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Investigation of factors affecting hearing loss of open pit coal mine employees with categorical data analyses

Açık ocak kömür madeni çalışanlarının işitme kaybını etkileyen faktörlerin kategorik veri analizleri ile araştırılması

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A B S T R A C T

One of the most important occupational diseases encountered in mining is the noise induced hearing loss (NIHL). In this study, analyses were carried out to examine the NIHL in the open pit lignite mine in Turkey. The NIHL was evaluated in accordance with the miners' age, experience, occupation, exposure value (L_{ex}), and maximum noise level (L_{peak}). Noise levels exposed the employees were measured with noise dosimeters and a hearing test was applied to the employees by a special hearing center. To determine the parameters that could be effective in NIHL, all of the obtained data were evaluated by the logistic regression analysis (LRA) and hierarchical log-linear analysis (HLA) methods. It was determined that the NIHL probability of field staff is approximately 6 times higher than operators and drivers. According to the 21-29 age group, it was found that the probability of NIHL in the 57-65 and in the 48-56 age group was 11.4 and 4.41 times higher, respectively. Experience and maximum noise levels were found to be the most important parameters in hearing loss. Besides these, it was determined that the interactions of age×experience, occupation×maximum noise levels, and occupation×average noise exposure levels increased the likelihood of NIHL. A logistic regression model has been developed for the NIHL estimation of employees and hearing loss was found to be a problem mostly for those working in the field. It was determined that hearing loss increased with age and experience, and varied according to occupational groups. In order to prevent NIHL, it is a priority to consider the noise levels to which occupational groups are exposed and to apply technical or personal precautions for all employees of the relevant occupational group.

Keywords: Hierarchical log-linear analysis, Logistic regression, Mining, Noise induced hearing loss, Occupational disease.

Introduction

Excessive noise, in addition to its negative social and physiological effects, is an occupational health hazard, particularly NIHL. The World Health Organization reports that 16% of adult hearing loss occurs as a result of exposure to occupational noise (Nelson et al., 2005). Since the 18th century, the NIHL has been considered an occupational disease for copper employees who suffered hearing loss from hammering metal (Hong el al., 2013) .

In the studies of Kovalchik et al., they emphasized that hearing loss was classified in the category of "all other illnesses" by the Bureau of Labor Statistics before 2004, it was categorized as a separate illness among work-related diseases in 2004. They express that occurred from hearing loss 11% of work-related diseases in 2004 and 2005 (Kovalchik et al., 2008). Picard et al., found that hearing loss may occur at noise levels exceeding 89 dBA and also that high noise levels increase occupational accidents (Picard et al., 2008).

One of the industries with the highest NIHL risk is mining (Concha-Barrientos et al., 2004; Vipperman et al., 2007). Noise in mining is one of the most important factors damaging employee health. The possibility of hearing loss increases as a result of exposure due to noise. In coal mining, noise exposure is higher than the specified limit levels and high noise levels are generated by the operation of powerful machines (Kovalchik et al., 2008). Almost all equipment used in open pit mine is a source of noise itself. Mean noise level of some machines used in open cast mining given in Table 1 (Sharma et al., 1998).

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Table 1. *Mean noise levels of machines (dB)*

Source	Idling	Fully accelerated
Shovel	80	97
Dumper	75	92
Bulldozer	84	100
Pay loder	82	100
Drill	85	90
Scraper	85	101
Air compresssor	-	96

Continuous exposure of employees to high noise levels may cause hearing loss due to noise (Sharma et al., 1998; Sensogut and Cinar, 2007). For NIHL, exposure of employees to noise levels of 82 dB (A) poses a risk, while levels above 90 dB (A) pose a high risk (Phillips et al., 2007). The NIHL is currently not curable and irreversible, but it can certainly be avoided, so it is important to implement adequate preventive programs (Goelzer, 2001).

Kursunoglu and Gogebakan (2021) used multinomial logistic regression to predict spontaneous combustion tendencies of coal mines. Iwasaki et al (2021) studied the changes in element concentrations of approximately 100 untreated discharges from old mines in Japan by a hierarchical-linear model. Since there are few studies aimed at preventing occupational hearing loss in mining (Bauer et al., 2006), in this study, a statistical investigation by the LRA and HLA methods was conducted and the parameters that could be effective in the formation of NIHL were tried to be determined.

1. Materials and methods

LRA is used to determine the probability of an event occurring, while HLA is used to evaluate the interaction between parameters that affect the occurrence of the event. In this study, since the variables are suitable for categorical data analysis and these methods are mostly used in the medical sciences to study disease occurrences, a logistic regression model was created first and the relationships between risk factors and NIHL formation were quantitatively evaluated. Then, the HLA was used to examine the interaction between parameters that affect the formation of NIHL (Onder et al., 2021; Onder, 2013). The common results obtained by using LRA and HLA methods together were tried to be interpreted. Detailed explanations about LRA and HLA are available in the categorical data analysis book prepared by *Agresti* (2002).

1.1. Measurement methodology

The study was achieved in the open pit lignite mine belonging to Turkish Coal Enterprises in Turkey. The location map of the open pit lignite mine is given in Figure 1.

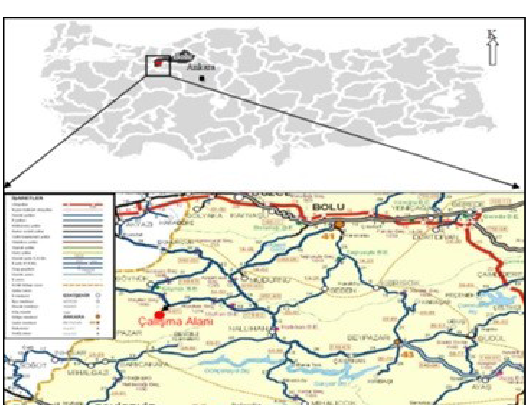

Figure 1. *Location map of the open pit lignite mine*

The open pit mine carries out its production with 100 employees. For excavating and loading are used excavators, and for transportation are used trucks. Within the scope of the occupational health and safety law in Turkey, in accordance with the regulation on protection of employees from noise related risks, the maximum action value for noise in the workplace is 85 dB (A) and the exposure limit value is 87 dB (A). Employers in Turkey, due to legal requirements, are obliged to have it made noise measurements in the workplaces. In addition, hearing loss is examined within the scope of health checks of employees (Official Gazette, 2013). After the enterprise management and employees approved the measurements, the personal noise exposure levels and hearing loss of all employees in the open pit lignite mine were determined. The data required for the study were compiled with special permission.

Noise measurements were recorded with noise dosimeter in order to measure the noise level of 100 employees working in different positions in open pit lignite mine. For dosimetric measurements, the CIRRUS CR-110 A personal dosimeter was used. Noise dosimeters have been developed to determine the noise that employees are exposed to during normal working days. This is a small, light, and compact piece of equipment that should be worn by the employees. It measures the total A-weighted sound energy received and expresses this as a ratio of the maximum A-weighted energy that can be received per day. This device is very useful when there are significant changes in exposure during the working day. A view showing the catalog and application of the measuring instrument used is given in Figure 2. Noise measurements were made with respect to TS 2607 ISO 1999 (2005).

Figure 2. *CIRRUS CR-110 A personal dosimeter*

The noise dosimeter can be worn without disrupting work. It is attached to the clothes of employees the microphone close to the ear. The noise values recorded by the instrument are transferred to the computer program and the data are evaluated, analysis and reports are generated. The dosimetric measurement results for an employee are shown in Figure 3.

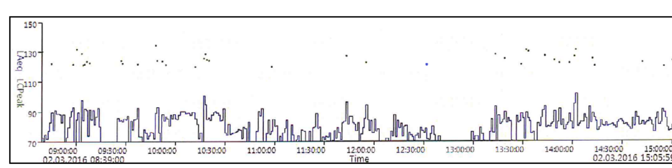

Figure 3. *Dosimetric measurement results for an employee*

1.2. Examination of NIHL

After this measurements it was made pure tone odyometri test for all employees. Dosimetric noise measurements and hearing loss tests were performed for 100 employees in the enterprise and occupation categories were determined with a single group code for those working in similar fields.

In this study, audiogram results of the employees were interpreted together with the workplace doctor. Also, the NIHL was evaluated to the occupation, miners' age, experience, L_{ex}, and L_{peak}. In the study, NIHL was accepted as the dependent variable because it caused by the noise in the working environment. It was categorized as no disease (No) and disease (Yes). Factors affecting the occurrence of NIHL were categorized into five groups in the study, such as occupation, age, experience, exposure value, and maximum noise, which are independent variables. Main categories determined as independent variables were divided into their subcategories. The coding plan and employees' distributions for the NIHL were given in Table 2.

(48%), age distributions are close to homogeneity, and the number of employees with less experience (66%) is high. Employees are often exposed to noise of 78.26-85.10 dB(A) (58%). Employees are often exposed to the maximum value of 138.6-143 dB(C) (84%). As a result of the calculations made to examine the NIHL rates in occupation sub-categories, because 8 out of 12 employees of the field staff had hearing loss, the NIHL rate was 66%. When the rates of the occupation sub-category among all employees with NIHL were calculated, it was determined that the number of drivers with hearing loss was 21 and the ratio was 47.73% in a total of 44 cases. All NIHL rates given in Table 2 were calculated similarly.

Table 2. *Coding plan and distributions for NIHL*

Variable	Categories	Code	Subcategories	%	NIHL	NIHL ratios in subcategories	Ratios by total NIHL
Y	NIHL	0	No	56			
		1	Yes	44			
$X_{Occupation}$	Occupation	1	Technical staff	15	6	40.00	13.64
		2	Operator	25	9	36.00	20.45
		3	Driver	48	21	43.75	47.73
		4	Field staff	12	8	66.67	18.18
X_{Age}	Age	1	21-29	24	6	25.00	13.64
		2	30-38	17	6	35.29	13.64
		3	39-47	18	8	44.44	18.18
		4	48-56	21	10	47.62	22.73
		5	57-65	16	10	62.50	22.73
		6	66-74	4	4	100.00	9.09
$X_{Experience}$	Experience	1	1-8 yrs	66	27	40.91	61.36
		2	9-16 yrs	13	7	53.85	15.91
		3	17-24 yrs	3	2	66.67	4.55
		4	25-32 yrs	12	4	33.33	9.09
		5	33-40 yrs	6	4	66.67	9.09
X_{Lex}	Exposure Value	1	71.4-78.25 dB(A)	42	17	40.48	38.64
		2	78.26-85.10 dB(A)	58	27	46.55	61.36
X_{Lpeak}	Maximum Value	1	134.1-138.5 dB(C)	16	6	37.50	13.64
		2	138.6-143 dB(C)	84	38	45.24	86.36

The categories of the occupation variables are technical staff, operator, driver, and field staff. Employees in the technical staff group are engineers, topographers, and technicians. Its general responsibilities are production, planning, supervision, and topographic measurements. Operators use large mining equipment such as excavators, while drivers use trucks. The employees in the field staff group are shunter, weigher, lubricator. The responsibilities of these staff working in the open pit area are to guide the maneuvers of the mining machinery, determine the weight of the shipped ore and refuel the mining machinery. The age variable was divided into six subcategories, the experience variable into five groups, and the exposure to noise (L_{ex}) and maximum noise variables (L_{peak}) into two groups. As shown in Table 2, 44% of all employees have NIHL. It was determined that the majority of the employees are driver

2. Results

In the study, the variables $X_{Occupation}$, X_{Age}, $X_{Experience}$, X_{Lex} and X_{Lpeak} are independent variables and the variable Y is the dependent variable (Table 2). After this determination, the interactions of parameters in NIHL formation were evaluated with advanced statistical techniques, and the important results obtained are given below.

LRA was carried out using SPSS package program to analyze data. The results of LRA including all variables are given in Table 3 and it can be interpreted as follows.

Table 3. *Results of the logistic regression model for NIHL*

Effect	Variable	β	p	Exp(β)	Probability (1/Exp(β))	95% C.I.for EXP(B) Lower	Upper
Occupation	Field staff		.092				
	Technical staff	-1.275	.101	.279	3.58	.061	1.281
	Operator	-1.842	.042*	.159	6.29	.027	.939
	Driver	-1.690	.040*	.185	5.41	.037	.925
Age	21-29		.291				
	30-38	.614	.430	1.847	1.847	.403	8.479
	39-47	1.018	.184	2.769	2.769	.616	12.434
	48-56	1.484	.062**	4.411	4.411	.931	20.907
	57-65	2.434	.018*	11.409	11.409	1.519	85.700
	66-74	23.390	.999	14388002142	-	.000	.
Experience	1-8 yrs		.511				
	9-16 yrs	.412	.560	1.510	1.510	.378	6.035
	17-24 yrs	.558	.683	1.746	1.746	.120	25.362
	25-32 yrs	-1.292	.142	.275	3.64	.049	1.538
	33-40 yrs	-.602	.638	.548	1.82	.045	6.714
Exposure Value	78.26-85.10 dB(A)	-.414	.600	.661	1.51	.140	3.112
Maximum Value	138.6-143 dB(C)	.492	.540	1.636	1.636	.338	7.914

* Significant at 95% probability level
**Significant at 90% probability level

According to the field staff, being an operator and the the truck driver increases the possibility of not having NIHL 6.29 times, 5.41 times, respectively. Compared to being the 21-29 age group, working in the 57-65 age group and 48-56 age group increases the probability of NIHL by 11.41 times and 4.41 times respectively. Being experienced for 25-32 years increases the likelihood of not having NIHL by 3.64 times compared to being experienced for 1-8 years. Being the most experienced employee increases the likelihood of not having NIHL by 1.82 times compared to being the least experienced employee. According to the exposure value of 71.4-78.25 dB (A), the exposure value of 78.26-85.10 dB (A) increases the probability of employees not NIHL by 1.5 times. Being the maximum value 138.6-143 dB (C) increases the probability of having NIHL by 1.64 times compared to being the maximum noise level of 134.1-138.5 dB (C).

According to the β coefficients (Table 3), the logistic regression model for NIHL can be written as in Equation 1.

$$\hat{Y} = -0.414X_{(78.26-85.1\;dB(A))} - 1.275X_{(Technical\;staff)} - 1.842X_{(Operator)} + 1.690X_{(Driver)} + 0.614X_{(30-38)} + 1.018X_{(39-47)} + 1.484X_{(48-56)} + 2.434X_{(57-65)} + 23.390X_{(66-74)} + 0.412X_{(9-16)} + 0.558X_{(17-24)} - 1.292X_{(25-32)} - 0.602X_{(33-40)} + 0.492X_{(138.6-143\;dB(C))} \quad (1)$$

While 56 of the 100 workers in the enterprise do not have the NIHL, 44 of them have the NIHL. The rate of correct classification employees without hearing loss in the developed logistic regression model is 82.1%, while the rate of predicting those with hearing loss is 56.8%. The correct classification rate of the model created for NIHL was determined as 71% and can be interpreted as a successful model. It is appropriate to use the generated logistic regression model to estimate NIHL in this mine (Onder and Mutlu, 2017).

For employees with NIHL, a HLA model has been established with the SPSS 17 version to specify which parameters cause the disease. The hierarchical log-linear model was established from five-way contingency table of occupation (O), age (A), experience (E), average noise exposure (L_{ex}) and maximum noise level (L_{peak}). A five-way h×i×j×k×l cross-classification of response variables O, A, E, L_{ex} and L_{peak} has several potential types of independence (Agresti, 2002). The saturated model includes terms corresponding to all possible main effects and interactions. In this study, the main effects for NIHL considered as O, A, E, L_{ex}, and L_{peak}. In other words, with the help of hierarchical log-linear models, the importance level of the main factors considered in the formation of the disease and the different interactions of these factors can be determined. The main effects and higher-order interaction terms of the hierarchical log-linear model were given in Table 4. The importance of interaction terms was determined by the likelihood-ratio (χ^2) test (Maiti et al., 2001).

The fourth and third order interaction terms were not evaluated in the study because they were not statistically significant. For more detailed data analysis, the statistically significant (p<.05) parameters in Table 4 were examined. Main effects and interaction parameters Age×Experience, Occupation×L_{ex} and Occupation× L_{peak} were found to be statistically significant. When c2 values are examined, it is determined that the most important main effect is experience. This is followed by L_{peak}, L_{ex}, occupation and age parameters according to the highest c2 value, respectively.

Table 4. *Results of the HLA for NIHL*

Degree of Interaction	Interaction	df	χ^2	p
2	Age×Experience	30	67.146	.000
	Occupation×L_{peak}	8	46.667	.000
	Occupation×L_{ex}	8	37.390	.000
	Occupation×Age	24	16.302	.877
	Occupation×Experience	20	13.776	.842
	Experience×L_{peak}	10	12.596	.247
	Age×L_{peak}	12	10.559	.567
	Age×L_{ex}	12	3.088	.995
	Experience×L_{ex}	10	1.846	.997
	L_{ex}×L_{peak}	4	.968	.915
Main effects	Experience	5	144.772	.000
	L_{peak}	2	131.788	.000
	L_{ex}	2	83.664	.000
	Occupation	4	74.312	.000
	Age	6	48.760	.000

In SPSS, one of the estimate parameters is the lambda coefficient. These parameters can be labeled as β coefficients and Exp (β) is the odds ratio (OR). The odds ratio is the measure of the effect size. The odds ratio of 1 indicates that there is no effect, a variable greater than 1 indicates that the variable in question increases the probabilities, and a variable less than 1 indicates that the variable decreases the rates. If the probability ratio is greater than 1, it can be said that a factor considered constitutes a significant risk for occupational diseases (Agresti, 2002). Second-order interaction results are given in Table 5.

Table 5. *Second-order interaction results for the log-linear model*

Effect	Variable	β	Exp(β)
Occupation×L_{ex}	Driver×78.26-85.10	.119	1.126
	Operator×71.4-78.25	.064	1.066
	Driver×71.4-78.25	-.079	0.924
Age×Experience	21-29 age×1-8 years	.192	1.212
	57-65 age×33-40 years	.070	1.073
	30-38 age×1-8 years	.069	1.071
Occupation×L_{peak}	Driver×138.6-143	.103	1.108
	Technical staff×134.1-138.5	.067	1.069
	Operator×138.6-143	.040	1.041

When the 2nd order interactions in Table 5 were evaluated Occupation×L_{ex} interaction shows that drivers and operators have a high possibility of NIHL in 71.4-78.25 and 78.26-85.10 dB(A) noise levels. Similarly, when Age×Experience association is evaluated, it can say that 21-29 age group with 1-8 years of experience has a high possibility of NIHL. Additionally, 57- 65 age group with 33-40 years of experience is mostly exposed to NIHL. Moreover, it can be said that, drivers and operators exposed to noise in 138.6-143 dB(C) have high risk. It is obvious that the higher the noise level exposed, the higher the possibility of hearing loss for drivers and operators. It is seen that the youngest employee group with less experience considered in this study has a high probability of hearing loss.

3. Discussion

Occupational diseases are among the most important risks to which employees must be protected and can be prevented by taking the necessary precautions in the working environment and for the employees at an early stage. LRA and HLA methods used in categorical data analysis can be used to evaluate the factors that affect the occurrence of occupational diseases. While LRA evaluates all employees with and without illness within a population, HLA can only be used to evaluate employees with occupational diseases. While the purpose of using LRA is to develop a prediction model, the purpose of HLA is to examine the factors in the occurrence of occupational disease and the interactions of these factors. Standard ISO 1999 (2013) can be used to estimate the risk of noise-induced hearing loss. With this standard, noise-related hearing losses can be estimated for each employee, taking into account age, noise, and experience periods.

When the presence of NIHL was examined with the logistic regression model, according to the field staff, operator is 6.29 times more likely to not have NIHL, and driver is 5.41 times more likely to not have NIHL. In other words, it can be said that the NIHL probability of field staff is approximately 6 times higher than the probability of operators and drivers. The reduction in NIHL of operators and drivers is due to the adaptation of the work equipment to technological developments. As the noise exposures of the field staff working beside the high capacity mining equipment are generally high, the probability of hearing loss increases. It was found that the probability of NIHL was 11.4 times higher in the 57-65 age group and 4.41 times higher in the 48-56 age group according to in the 21-29 age group. NIHL has been found to increase with increasing age.

When the data of the employees with the presence of hearing loss were examined by HLA; the factors affecting the likelihood of having NIHL were found to be experience, maximum noise level, average noise exposure level, occupation, and age respectively. It was found that Age×Experience interaction had the highest effect on the probability of NIHL, followed by Occupation×Lpeak and Occupation×L_{ex} interactions. Employees in the 21-29 age group with 1-8 years of experience are likely to experience hearing loss. It was determined that drivers were exposed to average exposure levels of 78.26 - 85.10 dB (A) and were more likely to NIHL. It can be said that drivers are exposed to maximum noise of 138.6-143 dB (C), which increases hearing loss. It can be said that if drivers and operators are exposed to noise without personal protection under normal working conditions, their possibility of hearing loss will increase. The reason for this can be explained by the fact that drivers and operators are more exposed to the noise generated by mining machines when idling or fully accelerated, compared to other occupational groups. The majority of young workers and those with less experience are field staff. Therefore, the possibility of hearing loss in this occupational group should not be overlooked in the interaction of Age×Experience.

Conclusion

Noise-induced hearing loss is one of the most common occupational diseases encountered in mining and various parameters are effective in its formation. Within the scope of the study, these parameters were determined as miners' age, experience, occupation, L_{ex}, and L_{peak}. It was found that the probability of NIHL for field personnel is approximately 6 times higher than that of operators and drivers. It has been found that NIHL increases up to 11 times with age. With the developed logistic regression model, NIHL can be successfully predicted in this enterprise and similar studies can be performed in other enterprise. Age × experience, occupation × maximum noise levels and occupation × average noise exposure levels are the interactions that has the highest impact on the probability of NIHL. In order to prevent NIHL in enterprises, it is necessary to follow the technological developments in equipment selection, organize the working environment, provide training and take personal precautions. In addition, the use of personal protective equipment must be supervised. To prevent occupational diseases and to eliminate the risks that may be encountered, personal exposure levels must be below the legal limits and the measurements are carried out periodically.

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