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, Korea 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
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 doubling all 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, 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-

| 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**             | 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) |
| **Machines & equipment generating noise and vibration** | No. of male & female workers exposed to 19 types of machines & equipment generating dust or fume, daily work time |
| **Jobs generating dust and fume** | No. of currently used welding & cutting equipment among 17 types |
| **Welding & cutting**            | Existence of gilding jobs, no. of exposed workers, daily work time |
| **Gilding**                      | No. of workers exposed to 7 types of jobs handling heat, daily work time |
| **High-temperature,**            | No. of workers exposed to 2 types of jobs in cold environments, daily work time |
| **low-temperature,**             | No. of workers exposed to 3 types of radioactive environments, daily work time |
| **or radioactive environments**  |                                                                   |
| **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 xj and wi referring to the number of the installed machines and equipment and the SPL, respectively. As seen in Equation 1, wi was estimated by calculating the equivalent sound pressure level (ESPL) through measured values on s spots Lps.

\[
w_i = 10 \log \left[ (10^{s_1} + 10^{s_2} + \cdots + 10^{s_n})/ s \right] \tag{1}
\]

The objective variable, z, was created to compare the worksites (zi = 1) with the wi over 90 dB and those (zi = 0) with wi 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 (di = 1) and worksites without NIHL patients (di = 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.

\[
t = \frac{X_2 - X_1}{\sqrt{\frac{s_2^2}{n_2} + \frac{s_1^2}{n_1}}} \tag{2}
\]

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.

\[
T_j = 1 \sum \frac{R_{i,j}^g}{n_i} \cdot \frac{N_i(N_i + 1)^2}{4} \tag{3}
\]

In Equation 3, njg referred to the number of worksites with the j type of machines and equipment in group g (g is defined by the ESPL), while Rj2g meant the ranks of the samples in terms of the number of machines and equipment. During the process, another Equation, \( s_j^2 = \frac{1}{N_j} \sum \left[ X_j - \frac{N(N + 1)}{4} \right]^2 \) 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 (xj) on SPL (wi) and NIHL occurrence (zi). 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 zi referring to NIHL occurrence (1: occurrence, 0: non-occurrence) and TJgj to the number of installed machines and equipment [19,20]. This model was completed by estimating the parameter coefficient, \( \beta_j \).

\[
\log \left( \frac{p(zi = 1|x_1, x_2, \cdots, x_p)}{1 - p(zi = 1|x_1, x_2, \cdots, x_p)} \right) = \alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p \tag{4}
\]

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 ex-
cellence, 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].

\[
p(y = 1|x_1, x_2, \ldots, x_p) = \frac{\exp(\alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p)}{1 + \exp(\alpha + \beta_1 x_1 + \beta_2 x_2 + \cdots + \beta_p x_p)}
\] (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 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
other 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 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 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 the 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.
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 ($\chi^2 = 1372.79$, 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 dB ESPL, was 9.7%.

### 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) | 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 ± .            | 1.4    | 0.236   |
| 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.
The Risk Rating System for NIHL
Saf Health Work 2011;2:336-47

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 ($\chi^2 = 104.22$, 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 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) | Control (mean ± SD) | t value | p-value | n |
| Press & cutter       | 2.58 ± 6.96     | 3.15 ± 7.38        | -2.38   | 0.0174  | 20  | 7.65 ± 8.95     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Air compressor       | 2.74 ± 3.48     | 3.53 ± 6.08        | -4.16   | <.0001  | 753 | 2.81 ± 2.65     | 2.20 ± 1.62        | 4.42    | 0.0356  | 4 |
| Steam washer & hydraulic power washer | 0.16 ± 0.99 | 0.30 ± 2.58        | -1.69   | 0.0921  | 5   | 3.40 ± 1.14     | 3.00 ± 1.41        | 0.16    | 0.6906  | 4 |
| Graining/grinding machine | 2.18 ± 12.47 | 24.65 ± 624.15     | -1.17   | 0.2436  | 29  | 11.52 ± 33.81   | 8.00 ± 6.16        | 1.89    | 0.1692  | 5 |
| Sandblasting (shotblasting) equipment | 0.18 ± 0.81 | 0.48 ± 3.69        | -2.64   | 0.0083  | 4   | 2.25 ± 1.50     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Circular saw         | 0.54 ± 2.66     | 0.76 ± 2.70        | -2.47   | 0.0136  | 11  | 3.64 ± 4.59     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Electrically powered hammer | 0.02 ± 0.52 | 0.04 ± 0.31        | -1.79   | 0.0737  | 17  | 3.94 ± 5.72     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Rotary press (printer) | 0.12 ± 0.84 | 0.05 ± 0.59        | 3.74    | 0.0002  | 17  | 3.94 ± 5.72     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Twisting/spinning/weaving machines | 3.19 ± 43.53 | 1.90 ± 18.95        | 1.73 | 0.0835  | 66  | 53.17 ± 34.73   | 59.38 ± 57.92      | 0.1    | 0.7539  | 8 |
| Crusher              | 0.40 ± 2.00     | 0.42 ± 2.92        | -0.22   | 0.8255  | 11  | 3.18 ± 4.07     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Pipe mill/rolling mill/wire drawing machine | 0.40 ± 5.78 | 0.91 ± 8.11        | -1.96   | 0.0506  | 11  | 3.18 ± 4.07     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Drill                | 1.06 ± 2.53     | 5.01 ± 117.20      | -1.09   | 0.2745  | 10  | 2.90 ± 3.21     | 2.00 ± 2.83        | 1.83    | 0.1757  | 10 |
| (High-speed) centrifuge | 0.10 ± 0.91 | 0.09 ± 0.62        | 0.39    | 0.6952  | 5   | 2.20 ± 0.84     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| High-speed mixer     | 0.17 ± 1.81     | 0.20 ± 1.78        | -0.49   | 0.6264  | 4   | 3.00 ± 2.16     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Rock drill           | 0.01 ± 0.18     | 0.02 ± 0.34        | -0.95   | 0.3418  | 2   | 2.00 ± 1.41     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Chain saw            | 0.05 ± 0.33     | 0.11 ± 0.49        | -3.85   | 0.0001  | 1   | 5.00 ± 5.00     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Engine cutter        | 0.07 ± 0.66     | 0.06 ± 0.37        | 0.33    | 0.7408  | 2   | 2.00 ± 1.41     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |
| Impact wrench        | 1.25 ± 9.89     | 7.07 ± 100.31      | -1.88   | 0.0605  | 4   | 4.25 ± 3.86     | 2.00 ± 2.00        | 0.63    | 0.4292  | 4 |
| Vibration sorter/carrier/compressor | 0.30 ± 3.41 | 1.13 ± 22.24       | -1.2    | 0.2306  | 4   | 2.75 ± 2.36     | 1.00 ± 0.00        | 3.04    | 0.0813  | 4 |

SD: standard deviation.
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
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-PP₁, which regarded ESPL, and PP₂, 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 PP₁ and PP₂ 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.

**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

**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    | 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                       |
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