SH@W Safety and Health at Work www.e-shaw.org

Saf Health Work 2011;2:336-47 | http://dx.doi.org/10.5491/SHAW.2011.2.4.336

pISSN : 2093-7911
eISSN : 2093-7997

Original Article

The Risk Rating System for Noise-induced Hearing Loss in Korean Manufacturing Sites Based on the 2009 Survey on Work Environments

Young Sun KIM, Youn Ho CHO, Oh Jun KWON, Seong Weon CHOI and Kyung Yong RHEE

Occupational Safety and Health Research Institute, Koera Occupational Safety and Health Agency, Incheon, Korea

Objectives: In Korea, an average of 258 workers claim compensation for their noise-induced hearing loss (NIHL) on an annual basis. Indeed, hearing disorder ranks first in the number of diagnoses made by occupational medical check-ups. Against this backdrop, this study analyzed the impact of 19 types of noise-generating machines and equipment on the sound pressure levels in workplaces and NIHL occurrence based on a 2009 national survey on work environments.
Methods: Through this analysis, a series of statistical models were built to determine posterior probabilities for each worksite with an aim to present risk ratings for noise levels at work.
Results: It was found that air compressors and grinding machines came in first and second, respectively in the number of installed noise-generating machines and equipment. However, there was no direct relationship between workplace noise and NIHL among workers since noise-control equipment and protective gear had been in place. By building a logistic regression model and neural network, statistical models were set to identify the influence of the noise-generating machines and equipment on workplace noise levels and NIHL occurrence.
Conclusion: This study offered NIHL prevention measures which are fit for the worksites in each risk grade.

Key Words: Noise-induced hearing loss, Sound pressure level, Survey on work environments

Introduction

Repeated noise, beginning at 4,000 Hz, hurts the delicate structure of the inner ear, causing hearing loss [1,2]. This illness is called noise-induced hearing loss (NIHL). Once hearing is impaired, it is impossible to restore it and therefore, reducing risk factors is the best way to prevent NIHL [3]. Recent studies point out that in addition to noise, other factors including organic solvents, heavy metals, smoking, high blood pressure, and hyperlipidemia are also related to NIHL [4-11]. However, noise still serves as the highest risk factor. Unfortunately, it has been found that a number of manufacturing workers in Korea are exposed to excessive noise levels. For example, the manufacturing sector accounts for over 80% of the 2,324 workers who claimed occupational insurance compensations for NIHL from 2001 to 2009-tantamount to 258 workers on an annual basis [12]. Moreover, hearing disorder currently takes the largest proportion of diagnoses made by occupational medical check-ups, which are regularly done for workers in Korea.

A previous study showed that mine workers were exposed to significant noises from circular saws (98 dB), line saws (99 dB), grinding machines (88 dB), and pneumatic machines (92 dB) [13]. Another study suggested that agricultural machines and equipment including hammers (99.6 dB) and grinding machines (86.6 dB) also generated harmful noises [14]. It was also

Received: December 7, 2010, **Revised:** August 16, 2011
Accepted: September 9, 2011, **Available online:** December 5, 2011
Correspondence to: Kyung Yong RHEE
Occupational Safety and Health Research Institute
Korea Occupational Safety and Health Agency
478, Munemi-ro, Bupyeong-gu, Incheon 403-711, Korea
Tel: +82-32-5100-751, **Fax:** +82-32-5100-863
E-mail: rheeky@hanmail.net

notable that an air compressor in the piston/motor shaft form produced as high as 91.1 dB [15].

Senior workers have been found to be more vulnerable to hearing impairment [16]. With the rapidly aging process worldwide, Korea entered an aging society in 2007. If the aging process maintains its current pace, the nation is expected to become an aged society by 2020 and an ultra-aged society by 2026 [17].

Against this backdrop, this study aimed to analyze the impact of 19 types of noise-generating machines and equipment on workplace noise and NIHL occurrences among workers. It used diverse statistical models to present risk ratings for the equivalent sound pressure levels and NIHL occurrences among manufacturing workers. By doing so, the author identified the impact of the noise-generating machines and equipment on noise levels and the hearing capability of manufacturing workers. These risk ratings are expected to serve as accident prevention indicators.

Materials and Methods

Data collection

The Korea Occupational Safety and Health Agency (KOSHA) investigates work environments nationwide and risk factors as part of its comprehensive plan to prevent occupational illnesses in cooperation with the Korean Ministry of Employment and Labor. For example, the agency conducts research on employment status, general work conditions, high-risk environments, chemical-handling jobs, and high-risk machinery and equipment on a regular basis. These studies are then reflected in the government's policies to improve workers' safety and health and to prevent accidents and injuries at work. KOSHA has also established a management system for high-risk chemicals, machinery, and equipment. The agency has delivered a survey on work environments nationwide every five years since its first round which targeted 52,552 worksites in 1991. The number of surveyed worksites has steadily rose from 52,070 in 1999, to 80,040 in 2004, and 107,295 in 2009.

The 2009 round performed from April 1 to October 30 had worksites covered by workers' insurance as the sampling frame. While manufacturing worksites with five employees or more were studied through complete enumeration, stratification methods considering the locations and industrial traits were applied to those with below five. When a sample was not eligible, the substitution sample was set by doublingall figures in the sample which was originally going to be investigated. Among 101,010 manufacturing worksites with five employees or more, 86,415 or 86.5% completed surveys, while 11,497 manufacturing companies with less than five workers did so, posting 114.9% in survey completion among 1,000 targeted worksites. Out of 10,000 non-manufacturing companies, 9,383 worksites or 93.8% fulfilled the survey (Table 1).

Experts were recruited as enumerators for the 2009 survey in related fields including health, occupational safety, and machinery. They also went through a four-step guidance to ensure consistency of the survey.

The survey items included: 1) worksite information and work environment, 2) installed machines, equipment, and facilities, and 3) chemical-handling jobs. As shown in Table 2, the worksite information dealt with the number of workers, welfare facilities, and worksite management numbers, which were issued by KOSHA to companies covered by workers' insurance. These numbers served as a key value in comparing the databases on accidents and injuries at work, each built by KOSHA, occupation medical institutions, and companies.

The work environment item composed of risk factors, the number of exposed workers, and their daily work time dealt with the number of worksites with 19 types of machines generating noise, the time of their usage, and the number of workers handling the equipment.

The item machines, equipment, and facilities item measured the number of 18 types of machines including cranes, hoists, lifts, gondolas, and forklifts installed in the worksites, and whether they were bought or rented.

The chemical-handling jobs item encompassed chemicals belonging to the following five categories:1) dangerous materi-

Table 1. Methods and response rate of the survey on work environments

Sector	No. of workers	Methods	No. of populations	No. of respondents
Manufacturing	Over 5	Complete enumeration	101,010	86,415
	Below 5	Stratified two-stage sampling	154,063	11,497
Non-manufacturing	-	Stratified three-stage sampling	133,753	9,383
Total	-	-	388,826	107,295

No: number.

als requiring approvals, 2) dangerous materials under control, 3) dangerous materials subject to surveys on work environments, 4) materials with exposure limits, and 5) high-risk materials (Table 2).

Data integration

Using workplace identification numbers, the data on occupational medical tests were integrated into the data from the survey on work environments to analyze the impact by the machinery and equipment on NIHL.

The occupational medical check-up system was introduced by the Korean Ministry of Employment and Labor and KOSHA with an aim to improve workers' health and prevent work-related disorders by offering annual medical tests. As of 2009, 874,018 workers received the test on an annual basis. The Ministry has designated 150 hospitals to deliver the check-up service for workers exposed to risk factors. The diagnoses and the tests' results, which are reported to KOSHA, are reflected in the database on occupational medical check-ups. The database consists of measured values regarding the 220 diagnosis items' results and the doctors' comments.

As Fig. 1 indicates, since each worksite had diagnostic information on a number of workers, the two databases' analysis units the survey on work environments and the occupational

Table 2. Survey items

Survey item			Content
Worksite information			Name, CEO, address, worksite management no., foundation date, main products, work type, industry type, welfare facilities, no. of workers
Work environment	Machines & equipment generating noise and vibration		No. of owned units among 19 types of machines and equipment generating noise and vibration, no. of currently used units, daily work time, no. of exposed workers (male & female)
	Jobs generating dust and fume		No of male & female workers exposed to 19 types of machines & equipment generating dust or fume, daily work time
	Welding & cutting		No. of currently used welding & cutting equipment among 17 types
	Gilding		Existence of gilding jobs, no. of exposed workers, daily work time
	High-temperature, low-temperate, or radioactive environments	High-temperature	No. of workers exposed to 7 types of jobs handling heat, daily work time
		Low-temperature	No. of workers exposed to 2 types of jobs in cold environments, daily work time
		Radioactive	No. of workers exposed to 3 types of radioactive environments, daily work time
	Confined spaces		No. of workers in 9 types of confined spaces, work frequency
Machines, equipment & facilities			No. of currently used machines, equipment & facilities among 18 types, no. of the used, the owned, and the rented
Chemical-handling jobs			Chemical's name, annual production, processes, purposes, no. of exposed workers, daily work time

No: number.

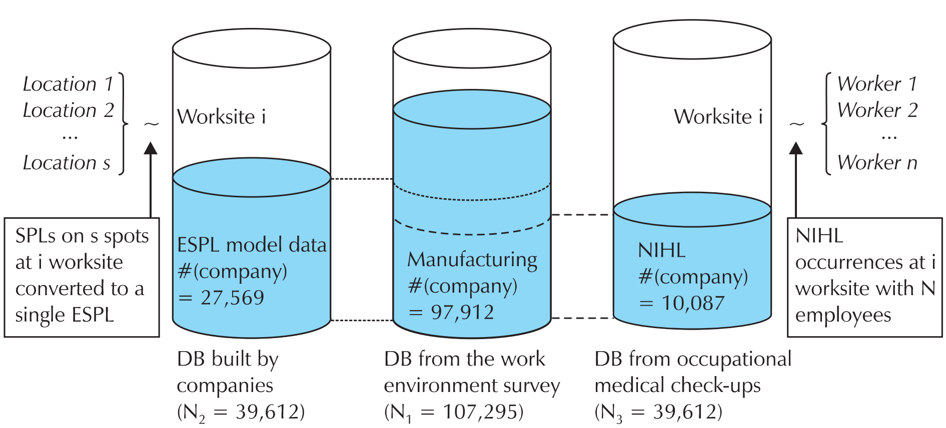

Fig. 1. Database relations. SPL: sound pressure level, ESPL: equivalent sound pressure level, NIHL: noise-induced hearing loss, DB: data base.

medical check-ups did not match. To address this incompatibility, the units of the work environment database and the occupational medical check-up database were altered into a worksite unit to gain information on whether a worksite had one or more employees proven to have NIHL.

Noise levels are usually measured at various points in a workplace. The information on noise levels withineach worksite is converted to a sound pressure level (SPL).

The integrated database covered work environments, occupational medical check-ups, and SPL. The number of worksites with all of three kinds of information reached 10,087, while those with the first two kinds were 10,087. Those with the data on work environments and SPL posted 27,569 (Fig. 1).

Risk factor analysis

This study analyzed SPL in workplaces and the diagnoses made by the occupational medical tests to understand which machines and equipment out of the 19 types caused NIHL. In this analysis, j meant the types of machines and equipment with x_j and w_i referring to the number of the installed machines and equipment and the SPL, respectively. As seen in Equation 1, w_i was estimated by calculating the equivalent sound pressure level (ESPL) through measured values on s spots Lp_s.

$$w_i = 10 \log [(10^{Lp_1} + 10^{Lp_2} + \cdots + 10^{Lp_s})/ s] \quad (1)$$

The objective variable, z_i was created to compare the worksites ($z_i = 1$) with the w_i over 90 dB and those ($z_i = 0$) with w_i below 90 dB. If a noise level exceeded 90 dB, it was considered harmful. It was found that around 13.46% of the surveyed worksites surpassed the 90 dB level.

The target variable was also formed for worksites with employees diagnosed with NIHL ($d_i = 1$) and worksites without NIHL patients ($d_i = 0$). When an employee was proven to have a hearing loss over 50 dB at 4,000 Hz through a speech audiometry and a pure tone audiometry, he/she was diagnosed with NIHL.

A t-test based on Equation 2 was conducted to see whether there was a difference in the number of the 19 types of machines and equipment between the worksites with the ESPL of 90 dB or above and those of under 90 dB.

$$t = \frac{\overline{X}_0 - \overline{X}_1}{\sqrt{\frac{s_0^2}{n_0} + \frac{s_1^2}{n_1}}} \quad (2)$$

The measurement of the ESPL was the result of noises from a multiple number of units since each worksite usually had various types of machines and equipment. In order to examine worksites using only j type of machines or equipment (j), a Kruskal-Wallis Test (Equation 3) was delivered to see if there was any difference between the group over 90 dB and that below 90 dB [18]. However, since most of the manufacturing sites in Korea had several types of machines and equipment, the data did not follow the normal distribution with an extreme value zone in which worksites with far more types of machines and equipment than the average existed.

$$T_j = \frac{1}{s_j^2}\left[\sum_{g=1}^{2} \frac{R_{jg}^2}{n_{jg}} - \frac{N_j(N_j+1)^2}{4}\right] \quad (3)$$

In Equation 3, n_{jg} referred to the number of worksites with the j type of machines and equipment in group g (g is defined by the ESPL), while R_{jg}^2 meant the ranks of the samples in terms of the number of machines and equipment. During the process, another Equation, $s_j^2 = \frac{1}{N_j - 1}\left[\sum_{g=1}^{2}\sum_{h=1}^{n_{ji}} R_{jgh}^2 - \frac{N_j(N_j+1)^2}{4}\right]$, was set. A t-test covering all data aimed to see the gap between the two groups in terms of the number of installed machines and equipment. In the meantime, a Kruskal-Wallis statistic was used to sort out the effects of the j type from other machines and equipment in worksites with multiple types. Equations 2 and 3 were also utilized to examine the difference between the worksites with NIHL patients and those free from the disorder.

ESPL and NIHL statistical models

The decision model in this paper presented the risk levels by calculating the effect of the number of installed j-type machines and equipment (x_j) on SPL (w_i) and NIHL occurrence (z_i). Since the response variable in this study-NIHL occurrence-was a binary type, a logistic regression was applied. As a result, Equation 5 was set with z_i referring to NIHL occurrence (1: occurrence, 0: non-occurrence) and T^*_{itg} to the number of installed machines and equipment [19,20]. This model was completed by estimating the parameter coefficient, β_i.

$$\log\frac{p(y=1 \mid x_1, x_2, \cdots, x_p)}{1 - p(y=1 \mid x_1, x_2, \cdots, x_p)} = \alpha + \beta_1 x_2 + \beta_2 x_2 + \cdots + \beta_p x_p \quad (4)$$

Since logistic regression is linear and parametric, its predictability about new data maintains a certain level. Meanwhile, a number of researchers have investigated the methods of data mining for non-linear and non-parametric models including a neural network, a decision tree, and a support vector machine [21-24]. Although these models have high predictability, they tend to be over-fit to the training sets which are used for model estimation. To gain an optimal one with proven excellence, various models should be compared. In this study, the optimal model for the decision-making system regarding NIHL occurrence was assumed by comparing the above mentioned models.

Model validation

There were two standards for model validation: 1) how effective the model was with as low a number of independent variables as possible, and 2) how reliable the results were when the model was applied to new data. In other words, generalization played a key role. If a model did not have a generalization capability, it was not effective at all, however high its predictability was. In most cases, the available data were categorized into the training set for model assumption and the validation set. In this study, 70% of the data was assigned for training with the other 30% for validating. To establish excellence of the model, an accuracy value, a sensitivity value, and a specificity value were considered. In particular, the sensitivity value was increased to enhance the predictability regarding the worksites with NIHL cases and high-level noises.

Noise-generating machines and risk rating

A credit rating estimates the credit worthiness of customers of financial institutions based on their credit history. Through this rating process, the customers are graded from poor to excellent. Likewise, this study presented a risk rating process to scale worksites from poor to excellent in terms of risk factors which cause NIHL. Equation 5 shows the posterior probability for each subject through the parameter coefficient assumed in the logistic model [25-27].

$$p(y=1|x_1,x_2,\cdots,x_p)=\frac{\exp(\alpha+\beta_1x_2+\beta_2x_2+\cdots+\beta_px_p)}{1+\exp(\alpha+\beta_1x_2+\beta_2x_2+\cdots+\beta_px_p)} \quad (5)$$

The posterior probability gained from the above Equation was used to categorize each subject. In addition, the parameter coefficient helped to calculate posterior probability for each observed value when a worksite had a NIHL case [y = 1]. This posterior probability in turn came up with the NIHL risk ratings, which could be harnessed as prevention indicators.

Results

Distribution of noise-generating machines and equipment in Korean manufacturing sites

The survey on work environments showed that air compressors took the largest proportion among noise-generating machines and equipment used by Korean manufacturers. It was found that 87% of manufacturing sites with five employees or above, 70% of those with under five, and 7% of non-manufacturing worksites had one or more air compressors, indicating that the majority of manufacturers are using the machine. Although an air compressor generates high-level noises over 100.3 dB, the use of an exhaust shroud can reduce the noise level to 89.3 dB. Among the 2,420,330 subjects of the survey, 239,479 employees, around 10%, were found to be exposed to the noise from air compressors.

Grinding machines, which create over 86.6 dB noise, were second among the noise-generating machines and equipment used by worksites. The survey indicated that 32,030 (37%) manufacturing sites with five employees or more out of 86,415 had one or more grinding machines, while manufacturers with below five employees and non-manufacturers posted 27% and 3%, respectively.

Although less than 1% of the surveyed worksites used pipe mills/rolling mills/wire drawing machines, among the worksites with five or more employees which have such machines and equipment, the average number of units was as high as 12 (Table 3).

Risk analysis on the number of installed noise-generating machines and equipment

This study compared worksites with the over 90 dB ESPL to those with below 90 dB in terms of the number of the 19 types of noise-generating machines and equipment installed. The analysis was based on the data from 27,569 worksites out of the 97,912 manufacturers surveyed. The worksites, which had multiple machines and equipment, and recorded over 90 dB ESPL, had an average of 1.42 unit of a press or cutter with those of the below 90 dB ESPL posting 3.48 units. According to a t-test, between these two surveyed groups, there was a less than 5% significant level in terms of the number of held presses and cutters. Since most worksites have multiple types of machines and equipment, a mere 78 worksites were found to have only presses and cutters. Among the 78 sites, those with below 90 dB ESPL had an average of 4.28 units while those with above 90 dB had 8.45 units. The Kruskal-Wallis test showed that the two groups had a less than 5% significant level. Among the worksites with only twisting/spinning/weaving machines, those of below 90 dB ESPL had an average of 14.29 units, while those over 90 dB had 51.86 on average. These figures suggested that the number of machines and equipment installed affected the ESPL, and consequently the work environments (Table 4).

Against this backdrop, to identify the relationship between the number of machinery and equipment and workers' health, this study compared the worksites with NIHL cases with the

Table 3. Number of installed noise-generating machines & equipment and exposed workers

Machines & equipment	Manufacturing worksites with over 5 employees			Manufacturing worksites with below 5 employees			Non-manufacturing worksites		
	Worksites with the units	No. of the units	Exposed workers	Worksites with the units	No. of the units	Exposed workers	Worksites with the units	No. of units	Exposed workers
Press & cutter	17,594	87,909	69,179	1,544	4,563	2,742	35	78	87
Air compressor	74,517	143,853	239,475	8,015	9,795	13,138	621	1,015	1,552
Steam washer & hydraulic power washer	3,948	7,041	11,239	268	357	419	102	174	574
Graining/grinding machines	32,030	108,622	94,551	3,097	6,468	4,938	292	394	680
Sandblasting (shotblasting) equipment	3,333	6,314	8,849	140	214	275	1	1	1
Circular saw	14,391	27,063	28,661	1,479	2,309	2,246	120	200	236
Electrically powered hammer	351	680	1,006	30	43	63	0	0	0
Rotary press (printers)	2,165	5,299	11,659	208	345	374	0	0	0
Twisting/spinning/weaving machines	1,797	62,804	19,705	170	2,593	581	0	0	0
Crushers	7,363	22,345	19,184	478	1,008	753	63	103	182
Pipe mill/rolling mill/wire drawing machine	1,214	14,774	7,122	47	129	88	0	0	0
Drill	29,005	61,318	58,449	3,098	5,672	4,480	94	139	266
(High-speed) Centrifuge	1,198	2,867	3,105	58	88	78	7	8	87
High-speed mixer	3,030	9,649	8,784	142	222	199	9	15	13
Rock drill	133	210	323	6	6	7	0	0	0
Chainsaw	1,617	2,240	3,405	136	169	176	154	813	851
Engine cutter	2,644	3,999	4,422	360	452	474	0	0	0
Impact wrench	12,367	57,361	53,563	1,149	3,190	2,143	81	192	290
Vibration Sorter/carrier/compressor	2,003	8,081	8,922	65	162	117	1	13	3

No: number.

others in terms of the number of the noise-generating equipment and machines. The survey on work environments showed that 10,087 worksites out of 97,912 manufacturers had their employees undergo medical tests, and that 1,051 workplaces had NIHL cases.When comparing the worksites with NIHL cases to the rest, air compressors, sandblasting (shotblasting) equipment, rotary presses (printers), and chainsaws demonstrated a significant difference. When analyzing worksites by the types of machinery and equipment, only an air compressor was proven to have an impact. As a matter of fact, this analysis had some limitations due to the lack of the data.

It seems that although noise-generating machinery and equipment had a significant impact on the noise levels at the worksites, there was no direct relationship with NIHL occurrence since the workers usually wore protective gear. However, since air compressors are used in a number of worksites, there must have been some workers not bothering to wear protective equipment, causing a direct impact on NIHL occurrence. Therefore, for risk ratings, individual models should be devised since ESPL did not directly affect NIHL occurrence (Table 5).

Table 4. Comparison test regarding the number of installed noise-generating machines & equipment in each equivalent sound pressure level category

Machines & equipment	Worksites with multiple types of machinery and equipment				Worksites with limited types of machinery and equipment					
	Less 90 dB (mean ± SD)	More 90 dB (mean ± SD)	t value	p-value	n	Less 90 dB (mean ± SD)	n	More 90 dB (mean ± SD)	K-Stat	p-value
Press & cutter	1.42 ± 4.77	3.48 ± 8.05	-15.16	<.0001	67	4.28 ± 6.73	11	8.45 ± 5.68	12.17	0.0005
Air compressor	2.18 ± 2.78	2.38 ± 2.63	-4.33	<.0001	3,261	2.19 ± 1.82	221	2.57 ± 2.82	4.02	0.0081
Steam washer & hydraulic power washer	0.11 ± 0.73	0.12 ± 1.34	-0.39	0.695	18	1.94 ± 1.30	1	3.00 ±.	0.98	0.3214
Graining/grinding machines	2.48 ± 131.12	2.26 ± 17.38	0.25	0.8061	50	7.68 ± 26.03	14	9.07 ± 12.85	2.88	0.0897
Sandblasting (shotblasting) equipment	0.11 ± 0.94	0.24 ± 0.98	-7.54	<.0001	7	1.86 ± 1.21	0	-	-	-
Circular saw	0.38 ± 1.74	0.67 ± 2.94	-6.02	<.0001	16	2.25 ± 1.53	5	6.40 ± 6.02	2.52	0.1125
Electrically powered hammer	0.01 ± 0.18	0.04 ± 0.76	-2.41	0.016	0	-	0	-	-	-
Rotary press (printers)	0.09 ± 0.66	0.06 ± 0.63	3.05	0.0023	66	2.59 ± 3.34	1	3.00 ±.	0.91	0.3414
Twisting/spinning/weaving machines	0.44 ± 19.70	7.87 ± 54.78	-8.18	<.0001	24	14.29 ± 13.06	88	51.86 ± 35.07	33.14	<.0001
Crusher	0.40 ± 2.19	0.20 ± 1.21	7.97	<.0001	49	3.00 ± 3.74	5	4.20 ± 2.86	3	0.0834
Pipe mill/rolling mill/wire drawing machine	0.23 ± 4.05	0.38 ± 4.19	-2.14	0.0328	6	13.17 ± 13.09	0	-	-	-
Drill	1.06 ±24.68	0.78 ± 1.66	1.77	0.0768	34	2.32 ± 2.47	1	5.00 ±.	2.05	0.1522
(High-speed) centrifuge	0.06 ± 0.68	0.07 ± 0.70	-0.11	0.9092	7	2.14 ± 0.69	0	-	-	-
High-speed mixer	0.16 ± 1.55	0.06 ± 0.53	8.1	<.0001	14	3.14 ± 2.11	1	1.00 ±.	1.4	0.236
Rock drill	0.00 ± 0.12	0.01 ± 0.22	-2.29	0.0219	0	-	1	5.00 ±.	-	-
Chain saw	0.03 ± 0.26	0.09 ± 0.42	-8.01	<.0001	0	-	0	-	-	-
Engine cutter	0.05 ± 0.36	0.08 ± 0.82	-2.42	0.0156	3	1.67 ± 1.15	0	-	-	-
Impact wrench	1.22 ± 21.48	0.79 ± 16.79	1.39	0.1639	19	6.58 ± 8.45	2	2.00 ± 0.00	0.25	0.6164
Vibration sorter/carrier/ compressor	0.17 ± 2.47	0.35 ± 11.59	-0.95	0.3426	10	2.10 ± 1.52	0	-	-	-

SD: standard deviation, K-stat: Kruskal-Wallis Statistic.

Statistical model for machinery and equipment

Discriminant model for ESPL

This study came up with a model aimed to identify the impacts caused by the machinery and equipment used in worksites on the noise levels, using logistic regression-a linear parametric model, and neural network-a non-linear and non-parametric model. The dependent variable of the model in this study took the binary form between the over 90 dB ESPL and the below 90 dB ESPL, while the independent variable referred to the number of the 19 types of machinery and equipment held by the worksites (χ^2 = 1372.79, d.f. = 19, p-value = 0.0001).

As shown in Table 6, presses, cutters, graining/grinding machines, sandblasting (shot blasting) equipment, electrically powered hammer, twisting/spinning/weaving machines, drills, high-speed mixers, rock drills, chain saws, engine cutters, and impact wrenches were significant factors.

The logistic regression model's data, which was divided according to a validation set, recorded a maximum 87.19% in accuracy. However, when the accuracy was the highest, the sensitivity, which was the probability to accurately predict groups with the over 90 dB ESPL, was 9.7%, while the specificity, which represented prediction for groups with below 90

Table 5. Comparison test regarding the number of installed noise-generating machines & equipment in each noise-induced hearing loss (NIHL) category

Machines & equipment	Worksites with multiple types of machinery and equipment				Worksites with limited types of machinery and equipment					
	NIHL (mean ± SD)	Control (mean ± SD)	t value	p-value	n	NIHL (mean ± SD)	n	Control (mean ± SD)	t value	p-value
Press & cutter	2.58 ± 6.96	3.15 ± 7.38	-2.38	0.0174	20	7.65 ± 8.95	2	1.00 ± 0.00	3.04	0.0813
Air compressor	2.74 ± 3.48	3.53 ± 6.08	-4.16	<.0001	753	2.81 ± 2.65	70	2.20 ± 1.62	4.42	0.0356
Steam washer & hydraulic power washer	0.16 ± 0.99	0.30 ± 2.58	-1.69	0.0921	5	3.40 ± 1.14	2	3.00 ± 1.41	0.16	0.6906
Graining/grinding machine	2.18 ± 12.47	24.65 ± 624.15	-1.17	0.2436	29	11.52 ± 33.81	5	8.00 ± 6.16	1.89	0.1692
Sandblasting (shotblasting) equipment	0.18 ± 0.81	0.48 ± 3.69	-2.64	0.0083	4	2.25 ± 1.50				
Circular saw	0.54 ± 2.66	0.76 ± 2.70	-2.47	0.0136	11	3.64 ± 4.59				
Electrically powered hammer	0.02 ± 0.52	0.04 ± 0.31	-1.79	0.0737						
Rotary press (printer)	0.12 ± 0.84	0.05 ± 0.59	3.74	0.0002	17	3.94 ± 5.72				
Twisting/spinning/weaving machines	3.19 ± 43.53	1.90 ± 18.95	1.73	0.0835	66	53.17 ± 34.73	8	59.38 ± 57.92	0.1	0.7539
Crusher	0.40 ± 2.00	0.42 ± 2.92	-0.22	0.8255	11	3.18 ± 4.07	1	9.00 ±.		
Pipe mill/rolling mill/wire drawing machine	0.40 ± 5.78	0.91 ± 8.11	-1.96	0.0506						
Drill	1.06 ± 2.53	5.01 ± 117.20	-1.09	0.2745	10	2.90 ± 3.21	2	3.00 ± 2.83	1.83	0.1757
(High-speed) centrifuge	0.10 ± 0.91	0.09 ± 0.62	0.39	0.6952	5	2.20 ± 0.84	1	2.00 ±.	0.13	0.7187
High-speed mixer	0.17 ± 1.81	0.20 ± 1.78	-0.49	0.6264	4	3.00 ± 2.16				
Rock drill	0.01 ± 0.18	0.02 ± 0.34	-0.95	0.3418						
Chain saw	0.05 ± 0.33	0.11 ± 0.49	-3.85	0.0001	1	5.00 ±.				
Engine cutter	0.07 ± 0.66	0.06 ± 0.37	0.33	0.7408	2	2.00 ± 1.41				
Impact wrench	1.25 ± 9.89	7.07 ± 100.31	-1.88	0.0605	4	4.25 ± 3.86	1	2.00 ±.	0.63	0.4292
Vibration sorter/carrier/ compressor	0.30 ± 3.41	1.13 ± 22.24	-1.2	0.2306	4	2.75 ± 2.36				

SD: standard deviation.

dB ESPL, was 99.3%. Although the sensitivity and specificity could be elevated to 100% at maximum, this model was not adequate. Therefore, when the cut-off value against posterior probability was set at 0.11, accuracy, sensitivity, and specificity were recorded 67.76%, 64.01%, and 68.34%, respectively. In the neural network model, accuracy, sensitivity, and specificity posted 74.02%, 58.79%, and 76.39% respectively with the cut-off value set at 0.11 (Fig. 2).

Discriminant model for NIHL cases

A discriminant model was built to identify the impact of the machinery and equipment on NIHL occurrence. The dependent variable was a diagnosis of NIHL in the binary form, while the independent variable referred to the number of the 19 types of machines and equipment in the workplaces. The likelihood ratio test showed that the model was significant (χ^2 = 104.22, d.f. = 19, p-value = 0.0001).

As shown in Table 7, air compressors, sandblasting (shotblasting) equipment, chain saws, and impact wrenches were significant factors. As mentioned above, since protective equipment has been widely used, the direct relationship between the workplace noise levels and the NIHL occurrence has not been

Table 6. Logistic regression results on the equivalent sound pressure level

Machines & equipment	Coefficient	Standard error	Wald T Statistic	p-value
Intercept	-2.11240	0.03120	4,592.49	<.0001
Press & cutter	0.06990	0.00380	338.6	<.0001
Air compressor	-0.00128	0.00807	0.03	0.874
Steam washer & hydraulic power washer	0.01740	0.02320	0.56	0.4547
Graining/grinding machine	0.00356	0.00157	5.14	0.0234
Sandblasting (shotblasting) equipment	0.24860	0.02770	80.74	<.0001
Circular saw	0.06540	0.01230	28.32	<.0001
Electrically powered hammer	0.33360	0.09200	13.14	0.0003
Rotary press (printer)	-0.06770	0.04340	2.44	0.1183
Twisting/spinning/weaving machines	0.06510	0.00330	389.05	<.0001
Crusher	-0.08430	0.02180	14.93	0.0001
Pipe mill/rolling mill/wire drawing machine	0.00760	0.00466	2.66	0.1029
Drill	-0.10300	0.01530	45.38	<.0001
(High-speed) centrifuge	0.01810	0.03260	0.31	0.5778
High-speed mixer	-0.19260	0.04730	16.6	<.0001
Rock drill	0.49780	0.15200	10.73	0.0011
Chain saw	0.60690	0.06580	85.08	<.0001
Engine cutter	0.13970	0.04470	9.74	0.0018
Impact wrench	-0.00581	0.00219	7.01	0.0081
Vibration sorter/carrier/compressor	0.00277	0.00418	0.44	0.5083

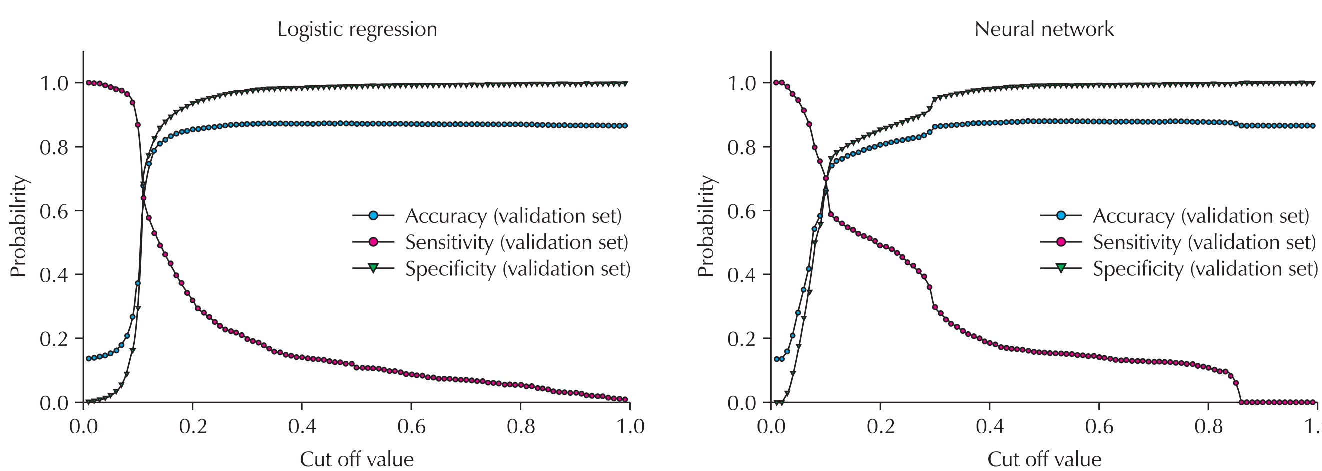

Fig. 2. Evaluation on the validation set of the equivalent sound pressure level models.

demonstrated. However, a number of workers using air compressors, sandblasting (shotblasting) equipment, chain saws, and impact wrenches still seem to be exposed directly to noises (Table 7).

The logistic regression model's data, which was divided according to a validation set, recorded a maximum 86.93% in accuracy. However, when the accuracy was the highest, the sensitivity, which was the probability to accurately predict groups

Table 7. Logistic regression results on the noise-induced hearing loss

Machines & equipment	Coefficient	Standard error	Wald T Statistic	p-value
Intercept	-2.33370	0.05210	2,007.02	<.0001
Press & cutter	0.00341	0.00535	0.41	0.5244
Air compressor	0.02890	0.00847	11.67	0.0006
Steam washer & hydraulic power washer	-0.00336	0.02370	0.02	0.8872
Graining/grinding machine	0.00194	0.00156	1.54	0.2143
Sandblasting (shotblasting) equipment	0.16960	0.03440	24.26	<.0001
Chain saw	0.01180	0.01650	0.51	0.4732
Electrically powered hammer	0.03110	0.05070	0.38	0.54
Rotary press (printer)	-0.13390	0.07100	3.56	0.0592
Twisting/spinning/weaving machines	-0.00512	0.00369	1.92	0.166
Crusher	0.00598	0.01640	0.13	0.7148
Pipe mill/rolling mill/wire drawing machine	0.00759	0.00562	1.83	0.1766
Drill	0.00923	0.01200	0.59	0.4408
(High-speed) centrifuge	-0.03640	0.05090	0.51	0.4755
High-speed mixer	-0.00174	0.01850	0.01	0.9253
Rock drill	0.05660	0.14860	0.15	0.7033
Chain saw	0.31240	0.09480	10.86	0.001
Engine cutter	-0.05360	0.08410	0.41	0.5237
Impact wrench	0.00735	0.00255	8.3	0.004
Vibration sorter/carrier/compressor	0.00211	0.00521	0.16	0.685

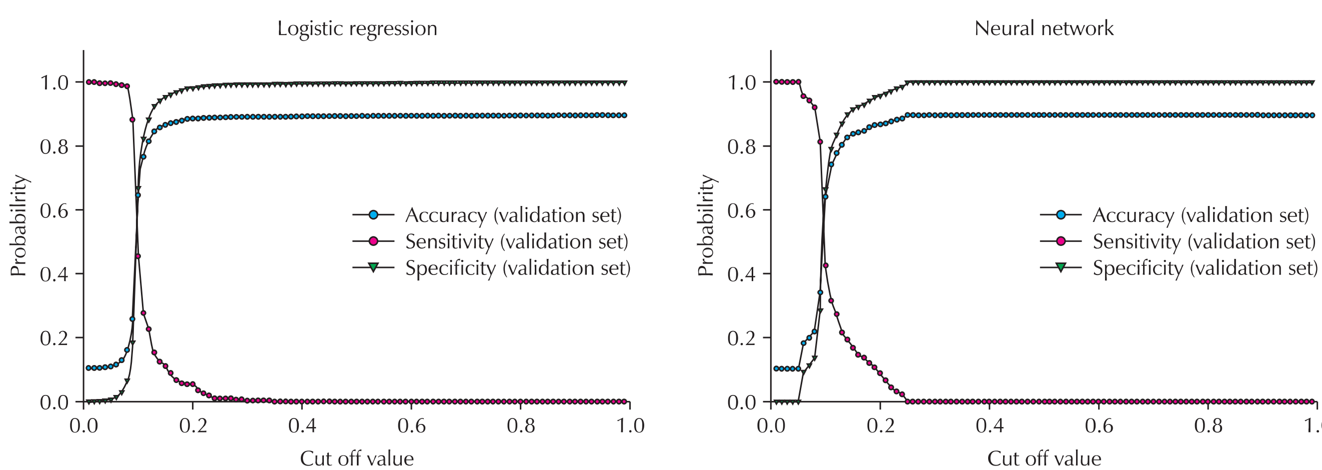

Fig. 3. Evaluation on the validation set of the noise-induced hearing loss models.

with NIHL cases, was 0%, while the specificity, which represented predictions for groups without NIHL cases, was 100%. Although the sensitivity and specificity could be escalated to 100% at maximum, this model was not adequate. Therefore, when the cut-off value against posterior probability was set at 0.10, accuracy, sensitivity, and specificity recorded 64.62%, 45.54%, and 66.83%, respectively. In the neural network model, accuracy, sensitivity, and specificity posted 64.03%, 42.68%, and

66.49% respectively with the cut-off value was set at 0.10 (Fig. 3).

It was rather difficult to come up with adequate models with high accuracy, but some of them showed the relationship between NIHL diagnoses and ESPL. It is assumed that more adequate models can be devised if other factors are considered including noise control equipment, NIHL patients' exposure to organic solvents and heavy metals, and their health conditions like smoking, blood pressures, diabetes, and hyperlipidemia.

Noise-generating machinery & equipment and risk rating

Noise-generating machinery and equipment were proven to have a large impact on the NIHL occurrences. To rate risk levels at the workplaces, two kinds of posterior probability were set-PP_1, which regarded ESPL, and PP_2, which referred to NIHL occurrences. Subsequently, the worksites were categorized into three grades in terms of ESPL and in terms of NIHL occurrences. In total, nine grades were created with PP_1 and PP_2 as shown in Table 8.

There were 11 worksites in the high-risk ESPL grade and also 11 in the high-risk NIHL grade. They held a large number of noise-generating machinery and equipment. According to the databases on the work environments and occupational medical check-ups, 28.57% of the worksites surveyed had employees who had been diagnosed with NIHL within a year. The workplaces over 90 dB ESPL recorded 45.45%. These workplaces need to build noise-control equipment to reduce risk and provide protective devices for workers. Meanwhile, 62 workplaces scored high in ESPL, but low in NIHL occurrences. These worksites have offered adequate protective devices to the employees, but the noise-control equipment and the arrangement of the noise-generating machinery have some issues. Therefore, guidelines should be delivered to these businesses to improve their noise-control capability. The worksites with the low ESPL grades and high grades in NIHL occurrence have adequate noise-control equipment, but have yet to provide protective devices to workers. These businesses should adjust work time to minimize worker noise exposure, or offer guidelines to prevent NIHL disorders.

Table 8. The equivalent sound pressure level (ESPL) and the noise-induced hearing loss (NIHL) grades

Grade ESPL	Grade NIHL	Worksites	Sensitivity ESPL (%)	Sensitivity NIHL cases (%)
High risk (top 1%)	High risk	11	45.45	28.57
	Moderate risk	11	27.27	10.00
	Low risk	62	80.65	8.33
Moderate risk (1-5%)	High risk	49	40.82	25.71
	Moderate risk	56	32.14	17.50
	Low risk	226	57.08	5.33
Low risk (5-100%)	High risk	27	7.41	28.57
	Moderate risk	255	15.69	15.54
	Low risk	7,575	11.11	9.27

Discussion

This study aimed to identify the impact of the 19 types of noise-generating machinery and equipment on ESPL and NIHL occurrences in workplaces based on a 2009 national survey on work environments. By doing so, risk ratings for worksites and prevention measures for each grade were presented. Among the 19 types of machinery and equipment, air compressors ranked first in the number installed as 74,517 worksites out of 107,295 held more than one, followed by graining/grinding machines. This study combined databases on occupational medical check-ups and work environments; however, since a number of workers in Korea have yet to receive medical services, some data were not matched. As a matter of fact, a new system for occupational medical check-ups announced in 2009 will deliver long-term surveys tracking exposure levels to high-risk materials.

Noise-generating machinery and equipment did not demonstrate a direct impact on NIHL occurrences. The NIHL disorders seemed to be related to other factors including exposure to organic solvents or heavy metals, smoking, hypertension, diabetes, and hyperlipidemia. Furthermore, each worksite showed differences according to the sound frequency of the machinery and equipment and their protective facilities. Nonetheless, it is still true that the noise-generating machinery and equipment is the biggest reason for NIHL occurrences. Against this background, this study built several models to understand the impact of these harmful machinery and equipment on ESPL and NIHL disorders. By calculating posterior probabilities for each model, risk rating was conducted for each worksite to identify room for improvement for each grade. It was found that 11 worksites were rated high in both ESPL and NIHL occurrences. Based on this, the KOSHA should deliver special management for these businesses by helping them build noise-control equipment, provide protective devices to workers, and run education programs. Although this study presented prevention indicators for NIHL disorders by harnessing various databases in a macroscopic way, it has some limitations in building sophisticated models from microscopic perspectives. To address these issues, it is recommended that other factors including workers' exposure to organic solvents or heavy metals, smoking, high blood pressure, diabetes, and hyperlipidemia be considered. Moreover, the arrangements of machinery and equipment in workplaces, noise-control facilities, frequencies of the machinery, and protective gear should also be researched for more accurate analysis. In this context, the author is planning to consider all of these factors in establishing a more reliable risk rating system.

Conflict of Interest

No potential conflict of interest relevant to this article was reported.

Acknowledgments

This study was supported by the intramural research fund of the Occupational Safety and Health Research Institute (OSHRI).

References

1. Dobie RA. Medical-Legal Evaluation of Hearing Loss. 2nd ed. San Diego (CA): Singular Publishing Group; 2001. 393 p.
2. Thorne PR, Gavin JB. Changing relationships between structure and function in the cochlea during recovery from intense sound exposure. Ann Otol Rhinol Laryngol 1985;94:81-6.
3. Zenz C, Dickerson OB, Horvath EP. Occupational Medicine. 3rd ed. St. Louis (MO): Mosby; 1994.
4. Hodgkinson L, Prasher D. Effects of industrial solvents on hearing and balance: a review. Noise Health 2006;8:114-33.
5. Gobba F. Sensory perception: an overlooked target of occupational exposure to metals. Bioinorg Chem Appl 2003:199-214.
6. Cruickshanks KJ, Klein R, Klein BE, Wiley TL, Nondahl DM, Tweed TS. Cigarette smoking and hearing loss: the epidemiology of hearing loss study. JAMA 1998;279:1715-9.
7. de Moraes Marchiori LL, de Almeida Rego Filho E, Matsuo T. Hypertension as a factor associated with hearing loss. Braz J Otorhinolaryngol 2006;72:533-40.
8. Starck J, Pyykkö I, Toppila E, Nieminen O, Pekkarinen J. Factors explaining individual variability in hearing level: Exposure to noise, hearing protection, blood pressure and cholesterol. Sixth US-Finnish Joint Symposium on Occupational Health and Safety, People and Work, Research Report 3. Proceedings of the Sixth FIOH-NIOSH Joint Symposium on Occupational Health and Safety; 1995 Aug 8-10; Espoo, Finland. Helsinki (Finland): Finninsh Institute of Occupational Health; 1995. 199 p.
9. Lalwani AK, Liu YH, Weitzman M. Secondhand smoke and sensorineural hearing loss in adolescents. Arch Otolaryngol Head Neck Surg 2011;137:655-62.
10. Bainbridge KE, Hoffman HJ, Cowie CC. Diabetes and hearing impairment in the United States: audiometric evidence from the National Health and Nutrition Examination Survey, 1999 to 2004. Ann Intern Med 2008;149:1-10.
11. Evans MB, Tonini R, Shope CD, Oghalai JS, Jerger JF, Insull W Jr, Brownell WE. Dyslipidemia and auditory function. Otol Neurotol 2006;27:609-14.
12. Ministry of Employment and Labor (KR). The 2009 Survey on Injuries and Illnesses. Gwacheon (Korea): Ministry of Employment and Labor (KR); 2009. 1151 p. Korean.
13. Sensogut C. Occupational noise in mines and its control-A case study. Polish J Environ Stud 2007;16:939-42.
14. Sistkova M, Peterka A. The exposure of working environment noise in the agricultural service workplace. Res Agr Eng 2009;55:69-75.
15. Nathak S, Puranik A, Schut J, Rao MD. Study on noise transmission from an air compressor. Proceedings of Noise-Con 2005; 2005 Oct 17-19; Minneapolis, MN. Washington, DC: Institute of Noise Control Engineering; 2005.
16. Nelson DI, Nelson RY, Concha-Barrientos M, Fingerhut M. The global burden of occupational noise-induced hearing loss. Am J Ind Med 2005;48:446-58.
17. Kinsella K, He W; US Census Bureau. An Aging World; 2008. International Population Reports P95/09-1. Washigton, DC: US Government Printing Office; 2009. 191 p.
18. Rosner B. Fundamentals of Biostatistics. 4th ed. Belmont (CA): Duxbury Press; 1995. 681 p.
19. Alan A. Categorical Data Analysis. 2nd ed. New York (NY): Wiley-Interscience; 2002.
20. Hosmer, David W, Lemeshow S. Applied Logistic Regression. 2nd ed. New York (NY): Wiley; 2000. 373 p.
21. Cheng B, Titterington D. Neural networks: a review from a statistical perspective. Statist Sci 1994;9:2-54.
22. Smith M. Neural Nnetworks for Statistical Modeling. Boston (MA): International Thomson Computer Press; 1996. 235 p.
23. Bigg D, De Ville B, Suen E. A method of choosing multiway pathway partitions for classification and decision trees. J Appl Statist 1991;18:49-62.
24. Cristianini N, Shawe-Taylor J. An Introduction to Support Vector Machines and Other Kernel-based Learning Methods. Cambridge (UK): Cambridge University Press; 2000. 189 p.
25. Hu MY, Shanker M, Hung MS. Estimation of posterior probabilities of consumer situational choices with neural network classifiers. Int J Res Mark 1999;16:307-17.
26. Ambergen AW, Schaafsma W. Interval estimates for posterior probabilities in a multivariate normal classification model. J Multivariate Anal 1985;16:432-9.
27. Chow GC. A comparison of the information and posterior probability criteria for model selection. J Econometrics 1981;16:21-33.