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

CURRENT STATUS: UNDER REVIEW

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

Corresponding Author
yajialan501@126.com
ORCiD: https://orcid.org/0000-0002-9818-3057

DOI:
10.21203/rs.2.21152/v2

SUBJECT AREAS
Health Policy

KEYWORDS
High frequency hearing loss, Prediction model, Risk point score
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 (BHFTA ≥ 40 dB). Age (OR=1.08, 95% CI: 1.071–1.083), sex (OR=3.34, 95% CI: 2.880–3.636), noise exposure time (OR=1.01, 95% CI: 1.008–1.018), manufacturing industry (OR=1.46, 95% CI: 1.302–1.647), construction industry (OR=2.14, 95% CI: 1.488–3.069), mining industry (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) 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 (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\textsuperscript{[1]}. The WHO reported that 16\% of adult hearing loss could be caused by occupational noise exposure\textsuperscript{[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\textsuperscript{[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\textsuperscript{[4]}. China has many manufacturing, construction and mining companies. As a result, noise pollution is one of the key public hazards\textsuperscript{[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 (GDP)\textsuperscript{[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\textsuperscript{[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\textsuperscript{[9]}. It was the second most common occupational disease after occupational pneumoconiosis in the years 2016 and 2017\textsuperscript{[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\%\textsuperscript{[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\textsuperscript{[11]} or risk factor assessment\textsuperscript{[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\textsuperscript{[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\textsuperscript{[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 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.

**Funding**

Not applicable

**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.

**Acknowledgements**

The authors are grateful to the staff of Sichuan CDC and occupational health examination institutions, and grateful to the data managers of the national key occupational diseases survey.

**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, Pidu District Center for Disease Control and Prevention, Pitong Street, Pidu District, Chengdu, Sichuan, China

**References**

1. Seixas, N. S., Neitzel, R., Stover, B., Sheppard, L., Feeney, P., Mills, D., et al. 10-year prospective study of noise exposure and hearing damage among construction workers. Occup Environ Med, 2012;69(9):643-650. https://doi.org/10.1136/oemed-2011-100578. PMID:22693267

2. World Health Organization, Prevention of blindness and deafness and grades of hearing impairment. 2019. Available from: URL: http://www.who.int/en/news-room/fact-sheets/detail/deafness-and-hearing-loss

3. World Health Organization. Prevention of blindness and deafness. 2018 Available from: URL: http://www.who.int/pbd/deafness/estimates/en/.

4. Rowley, C. Development in China: position and nationhood in Asia and the world. Asia Pacific Business Review. 2012; 18(1): 87-92. https://doi.org/10.1080/13602381.2011.591653

5. Fuente, A., Hickson, L. Noise-induced hearing loss in Asia. International Journal of Audiology. 2011; 50(S1): S3-S10. https://doi.org/10.3109/14992027.2010.540584
6. Southern M.D. The total health expenditure of China rising from 6% of the country’s GDP in 2015 to 6.2% in 2016. 2015. Available from: URL:http://epaper.oeeee.com/epaper/A/html/201708/19/content_62524.htm (in Chinese).

7. Wang, B., Wu, C., Kang, L., Huang, L., Pan, W. What are the new challenges, goals, and tasks of occupational health in china's thirteenth five-year plan (13th FYP) period? J Occup Health. 2018;60(3):208-228 https://doi.org/10.1539/joh.2017-0275-RA

8. National health commission of the people's republic of China. Notification of occupational disease. 2014. Available from: URL: http://www.zywsw.com/news/6331.html (in Chinese)

9. National health commission of the people's republic of China. Notification of occupational disease from 2016 to 2017. 2017. Available from: URL:http://www.nhc.gov.cn/zyjks/zcwj2/201712/90667a5571e44ccca42e317b68f50c40.shtml (in Chinese)

10. National health commission of the people's republic of China. Notification of occupational disease in 2017. 2017. Available from: URL: http://www.nhc.gov.cn/zyjks/zcwj2/201712/90667a5571e44ccca42e317b68f50c40.shtml (in Chinese)

11. Jung, S.J., Woo, K.H., Park, W.D., et al. Related factors of high frequency hearing loss in the noise-exposed male workers. Korean J Occup Environ Med. 2000;12(2):187-197. https://doi.org/10.35371/kjoem.2000.12.2.187

12. Chang, T. Y., Liu, C. S., Huang, K. H., et al. High-frequency hearing loss, occupational noise exposure and hypertension: a cross-sectional study in male workers. Environmental Health A Global Access Science Source. 2011; 10(1):35-35.
13. Zhu, X.J., Li, T., Wang, D. Analysis on current situation in key occupational disease monitoring and countermeasures to problems. Chinese Journal of Industrial Medicine. 2016;29(06):403-407. https://doi.org/10.13631/j.cnki.zggyyx.2016.06.001 (in Chinese)

14. Shi, Y.B. Martin, W. H. Noise induced hearing loss in china: a potentially costly public health issue. Journal of Otology. 2013;8(1): 51-56. https://doi.org/10.1016/S1672-2930(13)50007-9

15. Wilson, P. W. F., D’Agostino, R. B., Levy, D., et al. Prediction of coronary heart disease using risk factor categories. Circulation. 1998; 97(18):1837-1847. https://doi.org/10.1161/01.cir.97.18.1837

16. Jun, H. J., Hwang, S. Y., Lee, S. H., et al. The prevalence of hearing loss in South Korea: Data from a population-based study. The Laryngoscope. 2015;125(3): 690-694. https://doi.org/10.1002/lary.24913

17. Maccà, I., Scapellato, M.L., Carrieri, M., et al. High-frequency hearing thresholds: effects of age, occupational ultrasound and noise exposure. International Archives of Occupational & Environmental Health, 2015; 88(2):197-211. https://doi.org/10.1007/s00420-014-0951-8

18. Abujamra, A. L., Escosteguy, J.R., Dall'Igna, C., et al. The use of high-frequency audiometry increases the diagnosis of asymptomatic hearing loss in pediatric patients treated with cisplatin-based chemotherapy. Pediatric Blood & Cancer. 2013; 60(3):474-478. https://doi.org/10.1002/pbc.24236

19. Gan, W. Q., Mannino, D. M. Occupational noise exposure, bilateral high-frequency hearing loss, and blood pressure. J Occup Environ Med. 2018; 60(5) :462-468. https://doi.org/10.1097/JOM.0000000000001232

20. Rabinowitz, P.M. The Public Health Significance of Noise-Induced Hearing Loss. Noise-
21. Li, J., Li, M.L., Yang, X.Y., et al. Analysis of occupational noise deafness monitoring in Tianjin, 2016. Modern Preventive Medicine. 2017; 44(23): 4252-4255.

22. Yi, S.W., Lu, C.H., Zhou, P., et al. Analysis on binaural high-frequency hearing threshold of welding workers in Nantong City. Occup and Health. 2018;34(23):3293-3295. (in Chinese)

23. Chen, X.W., Feng, H.Y., Zhang, J., et al. Results of pre-employment occupational health examination of 11298 noise exposed workers in Jiangyin City. Occup and Health. 2016;32(11):1476-1479. (in Chinese)

24. Zhang, H., Zhu, X., Guo, R., et al. Study on hearing impairment at high frequency among the flight cadets. Journal of Clinical Otorhinolaryngology. 2014; 28(13):968-971.

25. Pelegrin, A. C., Canuet, L., Ángeles A.R., et al. Predictive factors of occupational noise-induced hearing loss in Spanish workers: a prospective study. Noise Health. 2015;17(78):343-349. https://doi.org/10.4103/1463-1741.165064

26. ISO, ISO 1999. Acoustics—estimation of noise-induced hearing loss, in international standard. Switzerland: ISO, 2013:24.

27. Ciorba, A., Benatti, A., Bianchini, C., et al. High frequency hearing loss in the elderly: Effect of age and noise exposure in an Italian group. J Laryngol Otol. 2011; 125(8):776-780. https://doi.org/10.1017/S0022215111001101

28. Yuri, A., Platz, E. A., Niparko, J. K. Prevalence of hearing loss and differences by demographic characteristics among us adults: data from the national health and nutrition examination survey, 1999-2004. Arch Intern Med. 2008;168(14): 1522-1530. https://doi.org/10.1001/archinte.168.14.1522
29. El Dib, R.P., Silva, E.M., Morais, J.F. et al. Prevalence of high frequency hearing loss consistent with noise exposure among people working with sound systems and general population in Brazil: A cross-sectional study. BMC Public Health. 2008; 8(1):151-0. https://doi.org/10.1186/1471-2458-8-151

30. Zhong, H. C., Shao, Y. X., Chen, W. Q. Cardiovascular Disease Related Indices in Workers with Occupational Noise Induced Binaural High Frequency Hearing Loss. Journal of Environmental & Occupational Medicine. 2013; 30(3): 185-188.

31. Wilcox, S., Saunders, K., Osborn, A. et al. High frequency hearing loss correlated with mutations in the GJB2 gene. Hum Genet. 2000;106(4): 399–405. https://doi.org/10.1007/s0043900000273

32. Chen, S., Ni, Y., Zhang, L. et al. Noise exposure in occupational setting associated with elevated blood pressure in China. BMC Public Health. 2017;17(1): 107.https://doi.org/10.1186/s12889-017-4050-0

33. Li, C., I., Li, T., C., Liu, C., S., et al. Risk score prediction model for dementia in patients with type 2 diabetes. Eur J Neurol. 2018; (25)7: 976-983. https://doi.org/10.1111/ene.13642

34. Stenberg, E., Cao, Y., Szabo, E., et al. Risk prediction model for severe postoperative complication in bariatric surgery. Obes Surg. 2018;28(26):1869-1875. https://doi.org/10.1007/s11695-017-3099-2

35. Driscoll, A., Barnes, E.H., Blankenberg, S., Colquhoun, D.M., Tonkin, A. Predictors of incident heart failure in patients after an acute coronary syndrome: the LIPIID heart failure risk-prediction model. Int J Cardiol. 2017;248: 361-368. https://doi.org/10.1016/j.ijcard.2017.06.098

36. Kuronen, P., Toppila, E., Starck, J., et al. Modelling the risk of noise-induced hearing loss among military pilots. Int J Audiol. 2004;43(2), 79-84.
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       | $n$   | %  |
|---------------------------------|-------------|-------|----|
| 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 |
| noise exposure group            | 45~         | 8707  | 27.11 |
|                                 | 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 (%)] | p   |
|-------------------------------|---------------|-----|
|                               | <25<sup>a</sup> | 25~ | 40<sup>b</sup>~ | 80<sup>c</sup>~ |     |
| **Sex**                       |               |     |               |               | <0.|
| 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.|
| 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.|
| 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.|
| 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.|
| 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

<sup>a</sup> BHFTA<25 dB, defined as a normal hearing level

<sup>b</sup> BHFTA>40 dB, defined as a warning value of HFHL
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                  |      |      |      |       |       |       |
| 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                |      |      |      |       |       |       |
| 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 |
|---------------------|-------------|-------|-----------------|-----------|----------|
| (1)                 | (2)         | (3)   | (4)             | (5)       | (6)      |
| Age group           | 0.073       | 20    | 22.5            | 22.5      | 0.000    |
|                     |             | 25    | 27.5            | 0.367     |
|                     |             | 30    | 32.5            | 0.733     |
|                     |             | 35    | 37.5            | 1.100     |
|                     |             | 40    | 42.5            | 1.467     |
|                     |             | 45    | 47.5            | 1.833     |
| Sex                 | 1.174       | 0     | 0               | 0.000     |
|                     |             | 1     | 1               | 1.174     |
| Noise exposure years| 0.013       | 0     | 2.5             | 0.000     |
|                     |             | 5     | 7.5             | 0.063     |
|                     |             | 10    | 12.5            | 0.126     |
|                     |             | 15    | 17.5            | 0.189     |
|                     |             | 20    | 22.5            | 0.253     |
|                     |             | 25    | 27.5            | 0.316     |
|                     |             | 30    | 32.5            | 0.379     |
| Industry type       | 0.381       | 0     | 0               | 0.000     |
| Manufacturing       |             | 1     | 1               | 0.381     |
| Construction        | 0.760       | 0     | 0               | 0.000     |
| Mining              | 0.942       | 0     | 0               | 0.760     |
| Enterprise type     | 0.066       | 0     | 0               | 0.000     |
| Public              |             | 1     | 1               | 0.066     |
| Private             | 0.274       | 1     | 1               | 0.274     |
| Con-                | -6.801      |       |                 |           |

22
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 (%)<sup>a</sup> | Score* | Risk (%)<sup>a</sup> | Score* | Risk (%)<sup>a</sup> | Score* | Risk (%)<sup>a</sup> |
|--------|----------------------|--------|----------------------|--------|----------------------|--------|----------------------|
| 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

<sup>a</sup> risk probability of HFHL
Sheet C1. The selected value of the statistical distribution of hearing threshold levels

| Age (years) | 500 M | 500 F | 1000 M | 1000 F | 2000 M | 2000 F | 3000 M | 3000 F | 4000 M | 4000 F | 6000 M | 6000 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 (25 dB HL criterion)

Figure 5

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

Supplementary Files
This is a list of supplementary files associated with this preprint. Click to download.
Appendix.pdf