The prediction and risk point score (RPS) of high frequency hearing loss in noise exposed workers

Ruican Sun

Sichuan University West China School of Public Health and West China Fourth Hospital

Weiwei Shang

Sichuan Center for Disease Control and Prevention

Yingqiong Cao

Pidu District Center for Disease Control and Prevention

Yajia Lan (✉ yajialan501@126.com)

Sichuan University West China School of Public Health and West China Fourth Hospital

<https://orcid.org/0000-0002-9818-3057>

Research article

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Abstract

Background: Occupational hearing loss is a significant occupational health concern in many countries, and high frequency hearing loss (HFHL) is an early symptom. Based on realistic demands, we aimed to build a prediction risk model of HFHL and developed the related risk point score (RPS). The results of this study are expected to provide technological support for interventions and management to enhance application-oriented research of HFHL.

Methods: A total of 32121 participants who were noise exposed workers were enrolled. The datasets from the National key occupational diseases survey (NKODS) performed from 2014 to 2017 in Sichuan Province in China were utilized. The sociodemographic and occupational characteristics were assessed by standardized questionnaires, and the level of HFHL were collected by audiometric testing and was defined as a binaural high frequency threshold average (BHFTA) over 40 dB in the right and left ears. The risk prediction models were generated by linear logistic regression, and based on the models, the risk point score (RPS) of HFHL were calculated.

Results: Of the 32121 participants in the study, 9.97% ($n=4029$) of workers had HFHL ($\text{BHFTA} \geq 40$ dB). Age ($\text{OR}=1.08$, 95% CI: 1.071–1.083), sex ($\text{OR}=3.34$, 95% CI: 2.880–3.636), noise exposure time ($\text{OR}=1.01$, 95% CI: 1.008–1.018), manufacturing industry ($\text{OR}=1.46$, 95% CI: 1.302–1.647), construction industry ($\text{OR}=2.14$, 95% CI: 1.488–3.069), mining industry ($\text{OR}=2.57$, 95% CI: 2.225–2.957), foreign enterprise ($\text{OR}=0.94$, 95% CI: 0.781–1.122), and private enterprise ($\text{OR}=1.32$, 95% CI: 1.200–1.442) were predictors of HFHL ($P<0.05$). By comparing the two risk prediction models, the 40 dB HL criterion model was found to be more effective than the 25 dB HL criterion model ($\text{AUC}=0.637$). Verification of the two models revealed that the 25 dB HL criterion model was more stable than the 40 dB HL criterion.

Conclusion: The study found that the prevalence of HFHL was moderate in Sichuan Province. Sex, age, noise exposure years, and employment in the manufacturing industry, construction industry, mining industry, foreign enterprise, or private enterprise were predictors of HFHL, and the development of the RPS of HFHL is necessary for application-oriented research on HFHL.

1 Background

Occupational hearing loss is the second most common form sensory-related hearing loss after age-related hearing loss and is one of the major occupational-related diseases in the world^[1]. The WHO reported that 16% of adult hearing loss could be caused by occupational noise exposure^[2]. They also indicated that the number of individuals with hearing loss could rise to 630 million by 2030 and might be over 900 million by 2050^[3].

Although China is a developing country, it has already become one of the largest global producers, and it is the most populous country and has the second largest economy in the world^[4]. China has many manufacturing, construction and mining companies. As a result, noise pollution is one of the key public

hazards^[5]. According to the National Bureau of Statistics, total spending on health expenditures reached 700 billion in 2016 and represented 6.2% of the gross domestic product (GPD)^[6]. From 2010 to 2014, there was a rapid rise in new cases of occupational ear, nose and throat diseases, affecting from 347 to 880 workers^[7,8]. In 2015, 1097 workers were diagnosed with occupational ear, nose and throat diseases, of which 95.90% were affected by noise induced hearing loss (NIHL). The incidence of NIHL has been increasing in recent years, and the number of new cases has exceeded those of occupational poisoning since 2015^[9]. It was the second most common occupational disease after occupational pneumoconiosis in the years 2016 and 2017^[10].

Occupational health is one of the basic policy areas. According to the 13th Five-Year Plan (FYP), China launched the National Key Occupational Diseases Survey (NKODS) in 2009. In 2015, the surveillance prefecture-level implementation rate reached 95%, and the district and rural coverage rates were 81%^[7]. However, the related occupational disease monitoring systems are still in a fragmented state, and most of these systems cannot be connected, which has a negative impact on the application of data sources. More importantly, in research on high frequency hearing loss (HFHL), there has been more focus on descriptive statistics^[11] or risk factor assessment^[12]. As a result, there are fewer developed research tools for the assessment of occupational hearing loss, which has caused a major obstacle for obtaining surveillance data and implementing preventive practices, reducing the efficient application of supervision and early warning systems^[13].

Currently, due to rapid industrialization, occupational noise exposure and noise exposure in daily life are on the rise among the world population, and there is an increasing concern over the potential health consequences of such exposures, especially hearing loss. Occupational NIHL involves changes in the perception of different sound frequencies and first appears at high frequencies. Noise exposed workers are one of the groups that are most damaged by high-noise environments, the risk prediction of HFHL is essential for noise exposed workers^[14]. Therefore, based on realistic demands, the aims of this study are building a risk prediction model for HFHL and developing the related risk point score (RPS). The results of this study expect to enhance application-oriented research on hearing loss and to provide technological support for interventions and management.

2 Method And Materials

2.1 Study Design and Setting

The NKODS aims to protect the health of individual workers or groups of workers. It provides organizations with an explanation of the health information for individuals and groups of workers, protects workers' health to maintain employment, and proposes practical measures to improve hearing protection. The study used datasets obtained from the NKODS from 2014 to 2017 in Sichuan Province in China. The data was collected from twenty-one prefecture-level centres for disease control (CDC) and occupational health examination institutions. The survey mainly included assessment of exposure to ten

key occupational hazards, including coal dust (coal silica dust), silica dust, asbestos, benzene, lead, noise, brucella, welding fumes, carbon disulfide, and phosphorus compounds.

The research data came from the datasets of the NKODS in Sichuan Province and included the results of the questionnaire survey and measurement of hearing levels. The sociodemographic information and occupational characteristics were obtained with the national standardized questionnaires for noise exposed workers. For the hearing test, audiometric testing is the accepted standard for measurement. For the NKODS, audiometric testing should be performed 48 hours after the worker is released from the acoustic noise environment. The audiometric testing should be carried out in a sound-isolating room by trained health technicians in specified health examination institutions. According to the Technical Specification For Occupational Health Surveillance (GBZ 188-2014), the ① Routine ear examination was performed. ② Pure tone audiometry The audiometric testing devices in each specified health examination institution were calibrated, and the error of each device was controlled to less than 3%. The diagnostic assessment was calculated based on the minimum 3-fold threshold per frequency (for pure tone audiometry according to the Chinese guidelines GB/T 7583 and GB/T 16403). ③ Regarding to the method of audiometric testing, the first step uses air conduction measurement, If hearing abnormality is detected, bone conduction measurement is used to determine whether there is occupational hearing loss. In this study, the HFHL diagnosis is mainly based on air conduction measurement. ④ The test results were corrected for age according to the Chinese guideline of acoustic statistical distribution of the hearing thresholds as a function of age (GB/T 7582-2004). ⑤ For diagnosis, other factors that cause hearing loss should be excluded, and the average high-frequency hearing threshold of both ears should be calculated. The research data used age-adjusted hearing thresholds in this paper (calculation steps are listed in Appendix C).

The binaural high-frequency threshold average (BHFTA) is an early warning indicator that is calculated using the arithmetic mean of the hearing thresholds at 3, 4, and 6 kHz in both ears. To exclude age-related hearing loss, according to The categories of HFHL levels according to the diagnosis of occupational noise-induced deafness (GBZ 49-2014). A BHFTA of 25 dB is considered as a cut-off point for normal hearing in each frequency. A BHFTA over 40 dB is a prerequisite for HFHL. The categories of HFHL levels are shown in Table 1.

2.2 Participants

In this study, the inclusion criteria were: ① all participants had complete NKDOS data and health examination reports from 2014 to 2017; ② the workers were continuously exposed to noise in routine work and only exposed to noise; ③ the noise exposure time was >1 year; and ④ the workers were older than 18 years old and younger than 50 years old. The

From 2014 to 2017, among a total of 90420 workers exposed to occupational hazards, 47739 workers were occupationally noise exposed. For the data analysis, we excluded those workers ① aged less than 18 years (16 workers) and workers aged over 50 years (excluded 4800 workers); ② according to the inclusion criteria, the participants with a noise exposure time <1 year (excluded 2490 workers); ③ the participants

who were exposed to other occupational hazards that could lead to hearing loss (excluded 8312 workers). Therefore, a final number of 32121 occupationally noise exposed workers were enrolled in the study.

2.3 Statistical 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 for HFHL, including age, sex, noise exposure time, industry type and enterprise type. In this study, we developed two risk prediction models for HFHL. In the first model, HFHL was processed as a binary outcome in the logistic model; “0” indicated a BHFTA below 40. The risk was expressed according to odds ratios (ORs) and 95% confidence intervals (CIs). The prediction model was generated by linear logistic regression. The ROC curve was used to examine the effectiveness of the prediction model. Used the margins effect to analysis the interaction of age and noise exposure time to HFHL. Based on the risk prediction model of HFHL, we calculated the prevalence for each worker and used calibration plots to compare the effectiveness of the two models at different levels of risk. A two-tailed P -value <0.05 was considered statistically significant. All statistical calculations were performed using *R* software (Version 3.5.0).

The risk point score (RPS) was put forward by Wilson et al^[15]. This tool would be mainly used for the prediction of cardiovascular diseases, such as coronary heart disease, it is widely used in clinical disease prediction. The method used in developing the HFHL-RPS is shown in Appendices A and B.

3 Result

3.1 The participants' characteristics and prevalence of HFHL

Of the 32121 workers in the study, 73.66% ($n=23661$) were male and 26.34% ($n=8460$) were female. The average age was 38.41 years ($SD=7.98$ years). Workers exposed to noise had a mean exposure of 8.63 ± 7.86 years. The sociodemographic characteristics and occupational characteristics of participants are summarized in Table 2.

The lowest BHFTA was 0 dB and the highest was 115 dB of the total of 32121. The distribution of BHFTA was expressed according to the approximate normal distribution of all parameters (see Figure 1).

Table 3 indicates that the prevalence of HFHL increased stepwise according to age and noise exposure time ($P<0.05$). The workers who worked at manufacturing industries and mining industries have higher HFHL levels compared to other industry workers ($P<0.05$). In addition, those in private enterprise had a significantly higher BHFTA than other groups ($P<0.05$).

3.2 The risk prediction model of HFHL

The Table 4 shows the risk prediction model of the 40 dB HL criterion, the variables age (OR=1.08, 95% CI: 1.071–1.083), sex (OR=3.24, 95%CI: 2.880–3.636), noise exposure time (OR=1.01, 95%CI: 1.008–1.018), manufacturing (OR=1.46, 95%CI: 1.302–1.647), construction (OR=2.14, 95%CI: 1.488–3.069), mining (OR=2.57, 95%CI: 2.225–2.957), foreign enterprise (OR=0.94, 95%CI: 0.781–1.122), and private enterprise (OR=1.32, 95%CI: 1.200–1.442) are shown to be risk factors for HFHL ($P<0.05$), the age and noise exposure years have a significantly interactive($P<0.05$). In Figure 2, the ROC curves show that the risk prediction model is better able to predict HFHL (AUC = 0.713). The Figure 3

The Table 5 shows the risk prediction model of 25 dB HL criterion. With regard to sex, the effect of sex on HFHL (OR=1.63, 95%CI: 1.547–1.725) was obviously decreased for the 40 dB HL criterion model (OR=3.24, 95%CI: 2.880–3.636). The results of the ROC curves of the risk prediction model of the 25 dB HL criterion showed an AUC of 0.637 (see Figure 4). In terms of the enterprise type, the risk prediction model of the 25 dB HL criterion showed this as a protective factor against HFHL. The age and noise exposure years have no significant interactive ($P>0.05$).

By comparing the calibration plots for the risk prediction model of BHFTA over 40 dB and the risk prediction model of BHFTA over 25 dB (see Figure 5.), the risk prediction model of BHFTA over 40 dB had a downward trend for deviation with respect to the reference line. The risk prediction model of BHFTA over 25 dB was relatively stable compared with the risk prediction model of BHFTA over 40 dB. For both models, there was a certain deviation.

Based on the risk prediction model, the individual score sheet was calculated as described in the Appendix A. In the sheet, the corresponding values of the predictors of HFHL were included (Appendix A, Table A2). The user can calculate the total individual score as support for the calculation of the probability of HFHL risk. Regarding the results of the study, for a risk probability less than 5%, the individual score should not be over 35. For a risk probability less than 10%, the individual score should not be over 46. For a risk probability score less than 15%, the individual score should not be over 53. For a risk probability less than 30%, the individual score should not be over 67. For a risk probability less than 35%, the individual score should not be over 71. For a risk probability less than 40%, the individual score should not be over 74. The explanation and details for the HFHL-RSP are shows in Appendix A. the examples of HFHL-RSP are shows in Appendix B.

4 Discussion

HFHL is a significant occupational health concern in workers exposed to noise in many countries^[16]. Most research evidence has showed that long-term noise exposure in workers is likely to cause HFHL, especially in noise exposed workers^[17]. Previous studies have documented that HFHL is a common symptom of early-stage NIHL^[18,19]. Based on realistic demands, the development of both a prediction risk

model and the HFHL-RPS are necessary for prevention of hearing loss in occupationally noise exposed workers.

In this study, a total of 32121 noise exposed workers were enrolled. The findings showed 27.82% (n=8937) of workers had suspected HFHL and 10.06% (n=3232) of workers had HFHL. Workers exposed to noise had a mean exposure of 8.63 ± 7.86 years. Hearing loss is a historic scientific issue that is also difficult to diagnose because the national hearing loss criteria used for diagnostic purposes vary from nation to nation, which is regarded as a major problem that makes it difficult to compare results^[20]. In China, compared to other regions, the prevalence of HFHL is moderate^[21-23]. The predictors in the risk prediction model included sex, age, noise exposure time, industry type, and enterprise type. Based on the risk prediction model used in the study, the HFHL-RPS was developed to calculate the risk probability of noise exposed workers. Most of the research evidence suggested that age, sex, years of noise exposure and industry type were important predictors for changes in the hearing threshold^[24-26]. Our study has supported these results indirectly. For hearing loss, age is usually associated with years of noise exposure, which are not independent of each other^[27]. In general, age may have an impact on years of noise exposure. The risk prediction model used in the study, age and years of exposure had independent effects on HFHL in both the 25 dB and 40 dB HL criterion models, which may suggested that the model showed that the influence of noise exposure goes beyond the effects of age.

Previous research mainly focused on the prevalence and risk factors for hearing loss^[28,29] or correlation analysis^[30-32]. These findings have important implications for in-depth research on the consequences of noise exposure and are evidence that supports the occupational health policy and strategy. However, there is still insufficient evidence, which fails to extend the research type for exploratory development and results in a lack of technological support for practical application. For the prediction of hearing loss, the prediction formula for noise-induced deafness by OSI was introduced in 1999^[26] and has been widely used for many years. Compared with the OSI model, our prediction risk model has some differences. In this study, we mainly predicted HFHL, and the BHFTA was used to build an early-risk prediction model for earlier warning and prevention. Based on the model, we also developed the HFHL-RPS. The HFHL-RPS developed in this study, which is a direct research tool, is simple and easy to use in daily work for assessment of the noise-exposed worker. The HFHL-RPS is convenient for use by managers, or it can be used for self-checks. There are some successful examples of prediction models and risk score prediction used in clinical medicine, such as the risk score prediction model used for assessing dementia in patients with type 2 diabetes^[33], the risk prediction model used for severe postoperative^[34], and the LIPID heart failure risk-prediction model et al^[35]. In addition to Pentti Kuronen et al^[36] built the model of NIHL for military pilots, but this model mainly focused on a military pilot group. It is well-known that pilots have better health monitoring and management compared with workers. Therefore, this prediction model is not fit for noise exposed workers.

Regarding future HFHL research, the HFHL-RPS could be considered a variable in studies that explore the correlations between the NIHL risk probability and health outcomes, such as hypertension, heart disease,

etc. In the workplace, the HFHL-RPS has applied functions, including: (1) producing the RPS-Card, which is distributed to occupational health managers in each department (it can be used to periodically calculate the individual score of workers to predict the probability of HFHL) and (2) an RPS-Poster, which can be posted on the wall at the workplace. It can help workers to calculate the probability of HFHL by themselves to enhance awareness of hearing protection in routine work.

5 Conclusion

Out of a total of 32121 noise exposed workers enrolled in the study, 10.06% (n=3232) of workers had HFHL (BHFTA over 40 dB). Regarding the 40 dB and 25 dB HL criterion prediction models, sex, age (years), years of noise exposure, manufacturing industry, construction industry, mining industry, foreign enterprise, and private enterprise were predictive factors for HFHL. Based on the risk prediction models, which tested the effectiveness of the prediction model by calibration, the 40 dB HL criterion model was more effective than the 25 dB HL criterion model; however, the 25 dB HL criterion model was relatively stable compared to the 40 dB HL criterion model. The HFHL-RPS was developed using the prediction model based on the 40 dB HL criterion, and it can calculate the risk probability of HFHL rapidly. The risk prediction model and HFHL-RSP are necessary to enhance application-oriented research on HFHL and provide the technological support for interventions and management. Future studies can conduct in-depth research on the correlations between the HFHL risk probability and hearing loss-related diseases.

6 Strengths And Limitations

This paper has some **strengths**. It used the surveillance data of the NKODS, as the quality of these data and materials are more reliable. It built the prediction risk model and HFHL-RPS, which allow the effective utilization of the surveillance data and provide a research tool for use in the workplace. The HFHL-RPS is simple and can be widely applied to a large population, especially workers who are used to self-checking in routine work. It could also enhance the awareness of the prevention of HFHL.

However, the study also has **limitations**. Based on common sense, the direct predictor of hearing loss is noise cumulative exposure (NCE), but the surveillance system failed to collect the NCEs of individuals. If the data on area noise monitoring instead of NCE was inputted into the model, there might be deviations. Therefore, we used the noise exposure time to represent the level of noise exposure.

List Of Abbreviations

HFHL: high frequency hearing loss, 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 ischaemic 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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Author details

1.Department of Occupational and Environmental Health, West China School of Public Health and West China Fourth Hospital, Sichuan University, Renmin Road, Wuhou District, Chengdu, Sichuan, China
2.Department of Occupational Health and Radial Control, Sichuan Center for Disease Control and Prevention, Middle School Road No.6, Wuhou District, Chengdu, Sichuan, China
3.Department of Occupational Disease Prevention and Control, Pidun District Center for Disease Control and Prevention, Pitong Street, Pidun District, Chengdu, Sichuan, China

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Tables

Table 1. The Categories of HFHL level

HFHL levels	BHFTA (dB)
Normal hearing	<25
Suspected HFHL	25□
HFHL	40□
Severe HFHL	80□

Abbreviations. HFHL = high frequency hearing loss

BHFTA = binaural high frequency threshold average

Footnote. According to General Guidelines for Diagnosis of Occupational Diseases (GBZ/T 265-2014), 40 dB is a cut-point of HFHL.

Table 2. The characteristics of 32121 participants

Variables	Types	<i>n</i>	%
Sex	Male	23661	73.66
	Female	8460	26.34
Age group	20~	1908	5.94
	25~	4191	13.05
	30~	3888	12.10
	35~	4559	14.19
	40~	8868	27.61
	45~	8707	27.11
noise exposure group	0~	13511	42.06
	5~	8137	25.33
	10~	3742	11.65
	15~	2006	6.25
	20~	2775	8.64
	25~	1441	4.49
	30~	509	1.58
Industry type	Manufacturing	23295	72.52
	Construction	294	0.92
	Mining	3341	10.40
	Others	5191	16.16
Enterprise type	Public	9661	30.08
	Foreign	2446	7.61
	Private	20014	62.31

Table 3. Different characteristics of hearing level in exposed noise workers

Variables	BHFTA [n (%)]				<i>P</i> [*]
	<25 ^a	25~	40 ^b ~	80 ^c ~	
Sex					<0.001
Female	5957(70.41)	2160(25.53)	332(3.92)	11(0.13)	
Male	13995(59.15)	6777(28.64)	2809(11.87)	80(0.34)	
Age group					<0.001
20~	1443(75.63)	428(22.43)	37(1.94)	0(0.00)	
25~	3044(72.63)	1001(23.88)	145(3.46)	1(0.02)	
30~	2691(69.21)	991(25.49)	204(5.25)	2(0.05)	
35~	2824(61.94)	1292(28.34)	432(9.48)	11(0.24)	
40~	5257(59.28)	2615(29.49)	966(10.89)	30(0.34)	
45~	4693(53.90)	2610(29.98)	1357(15.59)	47(0.54)	
noise exposure group					<0.001
0~	8937(66.15)	3564(26.38)	990(7.33)	20(0.15)	
5~	5217(64.11)	2148(26.4)	754(9.27)	18(0.22)	
10~	2177(58.18)	1079(28.83)	469(12.53)	17(0.45)	
15~	1156(57.63)	576(28.71)	264(13.16)	10(0.50)	
20~	1508(54.34)	898(32.36)	362(13.05)	7(0.25)	
25~	699(48.51)	517(35.88)	215(14.92)	10(0.69)	
30~	258(50.69)	155(30.45)	87(17.09)	9(1.77)	
Industry type					<0.001
Manufacturing	14901(63.97)	6178(26.52)	2168(9.31)	48(0.21)	
Construction	107(36.39)	147(50.00)	39(13.27)	1(0.34)	
Mining	1448(43.34)	1284(38.43)	582(17.42)	27(0.81)	
Others	3496(67.35)	1328(25.58)	352(6.78)	15(0.29)	
Enterprise type					<0.001
Public	5433(56.24)	3328(34.45)	880(9.11)	20(0.21)	
Foreign	1626(66.48)	659(26.94)	160(6.54)	1(0.04)	
Private	12893(64.42)	4950(24.73)	2101(10.5)	70(0.35)	

Abbreviation. BHFTA= Binaural high-frequency threshold average

Footnote. n=32121

^a BHFTA<25 dB, defined as a normal hearing level

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

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

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

Table 4. The risk prediction model of 40 dB HL criterion

Predictors	OR	SE	Z	P*	CI-L	CI-U
Age group	1.08	0.003	23.96	<0.001	1.070	1.083
Sex	3.24	0.19	19.74	<0.001	2.880	3.636
Years of noise exposure	1.01	0.003	5.06	<0.001	1.008	1.018
Industry type						
[Ref: Others]						
Manufacturing	1.46	0.09	6.35	<0.001	1.302	1.647
Construction	2.14	0.39	4.11	<0.001	1.488	3.069
Mining	2.57	0.19	12.97	<0.001	2.225	2.957
Enterprise type						
[Ref: Public]						
Foreign	0.94	0.09	-0.72	0.474	0.781	1.122
Private	1.32	0.06	5.85	<0.001	1.200	1.442
Age*noise exposure years	1.00	0.0005	-5.73	<0.001	0.996	0.998

Abbreviations. OR=odds 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 (including the BHFTA=40 dB), “1” defined as BHFBA over 40 dB

Table 5. The risk prediction model of 25 dB HL criterion

Predictors	OR	SE	Z	P*	CI-L	CI-U
Age group	1.04	0.002	23.86	<0.001	1.038	1.045
Sex	1.63	0.05	17.39	<0.001	1.544	1.725
Years of noise exposure	1.00	0.002	2.41	0.016	1.001	1.007
Industry type						
[Ref: Others]						
Manufacturing	1.15	0.04	4.08	<0.001	1.073	1.224
Construction	3.54	0.45	9.88	<0.001	2.755	4.549
Mining	2.30	0.11	17.76	<0.001	2.100	2.525
Enterprise type						
[Ref: Public]						
Foreign	0.80	0.04	-4.59	<0.001	0.723	0.878
Private	0.74	0.02	-10.62	<0.001	0.705	0.786
Age*noise exposure years	1.00	0.0003	-0.78	0.434	0.999	1.000

Abbreviations. OR=odds 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 25 dB (including the BHFTA=25 dB), “1” defined as BHFBA over 25 dB

Appendix Tables

Table A1. HFHL-PRS calculation sheet

Predictors	Coefficient	Class	Class Mid-value	Reference	Distance	b-coefficient	Score
(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)
Age group	0.073	20	22.5	22.5	0.000		0
		25	27.5		0.367	6	
		30	32.5		0.733	12	
		35	37.5		1.100	17	
		40	42.5		1.467	23	
		45	47.5		1.833	29	
Sex	1.174	0	0	0	0.000	0	
		1	1		1.174	19	
Noise exposure years	0.013					0.063	
		0	2.5	2.5	0.000		0
		5	7.5		0.063		1
		10	12.5		0.126		2
		15	17.5		0.189		3
		20	22.5		0.253		4
		25	27.5		0.316		5
		30	32.5		0.379		6
Industry type	0.381	0	0	0	0.000	0	
		1	1		0.381	6	
Construction	0.760	0	0	0	0.000	0	
		1	1		0.760	12	
Mining	0.942	0	0	0	0.000	0	
		1	1		0.942	15	
Enterprise type	0.066	0	0	0	0	0	
		1	1		0.066	1	
Private	0.274	0	0	0	0.000	0	
		1	1		0.274	4	
Con-	-6.801						

Table A2. The sheet of individual score

Sex	Female	Male					
Score	0	19					
Age	20~	25~	30~	35~	40~	45~	
Score	0	6	12	17	23	29	
noise exposure time	0~	5~	10~	15~	20~	25~	30~
Score	0	1	2	3	4	5	6
Industry type	Others	Manufacturing	Mining	Construction			
Score	0	6	12	15			
enterprise type	Foreign	Public	Private				
Score	0	1	4				

Table A3 The sheet of HFHL risk probability

Score*	Risk (%) ^a		Score*	Risk (%) ^a		Score*	Risk (%) ^a		Score*	Risk (%) ^a
0	0.59		19	1.95		38	6.18		57	17.93
1	0.63		20	2.07		39	6.55		58	18.88
2	0.67		21	2.20		40	6.95		59	19.87
3	0.72		22	2.34		41	7.37		60	20.89
4	0.76		23	2.49		42	7.81		61	21.95
5	0.81		24	2.65		43	8.28		62	23.06
6	0.87		25	2.82		44	8.77		63	24.19
7	0.92		26	2.99		45	9.29		64	25.37
8	0.98		27	3.18		46	9.84		65	26.59
9	1.04		28	3.38		47	10.41		66	27.84
10	1.11		29	3.60		48	11.02		67	29.12
11	1.18		30	3.82		49	11.65		68	30.44
12	1.26		31	4.06		50	12.32		69	31.79
13	1.34		32	4.31		51	13.01		70	33.18
14	1.43		33	4.58		52	13.75		71	34.59
15	1.52		34	4.87		53	14.51		72	36.04
16	1.62		35	5.17		54	15.31		73	37.50
17	1.72		36	5.49		55	16.15		74	38.99
18	1.83		37	5.82		56	17.02		75	40.51

Footnote. * individual score, calculated by the information of noise exposed workers

^a risk probability of HFHL

Sheet C1. The selected value of the statistical distribution of hearing threshold levels

Age years	Frequency											
	Hz											
	500		1000		2000		3000		4000		6000	
	M	F	M	F	M	F	M	F	M	F	M	F
20-29	0	0	0	0	0	0	0	0	0	0	0	0
30-39	1	1	1	1	1	1	2	1	2	1	3	2
40-49	2	2	2	2	3	3	6	4	8	4	9	6
50-59	4	4	4	4	7	6	12	8	16	9	18	12
60-69	6	6	7	7	12	11	20	13	28	16	32	21
70-	9	9	11	11	19	16	31	20	43	24	49	32

Footnote. M=male; F=female.

Figures

Figure 1

The distribution of hearing level on workers

Figure 2

The ROC curve of risk prediction model (40dB HL criterion)

Figure 3

Interaction of age and noise exposure time to HFHL Footnote. 20= aged 20 years old; 30= aged 30 years old; 50=aged 50 years old

Figure 4

The ROC curve of risk prediction model (25dB HL criterion)

Figure 5

Compare the calibration plots between BHFTA as 40 dB HL criterion and 25 dB HL criterion

Supplementary Files

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- [Appendix.pdf](#)