The prediction and risk point score (RPS) of noise induced hearing loss (NIHL)

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Abstract

Background Noise induced hearing loss (NIHL) is a significant occupational health concern in many countries. Based on the realistic demands, we aimed to build the prediction risk model of noise induced hearing loss (NIHL) and developed the related risk point score (RPS). The results of this study expect to provide technology support for interventions and management, in order to enhance the application-orientated research on NIHL.

Methods A total of 40433 participants of noise exposed workers were enrolled. The datasets from The National Key Occupational Diseases Survey (NKODS) from 2014 to 2017 in Sichuan province of China. The socio-demographic and occupational characteristics used the standardized questionnaires, and the level of NIHL were collected by audiometric testing, which was defined as binaural high-frequency threshold average (BHFTA) over 40dB. The prediction model expressed by linear format of logistic regression and based on model calculated the risk point score (RPS) of NIHL.

Results Of the 40433 participants in the study, there are 9.97%(n=4029) of workers have NIHL (BHFTA >40). Age (OR=1.08, 95%CI: 1.071-1.083), sex (OR=3.34, 95%CI:2.997-3.715), noise exposure time (OR=1.01, 95%CI: 1.008-1.017), manufacturing industry(OR=1.35, 95%CI:1.207-1.500), construction industry (OR=2.59, 95%CI: 1.941-3.458), mining industry (OR=2.42, 95%CI: 2.132-2.740), foreign enterprise(OR=1.14, 95%CI: 0.962-1.353), private enterprise(OR=1.48, 95%CI: 1.361-1.603) are predictors of NIHL(P <0.05). The risk prediction model has a better effectiveness of NIHL (AUC= 0.7150). According to the NIHL- RPS calculated the individual score was 75 that the risk probability of NIHL was 37.97%.

Conclusion The study found that the prevalence of NIHL at a moderate level in Sichuan province. Sex, age, noise exposure time, manufacturing industry, construction industry, mining industry, foreign enterprise, private enterprise are predictors of NIHL, and to develop the NIHL-RPS is necessary for application-orientated research on NIHL.

1 Background

Noise-induced hearing loss (NIHL) is the second most common sense-related hearing loss after age-related hearing loss, which is one of the major occupational diseases in many countries^[1]. WHO reported that 16% of adult hearing loss could cause by occupational noise exposure^[2] and it also indicated that the number of hearing loss could rise to 630 million by 2030 and may be over 900 million in 2050^[3].

Although China is a developing country, it has already become one of the largest global producers, the world's most populous country, and the world's second-largest economy^[4]. China have many companies of manufacturing, construction and mining, the noise pollution is one of the key public hazard^[5]. According to the National Bureau of Statistics, total spending on health expenditures reached 700 billion in 2016, or 6.2 percent of gross domestic product (GPD)^[6]. From 2010 to 2014, there was a rapid rise in new cases of occupational ear, nose and throat diseases, from 347 to 880 workers^[7, 8]. In 2015, there have

1097 of person have occupational ear, nose and throat diseases that 95.90% of people are noise induced hearing that it has been increasing in recent years, and the number of new cases has exceeded occupational poisoning since 2015^[9]. it is the second most occupational disease after occupational pneumoconiosis in recent years in 2016 and 2017^[10].

Occupational health is one of the basic policies. According to the 13th Five-Year Plan (FYP) period, China launched a National Key Occupational Disease Surveillance (NKODS) started in 2009. The surveillance in 2015, prefecture-level implementation rate reached 95%, district and rural coverage rate were 81%^[7], but the related occupational disease systems are still in a fragmented state, and the most of systems cannot be connected, which have a negative impact on application of data sources. Besides, more importantly, for the research on NIHL that more focus on descriptive statistics or risk factors assessment, there are less study on tool development of research and assessment, which cause of major obstacle to link between surveillance data and preventive practices, reduce the efficient function of supervision and early warning^[11].

Nowadays, As it is rapidly industrialized that occupational noise exposure and noise exposure in daily life among its population are on the rise and there is an increasing concern over there is an increasing concern over the potential health consequences of such exposures, especially the hearing loss, because of this, the prediction of NIHL is more essentially on noise exposed workers^[12]. Therefore, the aims of the study that is based on the realistic demands, building the prediction risk model of noise induced hearing loss and develop the related risk point score (RPS). The results of this study expect to enhance the application-orientated research on NIHL and to provide the technology support for interventions and management.

2 Method And Materials

2.1 Study Design and Setting

The study used datasets from the National Key Occupational Diseases Survey (NKODS) from 2014 to 2017 in Sichuan province of China. The data collected from twenty-one prefecture-level Centers for Disease Control (CDC), and Occupational Health Examination Institutions. The survey mainly included ten key occupational hazards of coal dust (coal silica dust), silica dust, asbestos, benzene, lead, noise, brucella, welding fumes, carbon disulfide, phosphorus and their compounds.

The research data came from the data of National Key Occupational Disease Survey in Sichuan, which included the questionnaire survey and hearing level measurement. The information of socio-demographic and occupational characteristics used the national standardized questionnaires among noise exposed workers. For the measurement of hearing level, audiometric testing is the accepted standard for measuring. In the survey, audiometric testing including three times of pure-tone test, the interval should more than three days at least. The audiometric testing used different audiometers in a sound-isolating room by trained health technicians in health examination institutions, and the error of each device was

controlled less than 3%. Binaural high-frequency threshold average (BHFTA) is an early warning indicator that it calculated using the arithmetic mean of hearing thresholds at 3, 4, and 6 kHz in both the right and left ears, respectively. The categories of noise induced hearing loss, which according to General Guidelines for Diagnosis of Occupational Diseases (GBZ/T 265–2014), The BHFTA of 25dB is considered as a cut-point for normal hearing sense in each frequency. The BHFTA of 40dB is a cut-point for the NIHL. The categories of NIHL level was showed in Table 1.

Table 1
The Categories of NIHL level

NIHL levels	BHFTA (dB)
Normal hearing	< 25
Suspected NIHL	25 ~
NIHL	40 ~
Severe NIHL	80~
Abbreviation. NIHL = noise induced hearing loss	
BHFTA = Binaural high-frequency threshold average	
Footnote. The NIHL level according to General Guidelines for Diagnosis of Occupational Diseases (GBZ/T 265–2014), 40 dB is a cut-point of NIHL.	

2.2 Participants

The participants’ inclusion criteria were consist of: (1) all of participants have complete data of National Key Occupational Diseases Survey and health examination report from 2014 to 2017; (2) the workers who continuous exposed to noise in routine work; (3) the noise exposure time more than 1 year, the workers aged over 18 years and below 50 years.

Since 2014 to 2017, among total of 90420 occupational hazard exposed workers, 47739 workers were occupational noise exposed workers. For the data analysis, we excluded the aged 18 years (16 workers) and retired workers that the age over 50 years (4800 workers). In addition, according to the inclusion criteria, the participants years of work < 1 year (2490 workers) also not participate in the study. Therefore, we totally excluded 7306 participants and a final number of 40433 occupational noise exposed workers were enrolled in the study.

2.3 Statistics analysis

Descriptive statistics were used to reveal the variable characteristics. Categorical variables were expressed as frequencies (%) and compared by Chi-square analysis. Multivariate logistic regression analyses were used to assess the risk factors on NIHL, including age, sex, noise exposure time, industry type and enterprise type. The NIHL was processed as binary outcomes in the logistic model, “0” showed

BHFBA below 40 (not including the BHFTA = 40), “1” showed BHFBA over 40, the risk expressed by odds ratios (ORs), 95% confidence intervals (CIs). The prediction model expressed by linear format of logistic regression. The ROC curve was used to examine the effectiveness of prediction model. A two-detail P-value < 0.05 was considered statistically significant. All statistical calculations were performed using the R software (Version 3.4.4).

The risk point score (RPS) put forward by Wilson. et al^[13]. This tool would be mainly used for the prediction of cardiovascular diseases, such as coronary heart disease. And now, it has widely used in clinical disease prediction. The method of developing the NIHL-RPS have showed in Appendix.

3 Result

3.1 The participants’ characteristics and prevalence of NIHL

Of the 40433 workers in the study, there are 74.54% of male and 25.46% of female. The average age was 39 years (SD = 7.9 years). Workers exposed to noise had a mean of 38.6 ± 7.9 years of exposure. The socio-demographic characteristics and occupational characteristics for participants are summarized in Table 2.

Table 2
The characteristics of 40433 participants

Variables	Types	n	%
Sex	Male	30,138	74.54
	Female	10,295	25.46
Age, y	20~	2,264	5.6
	25~	5,184	12.82
	30~	4,830	11.95
	35~	5,629	13.92
	40~	11,366	28.11
	45~	11,160	27.6
	50~	10,200	25.33
Noise exposure time, y	0~	16,252	40.19
	5~	10,240	25.33
	10~	4,812	11.9
	15~	2,581	6.38
	20~	3,860	9.55
	25~	2,000	4.95
Industry type	30~	688	1.7
	Manufacturing	28,689	70.95
	Construction	413	1.02
	Mining	5,365	13.27
Enterprise type	Others	5,966	14.76
	Public	12,963	32.06
	Foreign	2,696	6.67
	Private	24,774	61.27

A totally 40433 exposed noise workers in the study, the lowest BHFTA was 30dB and the highest was 115dB. For prevalence of hearing levels, 60.52%(n = 24469) of workers were normal hearing level, 29.53% (n = 11935) of workers BHFTA > 25 dB, 9.65%(n = 3901) of workers BHFTA > 40 dB, and the BHFTA > 80 dB was 0.32%(n = 128), which all have significant difference ($P < 0.05$). Additionally, the distribution of BHFTA was expressed as an approximating normal distribution of all parameters (Fig. 1).

The Table 3 indicated, the prevalence of NIHL increased stepwise across the age and Noise exposure time ($P < 0.05$). Comparing to other industry type, the manufacturing industry and mining industry workers have high NIHL level($P < 0.05$). In addition, the private enterprise was significant higher BHFTA than other groups($P < 0.05$).

Table 3
Different characteristics of hearing level on workers

Variables	BHFTA [n (%)]				P-value *
	> 25 ^a	25~	40 ^b ~	80 ^c ~	
Age, y					< 0.001
20~	1725(7.05)	495(4.15)	43(1.10)	1(0.78)	
25~	3761(15.37)	1243(10.41)	178(4.56)	2(1.56)	
30~	3315(13.55)	1263(10.58)	248(6.36)	4(3.13)	
35~	3431(14.02)	1685(14.12)	500(12.82)	13(10.16)	
40~	6495(26.54)	3620(30.33)	1215(31.15)	36(28.13)	
45~	5742(23.47)	3220(26.98)	1717(44.02)	72(56.25)	
Sex					< 0.001
Female	7105(29.04)	2791(23.39)	387(9.92)	12(9.38)	
Male	17364(70.96)	9144(76.61)	3514(90.08)	116(90.63)	
Noise exposure time, y					< 0.001
< 5	10655(43.54)	4395(36.82)	1172(30.04)	30(23.44)	
5~	6379(26.07)	2897(24.27)	942(24.15)	22(17.19)	
10~	2705(11.05)	1502(12.58)	585(15.00)	20(15.63)	
15~	1442(5.89)	813(6.81)	316(8.10)	10(7.81)	
20~	2033(8.31)	1333(11.17)	474(12.15)	20(15.63)	
25~	938(3.83)	758(6.35)	288(7.38)	16(12.50)	
30~	317(1.30)	237(1.99)	124(3.18)	10(7.81)	

Abbreviation. BHFTA = Binaural high-frequency threshold average

Footnote. n = 40433

^a BHFTA < 25, defined as a normal hearing

^b BHFTA > 40, defined as a warning value of NIHL

^c BHFTA > 80, defined as a severe level of NIHL

*P-value was analyzed by Chi-square test, sig at < 0.05

Variables	BHFTA [n (%)]				P-value *
	> 25 ^a	25~	40 ^b ~	80 ^c ~	
Industry type					< 0.001
Manufacturing	18030(73.69)	8058(67.52)	2538(65.06)	63(49.22)	
Construction	173(0.71)	172(1.44)	67(1.72)	1(0.78)	
Mining	2271(9.28)	2162(18.11)	887(22.74)	45(35.16)	
Others	3995(16.33)	1543(12.93)	409(22.74)	19(14.84)	
Enterprise type					< 0.001
Public	7160(29.26)	4636(38.84)	1134(29.07)	33(25.78)	
Foreign	1793(7.33)	723(6.06)	177(4.54)	3(2.34)	
Private	15516(63.41)	6576(55.10)	2590(66.39)	92(71.88)	
Total	24469(100)	11935(100)	3901(100)	128(100)	
Abbreviation. BHFTA = Binaural high-frequency threshold average					
Footnote. n = 40433					
^a BHFTA < 25, defined as a normal hearing					
^b BHFTA > 40, defined as a warning value of NIHL					
^c BHFTA > 80, defined as a severe level of NIHL					
*P-value was analyzed by Chi-square test, sig at < 0.05					

3.2 The risk prediction model of NIHL

The result of Table 4, the variables of age (OR = 1.08, 95%CI: 1.071–1.083), sex (OR = 3.34, 95%CI: 2.997–3.715), noise exposure time (OR = 1.01, 95%CI: 1.008–1.017), manufacturing (OR = 1.35, 95%CI: 1.207–1.500), construction (OR = 2.59, 95%CI: 1.941–3.458), mining (OR = 2.42, 95%CI: 2.132–2.740), foreign enterprise (OR = 1.14, 95%CI: 0.962–1.353), private enterprise (OR = 1.48, 95%CI: 1.361–1.603) are the risk factors of NIHL (P < 0.05). The Fig. 2. indicated, the result of ROC curve shown that the risk prediction model has a better prediction of NIHL, area under curve (AUC) was 0.7150.

Table 4
The prediction risk model of NIHL

Predictors	OR	SE	Z	P*	CI-L	CI-U
Age, y	1.08	0.003	26.51	> 0.001	1.071	1.083
Sex	3.34	0.183	21.98	> 0.001	2.997	3.715
Noise exposure time, y	1.01	0.002	5.73	> 0.001	1.008	1.017
Industry type						
(Ref: others)						
Manufacturing	1.35	0.075	5.35	> 0.001	1.207	1.500
Construction	2.59	0.382	6.46	> 0.001	1.941	3.458
Mining	2.42	0.155	13.77	> 0.001	2.132	2.740
Enterprise type						
(Ref: Public)						
Foreign	1.14	0.099	1.51	0.130	0.962	1.353
Private	1.48	0.061	9.37	> 0.001	1.361	1.603
Abbreviation. NIHL = Noise induced hearing loss, OR = Odd Ratio, SE = Standard Error,						
CI-L = Confidence Intervals-Lower, CI-U = Confidence Intervals-Upper						
Footnote. *P-value was analyzed by multiple logistic regression, sig at < 0.05						
In the logistic regression model, "0" defined as BHFBA below 40dB (not including the BHFTA = 40 dB), "1" defined as BHFBA over 40 dB						

Based on the risk prediction model, the individual score sheet would be calculated that the details all describe in Appendix. In the sheet, it included the corresponding values of predictors of NIHL (Appendix, Table A2). The user can calculate the totally individual score to support for calculate the probability of NIHL risk. Regarding to the result of the study, while the risk probability less than 5%, the individual score shouldn't over 37; while the risk probability less than 10%, the individual score shouldn't over 49; while the risk probability less than 15%, the individual score shouldn't over 56; while the risk probability less than 30%, the individual score shouldn't over 70. the explication and details of NIHL-RSP all showed in Appendix, Table A3.

4 Discussion

Noise induced hearing loss (NIHL) is a significant occupational health concern in workers exposed to noise in many countries^[14]. Most of research evidence showed that long-term noise exposed workers

likely to cause hearing impairment, excessive noise exposure can lead to noise-induced hearing loss (NIHL)^[15, 16]. The research evidences suggested that high-frequency hearing loss is a common symptom of NIHL in the early stage^[17]. Based on the realistic demands, developing the prediction risk model and developed NIHL- risk point score (RPS) are necessary for the prevention of occupational health of noise exposed workers.

In this study, the totally 40433 of noise exposed workers have enrolled in this study, the finding showed that there are 39.48%(n = 15836) have suspected-NIHL, 9.97%(n = 3901) of workers have NIHL. Workers exposed to noise had a mean of 38.57 ± 7.92 years of exposure. Hearing loss is a historic scientific issue, which also a difficult diagnosis to make, because of the national hearing loss criteria used for diagnosis purposes vary from nation to nation, which is regarded as a major problem because it makes it difficult to compare results^[18]. In China, comparing to other districts that the prevalence of NIHL at a moderate level^[19–22]. The predictors included sex, age, noise exposure time, industry type, enterprise type in the risk prediction model. Based on the model, the NIHL-RPS have be developed that it can calculate the risk probability of noise exposed workers. Most of research evidences suggested that age, sex, noise exposure time and industry type were important predictors for change in the hearing threshold^[23–25]. Our study has support for those results indirectly.

Regarding to previous research, it mainly focus on prevalence and risk factors of hearing loss^[26, 27], correlation analysis^[28, 29]. As those findings all have important roles for depth research on consequence of noise exposure and an evidence support for the occupational health policy and strategy. However, there are still insufficient that it fails to extend the research type on exploratory development, lack of the technology support to practical application. For the prediction on NIHL, there have the prediction formula for noise induced deafness by OSI in 1999^[23], and has been widely used for many years. Comparing with OSI model, our prediction risk model has some differences: (1) In this study, we mainly used BHFTA to build early risk prediction model, the earlier warning and the earlier prevention. Based on the model, we also developed the NIHL-RPS. (2) The NIHL-RPS in the study, which is a simple research tool and easier use in daily work. NIHL-RPS is convenient to use by managers, or use to self-check for workers. There are some successful examples of prediction model and risk score prediction in the clinical medicine, such as risk score prediction model for dementia in patients with type 2 diabetes^[30], risk prediction model for severe postoperative^[31], the LIPID heart failure risk-prediction model^[32]. Pentti Kuronen et al^[33] built the model of noise-induced hearing loss among military pilots, but the model mainly focus on military pilot group, as is well-known that the pilots have the better health monitoring and management than workers. Therefore, the prediction model is not fit in noise exposed workers.

Regarding to future NIHL research, NIHL- risk prediction score (RPS) could be consider as a variable in studies that it can explore the correlations between NIHL risk probability and health outcomes, such as hypertension, heart disease, etc. At workplace, the NIHL-RPS have applied function can be used: (1) Producing the RPS-Card that distribute to occupational health managers in each department, it can periodically calculate the individual score of workers to predict probability of NIHL. (2) An RPS-Poster can

post it on the wall at the workplace, it can help workers to calculate the probability of NIHL by themselves, enhancing the consciousness of hearing protection in routine work.

5 Conclusion

There are totally 40433 of noise exposed workers have enrolled in the study, there are 9.97%(n = 4029) of workers have NIHL (BHFBA > 40). Sex, age, noise exposure time, manufacturing industry, construction industry, mining industry, foreign enterprise, private enterprise are prediction factors in NIHL risk prediction model. Based on the model, we develop the NIHL-risk point score (RSP) that it can calculate the risk probability of NIHL rapidly. The risk prediction model and NIHL-RSP is necessary to enhancing the application-orientated research on NIHL and providing the technology support for interventions and management. The future study that it can conduct depth research on correlations between NIHL risk probability and hearing loss related diseases.

6 Strengths And Limitations

Regarding to this paper that it has some strengths: (1) Using the surveillance data of National Key Occupational Disease Survey, the quality of data and materials are more reliability. (2) Building the prediction risk model and NIHL-risk point score (RPS) that it is effective utilization on the surveillance data and provide the research tool of practice in workplace. (3) The NIHL-risk point score is simple that it can be widely applied to a large population, especially the workers who can used to self-checking in routine work that it would enhance the awareness of prevention of NIHL.

However, the study also exists the limitation: Based on common sense, the directly predictor of NIHL is noise cumulative exposure (NCE), but the surveillance system failed to collection the NCE of individual. If using the date of area noise monitoring instead of NCE put into the model that it might be have deviations. Therefore, we used noise exposure time to represent the level of noise exposed.

Abbreviations

NIHL
noise induced hearing loss, GPD: gross domestic product, FYP: five-year plan, NKODS: national key occupational disease survey, RPS: risk point score, CDC: centers for disease control, BHFTA: binaural high-frequency threshold average, OR: odd ratio, SE: standard error, CI-L: confidence interval-lower, CI-U: confidence interval-upper, AUC: area under the curve, LIPID: long-term intervention with pravastatin in is chasmic heart disease, CHD: coronary heart disease, NCE: noise cumulative exposure.

Declarations

Ethics approval and consent to participate

Not Applicable

Consent for Publication

Not Applicable

Availability of data and materials

The all of research materials are in the manuscript.

Competing interests

The authors declare that they have no competing interests.

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Authors' contributions

Study design, data analysis, data interpretation and finished the manuscript: RCS. Study design, data acquisition: WWS. Data analysis: YQC. Study design and supervision of study: YJL. All authors read and approved the final manuscript.

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Figures

Figure 1

The distribution of hearing level on workers

Figure 2

The ROC curve of NIHL risk prediction model

Supplementary Files

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- [TablesA1A3.docx](#)
- [AppendixACalculateNIHLRiskPointScoreRPS.docx](#)