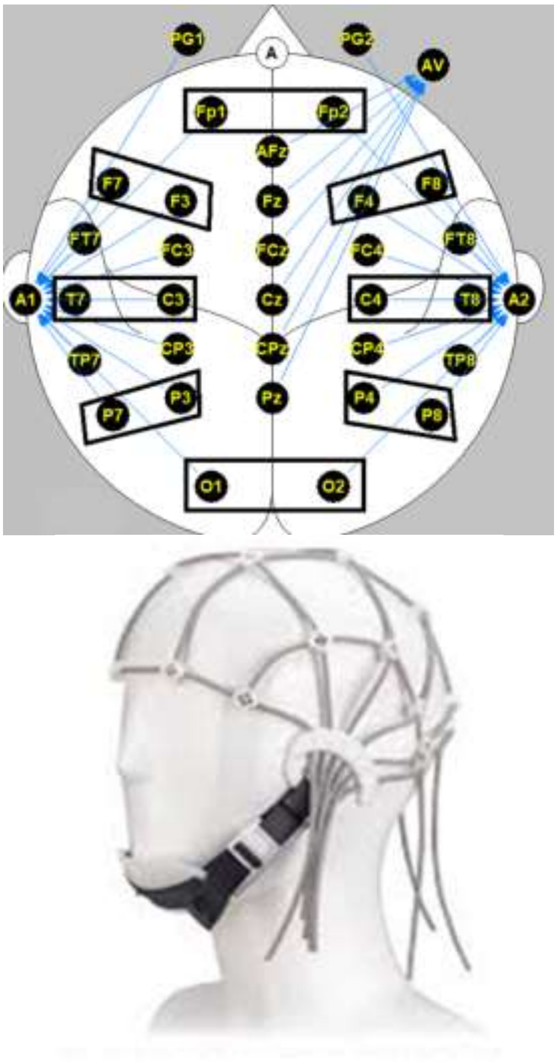

Figure 5. Electroencephalography Electrode Layout Diagram.

2.5. Statistical Analysis

The data obtained from the research were analyzed as dependent data in the SPSS statistical analysis program. Statistical analysis of the data, arithmetic mean and standard deviation (SD) were calculated according to the nature of each variable. Whether the data violated the assumption of normal distribution was checked using Kolmogorov-Smirnov's Lilliefors Significance Correction and Shapiro-Wilks Test. As a result of the controls, the tests of the workers and the scores they got from the attitude scale were compared using the Parametric T-Test for Related Samples, and the Nonparametric T Test for Unrelated Samples and the Wilcoxon Test. While analyzing the data, the significance level (p) was taken as 0.05.

3. Findings

In the present study, the effects of noise generated in underground mining on worker health were examined. During the study, the brain electrical activities of 100 people who work or will work in the mining sector were recorded for two different situations, and the data obtained in a noise-free environment and a noisy environment were compared, and the risk levels of noise and its effects on people were statistically analyzed.

3.1. Electroencephalography Results

At the measurement area prepared in the Underground Training , 16 EEG electrodes were connected to examine the brain's electrical activities to 100 volunteers who passed the audiometry test. In the first place, the signals of the people were recorded in the conditions when the systems called the 1st case were turned off. Afterward, people were exposed to the noise of machines for a while. After being exposed to noise, people rested outside the underground training for 5 minutes. The rested people were taken back to the underground training to take the final measurements, and in the 3rd case after the noise measurements were made and the data were recorded. EEG results of individuals were obtained as Numerical BEAM average values in microVolts for all frequency bands.
Statistical significance analyzes were performed using EEG signals recorded before and after noise. The results were created separately for the delta (0-4Hz), and theta (4-8Hz) bands of the EEG for each person. 16 electrode placements of each participant were examined. Case 1 and Case 3 values were compared for the Delta (δ) and Theta (θ) frequency bands with the highest electrical activity, and statistical analyzes of the remaining 61 individuals were made after the artifacts were filtered out.
When the values before noise (Case 1) and after (Case 3) were compared, no significant difference was observed in the values obtained from the Delta frequency bands ($p>0.05$, Table 3).

Similar to the delta band results, when the values before and after the noise were compared, there was no or very small change in the values obtained from the Theta frequency bands, and no significant difference was detected ($p>0.05$, Table 4).

Table 3. Table of Comparison of Delta Frequency Band Values of Volunteers in Before and After Noise Environments.

Statistical Test[a]

	Fp1_δ3 Fp1_δ1	Fp2_δ3 Fp2_δ1	F7_δ3 F7_δ1	F3_δ3 F3_δ1	F4_δ3 F4_δ1	F8_δ3 F8_δ1	T7_δ3 T7_δ1	C3_δ3 C3_δ1
Z	-,798[b]	-,766[c]	-,383[c]	-,767[c]	-,600[b]	-,331[b]	-,366[b]	-,798[b]
Sig.	,425	,444	,701	,443	,548	,740	,715	,425
	C4_δ3 C4_δ1	**T8_δ3 T8_δ1**	**P7_δ3 P7_δ1**	**P3_δ3 P3_δ1**	**P4_δ3 P4_δ1**	**P8_δ3 P8_δ1**	**O1_δ3 O1_δ1**	**O2_δ3 O2_δ1**
Z	-,250[c]	-,029[c]	-,891[b]	-,030[c]	-,430[b]	-,710[c]	-,941[b]	-,812[b]
Sig.	,802	,977	,373	,976	,667	,477	,347	,417

a: Wilcoxon Signed Ranks Test, b: According to positive ranks, c: According to negative ranks

Table 4. Table of Comparison of Volunteers' Theta Frequency Band Values in Before and After Noise Environments.

Statistical Test[a]

	Fp1_ θ3 Fp1_ θ1	Fp2_ θ3 Fp2_ θ1	F7_ θ3 F7_ θ1	F3_ θ3 F3_ θ1	F4_ θ3 F4_ θ1	F8_ θ3 F8_ θ1	T7_ θ3 T7_ θ1	C3_ θ3 C3_ θ1
Z	-,662[b]	-,906[c]	-,807[c]	-1,20[c]	-,676[b]	-,751[c]	-,115[b]	-,792[c]
Sig.	,508	,365	,420	,227	,499	,453	,908	,428
	C4_ θ3 C4_ θ1	**T8_ θ3 T8_ θ1**	**P7_ θ3 P7_ θ1**	**P3_ θ3 P3_ θ1**	**P4_ θ3 P4_ θ1**	**P8_ θ3 P8_ θ1**	**O1_ θ3 O1_ θ1**	**O2_ θ3 O2_ θ1**
Z	-1,07[c]	-1,38[b]	-,360[c]	-,284[c]	-,478[b]	-,086[b]	-,164[b]	-,254[c]
Sig.	,281	,167	,718	,776	,633	,931	,870	,799

a: Wilcoxon Signed Ranks Test, b: According to positive ranks, c: According to negative ranks

4. Discussion

The aim of this study is to determine the instantaneous noise exposure of workers exposed to noise in the mining sector and its effects on the body during noise exposure.

As a result of these measurements, the effects of the noise on the workers were observed by statistically comparing the values collected at the moment and after the noise exposure for the workers or volunteers who will work in underground mining.

When the neurological effects of the study were examined, the data obtained before and after the noise exposure in 6 frequency bands of 16 electrodes connected to the volunteers were analyzed and no significant difference was observed. Jinjing Ke et al. [26], in their study on the distraction of construction workers exposed to noise, concluded that although the noise group had a lower level of attention than the control group, there was no statistically significant difference. They concluded that this situation may be due to individual factors such as age, gender and noise sensitivity of the participants. In line with this view, they stated that the participants cared about their performance during the experiment, they were willing to work harder, and they consciously controlled their attention levels to complete the task. In this study, which was conducted on underground mine workers or those who will work, it was concluded that the results did not differ significantly, due to similar individual effects.

5. Result and Suggestions

In this study, the effects of the noise that the workers who work or will work in the underground mining sector are exposed to in the working areas have been observed experimentally and the important results and suggestions to reduce these effects are as follows:

1. Noise measurements were made in 4 sections of the underground mining training colliery within the Soma Vocational School of Manisa Celal Bayar University, which are a constant source of the noise. In the ambient noise measurements made, 94 dB(A) values were obtained in the section with the chain conveyor, 86 dB(A) in the section with the belt conveyor, 84 dB(A) in the section with the water discharge system, and 88 dB(A) in the section with the ventilation system. The daily noise exposure values were determined in the section where the chain conveyor was the most.
2. Persons who work or will work in the underground training colliery were subjected to an audiometry test in a sound-insulated room and it was examined whether they could hear the noise intensity and frequency range revealed by the devices. Due to the fact that 4 out of 104 people could not hear the operating noise frequency threshold of the mentioned machines, they were not taken to the next measurements, and 100 people whose hearing ability was within the desired tolerances were taken to the Underground Training Colliery. Measurements were made for both ears at frequencies of 125, 250, 500, 750, 1,000, 1500, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz. For the determination of hearing loss, 500, 1,000, 2,000, and 4,000 Hz frequency combination and 25 dB average hearing threshold value recommended in ISO-1999 and TS-2607: ISO 1999 standards were taken into consideration in the evaluation of the test results.
3. In the measurement area prepared in the Underground Training Colliery, 16 EEG electrodes were connected to examine the brain's electrical activities to 100 volunteers who passed the audiometry test. In the first place, the signals of the people were recorded under the conditions when the systems called the 1st case were closed. Afterward, people were exposed to the noise of machines for a while. After being exposed to noise, people rested outside the underground training for 5 minutes. The rested people were taken back to the underground training to take the final measurements, and in the 3rd case after the noise measurements were made and the data were recorded.

• In the present work, EEG measurements were recorded using 16 electrodes placed (C3, C4, F3, F4, F7, F8, FP1, FP2, O1, O2, P3, P4, P7, P8, T7, T8) on the scalp using the Contec KT88-3200 brand electroencephalography device.

• After the EEG measurements were made, artifact evaluations of the measurements were made and measurements containing too many artifacts were eliminated. After this elimination, 61 data remained.

• In the EEG measurements of the participants, the digital BEAM data obtained before and after the noise exposure in 6 frequency bands (Delta, Theta, Alpha 1, Alpha 2, Beta 1, and Beta 2) of 16 electrodes were analyzed. The frequency bands for digital BEAM are Delta 1– 4 Hz, Theta 4 – 8 Hz, Alpha1 8-12 Hz, Alpha2 12 – 16 Hz, Beta1 16-24 Hz, and Beta2 24-32 Hz. When the before (Case 1) and after (Case 3) values were compared in the SPSS program analysis platform, no statistically significant difference was found as seen in Tables 2 and 3 ($P>0.05$). The main reasons for not finding a difference may be:

- Young workers participating in the experiment. Jinjing Ke et al. [26] emphasized in his study that this is likely.
- Awareness of the participants that they will be exposed to noise at the time of measurement.

As a result, in underground mines, noise-related physiological effects can be seen in workers who are exposed to noise, especially if they do not use personal protective equipment. For this reason, it is recommended that those who will work in unit areas with high ambient noise levels use personal protective equipment to reduce the noise level they are exposed to. In addition, it is recommended to provide training and inspections aimed at raising awareness among employees about the harmful effects of ambient noise on hearing and other physiological systems and reducing noise levels.
Employers are advised to evaluate risk factors by managing their employees' health examinations and health education, monitoring for significant hearing loss by having audiometry measurements at regular intervals and controlling noise measurements.
It is thought that the results of this study will be a guide for the people who work or will work in the mining sector and the sector representatives. The application of these findings is not only limited to

the mining sector but is important for any environment that requires constant attention in a noisy environment.

In the next study, the cardiovascular effects of noise will be discussed. It is also planned to take into account the age, weight, height and working time of the participants. In order to enrich the results of the study, it is planned to compare the measurements with a reference group.

Author contributions

All authors listed have significantly contributed to the development and the writing of this article.
Ayla TEKİN: Supervised the experimental work and the manuscript process.
Mustafa Oğuz NALBANT: Did literature review and prepared the manuscript
Mustafa ORHAN: Compiled study data.
Fırat TEKİN: Compiled study data.
Fatih SUVAYDAN: Compiled study data.
Kemal BERKİ: Compiled study data.
Sami GUMUS: Were involved in the analysis, interpretation of the data.
Aslı Aydın SAVRAN: Were involved in the analysis, interpretation of the data.

Acknowledgments

This study was supported by Manisa Celal Bayar University Scientific Research Projects Coordination Unit within the scope of project no 2019-083.

Ethics

There are no ethical issues after the publication of this manuscript.

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