Original Article

Changes of Occupational Noise-Induced Hearing Loss due to Working in the Steel Industry and Associated Effective Factors: Application of Bayesian Multivariate Multilevel Modeling using Skew Distribution

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Abstract

Background: There have been a limited number of studies on the relationships between time and occupational and demographical variables with the mean changes of low-frequency hearing (LFH) and high-frequency hearing (HFH).
Objectives: This study investigated the rate of occupational noise-induced hearing loss (NIHL) due to working in the steel industry and associated effective factors.
Methods: This historical cohort study was conducted within 2000 to 2010. Two LFH and HFH definitions of NIHL were used in this study. The average changes of LFH and HFL were considered the response variables. In addition, time and occupational (i.e., shift work and work experience) and demographic (i.e., age and educational level) variables were regarded as the independent variables. For data analysis, Bayesian multivariate multilevel modeling using skew distribution and OpenBUGS (version 3.2.2) and R (version 2.13.2) software were used in this study.
Results: The present study was performed on 1,959 male workers with a mean age of 36.64±3.92 years. Among these subjects, 913 (46.6%), 134 (6.8%), and 912 (46.6%) participants were day workers, weekly-rotating shift workers, and routinely-rotating shift workers, respectively. The obtained results showed that age, work experience, educational level, and shift work had significant relationships with the changes of LFH and HFH.
Conclusion: Overall, the findings of this 10-year historical cohort study demonstrated a relationship between time and demographic and occupational variables with the changes of LFH and HFL. Therefore, it is recommended to design preventive measures to reduce the deleterious effects of such variables on LFH and HFL.

Keywords: Hearing problem, Iran, Occupational, Multilevel modeling, Steel worker

1. Background

Noise-induced hearing loss (NIHL) remains one of the most prevalent occupational disorders, arising across a wide variety of industries (1). This problem is a well-known health problem related to otolaryngology (2). The major cause of NIHL is noise pollution in the workplace (3-5). Noise exposure (6, 7) may have adverse effects on the functioning of different parts of the body, such as heart (8) and blood circulatory system (9), and individuals' performance (10). The risk of occupational NIHL varies from one workplace to another. Steelmaking is one of the high-risk occupations in the area of hearing problems (11, 12). The NIHL can be avoided by means of a control hierarchy prioritizing the use of engineering controls over administrative controls and personal protective equipment (13).

Since hearing loss is completely preventable (14) and due to uninterrupted occupational noise exposure, it is necessary to determine the long-term effects of uninterrupted hearing noise exposure. The two most common types of hearing loss are known as low-frequency hearing (LFH) and high-frequency hearing (HFH). The diagnosis of LFH and HFH is established after a hearing test. If an individual has LFH, the audiogram will show a slope to the right indicating trouble hearing frequencies within 1 to 2 kHz; however, for HFH the range is within 2 to 8 kHz.

The cut-off point for the determination of NIHL is different in several studies; therefore, LFH and HFH in this study were considered the continuous variables. On the other hand, because LFH and HFH are correlated with each other, multivariate analyses (15) are suitable candidates for such data. In addition, data collection for a cohort study tends to longitudinal data, and the best choice for longitudinal data is multilevel analysis (16). Another problem in the analysis of this field is data asymmetry. One of the best techniques for the analysis of asymmetric data is the use of skew distribution (17).

2. Objectives

Actually, in this study, three statistical methods (i.e., multivariate analysis, multilevel analysis, and skew distribution) were combined and used for analyzing the rate of occupational NIHL due to working in the steel industry and associated effective factors.

3. Methods

This historical cohort study was carried out on 1,959 employees in Isfahan, Iran, who were subjected to audiometric tests within 2000 to 2010. The inclusion criteria were male gender, official employment, $25 \leq$ age ≤ 50 years, $3 \leq$ work experience ≤ 25 years, and no hearing problem at the first examination. In addition, the exclusion criteria were retirement, death, or withdrawal from the study without any missing value in medical records (Figure 1). Those participants who had noise safety evaluation during the study period and met the inclusion criteria also joined the present study. In the current study, an ALPS diagnostic audiometer (Model AD 229e, Interacoustics, Denmark) was used by a trained audiologist to calculate hearing thresholds at different frequencies of air conduction (AC).

The test was conducted in an enclosed acoustic room following the requirements of the American National Standards Institute S3.1-1991, away from the workplace with at least 16 h of interval from the last exposure. In this study, pure-tone hearing thresholds for AC is measured in both ears at 1, 1.5, 2, 4, 6, and 8 kHz. In addition, two separate NIHL definitions were established as the average binaural pure-tone average. In this study, HFH and LFH were defined as 4 kHz + 6 kHz + 8 kHz/3 and 1 kHz + 1.5 kHz + 2 kHz/3, respectively. The changes of HFH and LFH from the baseline were considered the response variables. In addition, age, work experience, educational level, and shift work were regarded as the independent variables.
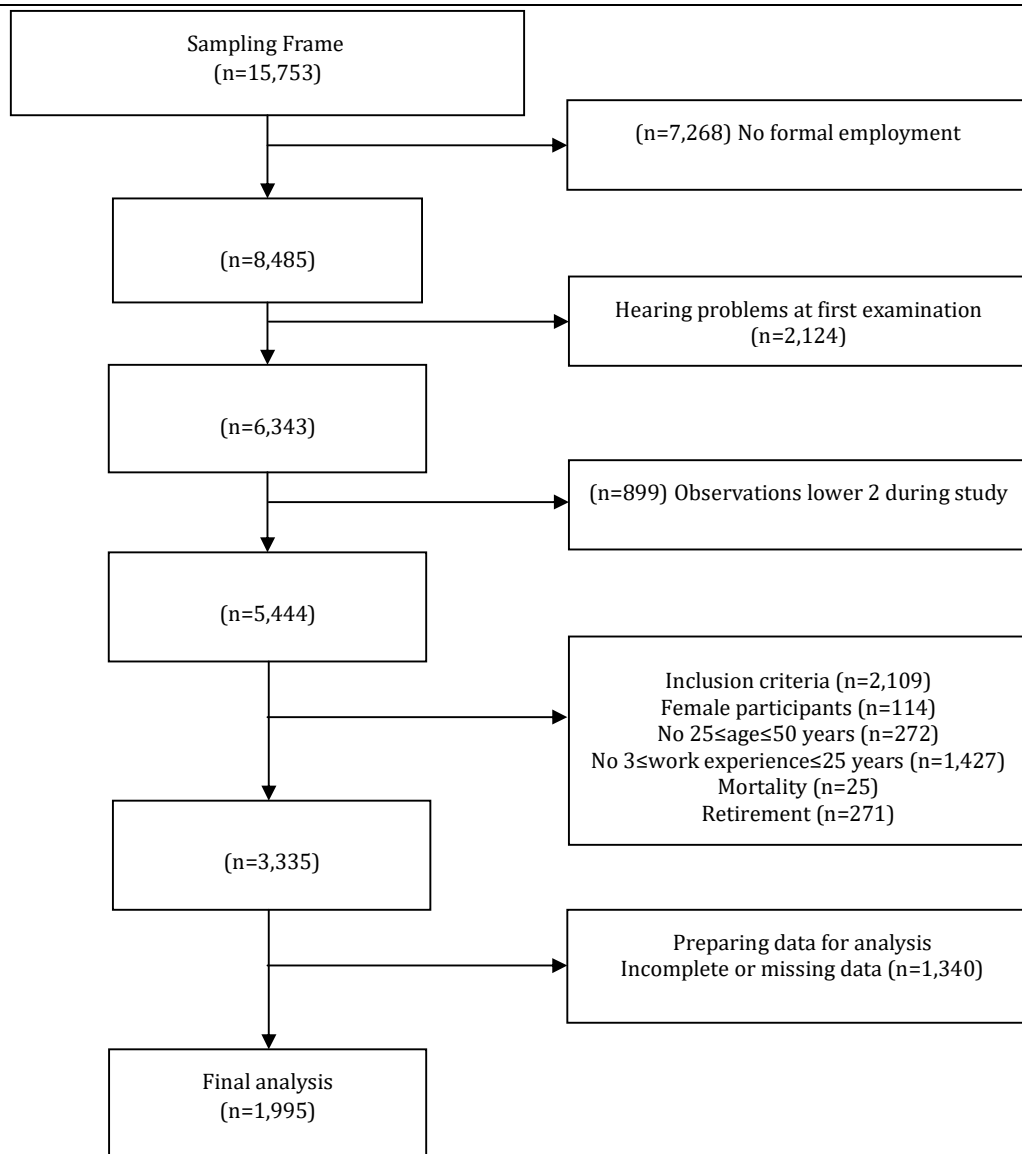

Figure 1. Cohort flow diagram

The schedule of shift time (i.e., routinely-rotating shift workers, weekly-rotating shift workers, and day workers) by Gholami Fesharaki et al. was used in this study ([18]). The Ethics Committee of Faculty of Medical Sciences of Tarbiat Modares University, Tehran, Iran, approved the present study (code no.: IR.MODARES.REC.1397.223).

3.1. Statistical Analysis

The statistical analysis was performed using OpenBUGS (version 3.2.2) and R (version 2.13.2) software. The association between the effective factors and changes of LFH and HFH from the baseline was investigated by the Bayesian multivariate multilevel modeling using skew distribution. In this model, the distribution for the changes of LFH and HFH from the baseline was considered the multivariate skew t-distribution. The model was defined as follows:

$$\begin{bmatrix} DLFH_i \\ DHFH_i \end{bmatrix} \sim Mt(\begin{bmatrix} \mu_{1i} \\ \mu_{2i} \end{bmatrix}, \Sigma, df)$$

where Mt is a multivariate t-distribution with the location of $\begin{bmatrix} \mu_{1i} \\ \mu_{2i} \end{bmatrix}$, scale parameter of Σ, and degree of freedom of df. In this formula, μ_{1i} is defined as follows:

$$\beta_{01} + \beta_{11}x_{1i} + \beta_{21}x_{2i} + \cdots + \beta_{k1}x_{7i} + u_{1i} + v_{1i} + \lambda_1 |Z_{1i}|$$

In addition, μ_{2i} is defined as follows:

$$\beta_{02} + \beta_{12}x_{1i} + \beta_{22}x_{2i} + \cdots + \beta_{27}x_{ki} + u_{2i} + v_{2i} + \lambda_2 |Z_{2i}|$$

where x_k are the explanatory variables; Z_{1i} in addition Z_{2i} are the two random variables with t-distribution (location=0; scale=1); moreover, u_{1i} and u_{2i} are the two random variables with a normal distribution; $N(0, \sigma_{u1}^2)$ and $N(0, \sigma_{u2}^2)$ are considered for the dependency related to the left and right ear for LFH and HFH, respectively; in addition, v_{1i} and v_{2i} are the two random variables with a normal distribution; $N(0, \sigma_{v1}^2)$ and $N(0, \sigma_{v2}^2)$ are regarded for the dependency related to the repetition for LFH and HFH, respectively; furthermore, λ_1 and λ_2 are the parameters of skewness in the response variables for LFH and HFH, respectively.

In this study, the prior distribution for all the betas and skewness parameters was considered a normal distribution $N(0, 100)$ ($N(0, 100)$). Moreover, for variance parameters $(\sigma_{v1}^2, \sigma_{v2}^2, \sigma_{u1}^2, \sigma_{u2}^2)$ the gamma distribution ($\alpha = \beta = 0.001$), for Σ parameters the $Wishart(\begin{bmatrix} 0.001 & 0 \\ 0 & 0.001 \end{bmatrix}, 2)$ distribution, and for degree of freedom (df) t-distribution and Chi-square distribution ($\chi^2(5)$) were considered, respectively.

In the present study, the obtained results were based on 100 draws from a Markov Chain Monte Carlo of length 11,000 iterations with a burn-in of 1000 iterations in order to characterize posterior distributions for the beta parameters. The p-values of less than 0.05 were considered statistically significant.

4. Results

The present study was carried out on a total of 1,959 male workers with a mean age of 36.64±3.92 years and mean work experience of 11.70±3.06. Among these participants, 913 (46.6%), 134 (6.8%), and 912 (46.6%) individuals were day workers, weekly-rotating shift workers, and routinely-rotating shift workers, respectively. Table 1 tabulates the demographic information of the study participants. Most of the study participants were reported with

Table 1. Demographic information of participants in addition to mean and standard deviation of low-frequency hearing and high-frequency hearing at first examination

Variable	Level	Frequency		LFH		HFH	
		n	%	Mean	SD	Mean	SD
Age (year)	≤30	81	4.1	4.16	13.37	3.85	7.14
	30-35	610	31.1	5.06	12.19	2.58	4.73
	36-40	902	46.0	4.88	13.58	2.49	5.45
	41-45	313	16.0	4.89	14.05	2.59	5.73
	≥46	53	2.7	4.44	14.97	3.00	6.60
Work experience (year)	≤5	137	7.0	4.50	14.04	3.68	7.58
	6-10	221	11.3	5.19	12.81	2.70	5.04
	11-15	1428	72.9	4.97	13.08	2.48	5.10
	≥16	173	8.8	4.57	14.58	2.18	6.32
Educational level	Nonacademic	1470	75.0	5.00	13.18	2.73	5.35
	Academic	489	25.0	4.82	13.47	2.50	5.44
Shift schedule	Day workers	913	46.6	4.73	13.30	2.68	5.44
	Routinely-rotating shift workers	912	46.6	5.21	13.13	2.75	5.29
	Weekly-rotating shift workers	134	6.8	4.61	13.79	2.09	5.46

LFH: Low-frequency hearing
HFH: High-frequency hearing
SD: Standard deviation

Table 2. Relationship between study variables regarding changes of low-frequency hearing and high-frequency hearing from baseline using Bayesian multivariate multilevel modeling and skew distribution

Independent variable	$LFH_t - LFH_0$				$HFI_t - HFI_0$			
	Estimate	Standard error	95% Credible interval		Estimate	Standard error	95% Credible interval	
Intercept (β_0)	-1.617	0.102	-1.827	-1.426	-5.758	0.291	-6.208	-5.276
Age (β_1)	-0.032	0.002	-0.037	-0.029	0.185	0.006	0.174	0.193
Work experience (β_2)	0.218	0.012	0.195	0.236	0.018	0.008	0.004	0.034
Education level (β_3)	0.073	0.022	0.044	0.114	0.059	0.010	0.038	0.077
Time (year) (β_4)	0.408	0.012	0.384	0.432	0.576	0.012	0.552	0.6
RRS workers (β_5)	-1.219	0.105	-1.443	-1.059	-0.341	0.198	-0.726	0.062
WRS workers (β_6)	-0.734	0.089	-0.923	-0.574	0.695	0.362	-0.015	1.405
Day worker (β_7)	Considered reference category				Considered reference category			
σ_u^2	0.018	0.004	0.012	0.016	10.424	0.452	9.498	10.140
σ_v^2	8.080	0.280	7.551	7.883	21.754	1.040	20.044	21.020
σ_e^2	2.463	0.049	2.352	2.552	11.767	0.227	11.265	11.620
λ	-0.024	0.026	-0.072	-0.043	-0.556	0.061	-0.675	-0.595
ρ	0.270	0.008	0.255	0.265	0.270	0.008	0.255	0.265
df	2.607	0.051	2.472	2.588	2.607	0.051	2.472	2.588

λ: Skewness parameter, ρ: Correlation of low-frequency hearing and high-frequency hearing, df: Degree of freedom, σ_e^2: Error variance, σ_v^2: Repetition variance, σ_u^2: Between-ear variance, RRS: Routinely-rotating shift, WRS: Weekly-rotating shift

nonacademic education. Furthermore, most of the study subjects were reported within the age range and with a work experience of 36-40 and 11-15 years, respectively.

Table 2 shows the relationship between the study variables regarding the changes of LFH and HFH from the baseline by Bayesian multivariate multilevel modeling using skew distribution. The obtained results of the current study demonstrated that the age, work experience, educational level, and shift work had significant relationships with the changes of LFH and HFH. The significance of the parameters, such as σ_u^2, σ_v^2, σ_e^2, λ, ρ, and df demonstrated that the Bayesian multivariate multilevel modeling using skew distribution was a convenient model for analyzing the changes of LFH and HFH data.

Using the test statistics, it can be said that the time had the greatest effect on the changes of LFH and HFH among other variables. After the adjustment of the age and work experience, the results showed that LFH and HFH increased 0.408 and 0.576 per year, respectively. The findings of the present study showed the significant relationship between shift work and LFH changes. Shift workers have a lower average of LFH changes in comparison to the day workers. This difference in the routinely-rotating shift workers was higher than that reported for the weekly-rotating shift workers.

5. Discussion

The most common occupational health condition

following musculoskeletal problems and respiratory diseases (due to long-term workplace noise exposure) is NIHL (19). Although countermeasures in many workplaces have effectively lowered noise levels, noise remains a significant occupational risk factor, and NIHL is one of the major occupational diseases worldwide (19-21). The result of the present study showed a significant relationship between shift work and LFH changes. The shift workers had a lower average of LFH changes in comparison to that of the day workers. A lack of the use of protective equipment among the day workers, compared to that reported for the shift workers (15, 16), can be a reason for such a relationship.

The results of this study are consistent with the findings of studies performed by Wang et al. (22), Chou et al. (23), Holzmüller (24), and Golmohammadi et al. (25) and inconsistent with the findings of a study conducted by Zare et al. (26). There was no strong evidence that work patterns, including shift work or overtime, affected safety. Protective compensatory strategies or experience may maintain safe working practices (27). Wang et al. showed that the association between short duration of shift work and bilateral hearing loss was not significant in men when those with occupational noise exposure were excluded (22).

Chou et al. (23) demonstrated that the severity of hearing loss in both ears was significantly lower in subjects who worked in a 12-hour shift. In conclusion, working in a 12-hour shift followed by a day off is the best condition for workers, and hearing

protection should be provided in high-noise areas. The result of the current study similar to those reported for previous studies showed the relationship between age (25, 28, 29) and work experience (30) with LFH and HFL changes. The strengths of the present study were the use of an effective type of study (i.e., historical cohort study), appropriate sample size, and homogeneity of the study population. Some of the limitations of the study were no evaluation of the NIHL family and disability history to determine previous job interactions, sleep, income, and stress as potential confounding factors.

6. Conclusion

Overall, the findings of a 10-year historical cohort study demonstrated a relationship between shift work and change of LFH. Therefore, it is recommended to design preventive measures for the reduction of the deleterious effects of shift work on LFH.

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Footnotes

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