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Occupational noise-induced hearing loss in China: a systematic review and meta-analysis

Jiena Zhou ,[1] Zhihao Shi,[2] Lifang Zhou,[1] Yong Hu,[1] Meibian Zhang[1]

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[1]Occupational Health and Radiation Protection Department, Zhejiang Provincial Center for Disease Control and Prevention, Hangzhou, China
[2]School of medicine, Ningbo University, Ningbo, China

Correspondence to
Dr Meibian Zhang;
mbzhang@cdc.zj.cn

ABSTRACT

Objective Most of the Chinese occupational population are becoming at risk of noise-induced hearing loss (NIHL). However, there is a limited number of literature reviews on occupational NIHL in China. This study aimed to analyse the prevalence and characteristics of occupational NIHL in the Chinese population using data from relevant studies.

Design Systematic review and meta-analysis.

Methods From December 2019 to February 2020, we searched the literature through databases, including Web of Science, PubMed, MEDLINE, Scopus, the China National Knowledge Internet, Chinese Sci-Tech Journal Database (weip.com), WanFang Database and China United Library Database, for studies on NIHL in China published in 1993–2019 and analysed the correlation between NIHL and occupational exposure to noise, including exposure to complex noise and coexposure to noise and chemicals.

Results A total of 71 865 workers aged 33.5±8.7 years were occupationally exposed to 98.6±7.2 dB(A) (A-weighted decibels) noise for a duration of 9.9±8.4 years in the transportation, mining and typical manufacturing industries. The prevalence of occupational NIHL in China was 21.3%, of which 30.2% was related to high-frequency NIHL (HFNIHL), 9.0% to speech-frequency NIHL and 5.8% to noise-induced deafness. Among manufacturing workers, complex noise contributed to greater HFNIHL than Gaussian noise (overall weighted OR (OR)=1.95). Coexposure to noise and chemicals such as organic solvents, welding fumes, carbon monoxide and hydrogen sulfide led to greater HFNIHL than noise exposure alone (overall weighted OR=2.36). Male workers were more likely to experience HFNIHL than female workers (overall weighted OR=2.26). Age, noise level and exposure duration were also risk factors for HFNIHL (overall weighted OR=1.35, 5.63 and 1.75, respectively).

Conclusions The high prevalence of occupational NIHL in China was related to the wide distribution of noise in different industries as well as high-level and long-term noise exposure. The prevalence was further aggravated by exposure to complex noise or coexposure to noise and specific chemicals. Additional efforts are needed to reduce occupational noise exposure in China.

Strengths and limitations of this study

- The study attempts to addresses the limited number of literature reviews on occupational noise-induced hearing loss in China.
- A very large sample of workers with harmful exposure to occupational noise were included in the study.
- Our findings could provide a basis for the early prevention and control of occupational noise-induced hearing loss and the implementation of hearing protection programmes in China and other low/middle-income countries.
- The number of Chinese studies focusing on speech-frequency noise-induced hearing loss and deafness was limited, resulting in an insufficient sample in these categories.
- There were no well-designed prospective studies on noise, and there were insufficient cohort studies on the topic.

INTRODUCTION

Hearing loss is the most prevalent sensory disability worldwide, and noise-induced hearing loss (NIHL) has been a global public health problem. NIHL is a type of progressive sensorineural hearing loss caused by noise exposure. With the rapid development of industrialisation, people are increasingly becoming at risk of NIHL. WHO estimated that 10% of the global population are exposed to noise pollution, of whom 5.3% experience NIHL.[1 2]

Approximately 16% of adult hearing loss cases are associated with exposure to noise in the workplace.[3] Occupational NIHL is the most prevalent occupational disease worldwide, with >10% of workers in developed countries having NIHL.[4] About 600 million workers are exposed to harmful levels of noise globally.[5] Each year, about 22 million workers are exposed to harmful levels of noise in the USA,[6] while about 1.7 million workers are exposed to >85 dB(A) (A-weighted decibels) of noise in Britain.[7] Occupational noise-induced deafness (NID) accounts for >60% of all occupational diseases reported in Norway.[8] From 2002 to 2005, 16.2%%–22.9% of Korean workers were exposed to workplace noise exceeding 85 dB(A), and 4483 workers had NID.[9] In China, >10 million workers are exposed to harmful noise.[10] In recent years, China has been facing a change in the spectrum of occupational diseases, that is, NID followed by pneumoconiosis has replaced occupational poisoning as the second most common occupational disease, with an annual increase of 20%.[11] The prevalence of occupational NIHL in China is estimated to be >20%.[12] In some low/middle-income countries, workers exposed to noise in the transportation and manufacturing industries account for a high prevalence of NIHL, ranging from 18% to 67%.[13 14]

Industrial noise may consist of steady noise (Gaussian noise) or complex noise (non-Gaussian noise), with the latter being the dominant type in the workplace. Complex noise is composed of transient high-energy impulsive noise superimposed on stationary (Gaussian) background noise.[15] Animal experiments and a few epidemiological surveys revealed that exposure to complex noise could lead to greater hearing damage and is not only associated with noise energy but also with its complex temporal structure.[16] These findings have challenged the appropriateness of the international noise exposure standard (ISO-1999, 2013)[17 18] and the safety of the occupational exposure limit of noise (eg, 85 dB(A)), in which the measurement of noise energy (the equivalent sound level) serves as the sole method for evaluating noise based on the 'equal energy hypothesis.'[19–21] Currently, kurtosis is considered a good parameter for reflecting the temporal structure and impulsiveness of noise, and its combination with energy is an effective indicator for evaluating hearing loss caused by complex noise.[22 23] In addition, combined exposure to noise and chemicals may exacerbate hearing loss.[10 24–27] Epidemiological studies have shown that exposure to mixed organic solvents is associated with an excessive risk of developing hearing loss, with or without concurrent noise exposure, in humans. Workers from a wide range of industrial sectors, whose jobs involve the use of paints, thinners, lacquers and printing inks, are usually exposed to mixtures of xylene, toluene, benzene, methyl ethyl ketone.

Although a large number of workers in China are reported to be at high risk of developing NIHL, the epidemiological characteristics and prevalence of NIHL are not well understood, and there is a limited number of literature reviews on the topic. This study, therefore, aimed to review the literature regarding NIHL in the Chinese occupational population and analyse the data to understand the prevalence and characteristics of NIHL in the workplace, including exposure to different types of noise or coexposure to noise and chemicals. Our findings could provide a basis for the early prevention and control of occupational NIHL and the implementation of hearing protection programmes in China and other low/middle-income countries.

METHODS

Literature retrieval

We used English literature databases such as the Web of Science, PubMed, MEDLINE and Scopus. We also searched Chinese literature databases including the China National Knowledge Internet, Chinese Sci-Tech Journal Database (weip.com), WanFang Database and China United Library Database. The keywords searched were "noise-induced hearing loss," "noise and hearing loss," "noise-induced deafness," "NIHL," "hearing threshold shift," "complex noise," "co-exposure," and "noise and chemical exposure." The date of search was between December 2019 and February 2020.

Inclusion and exclusion criteria

We included studies on overt hearing loss associated with occupational exposure to noise in Chinese populations published in Chinese and English journals from 1993 to 2019. The inclusion criteria were as follows: (1) studies with Chinese subjects, (2) studies whose subjects had a clear history of occupational exposure to noise and (3) studies in accordance with an occupational health standard in China (eg, Diagnosis of Occupational NID, GBZ 49–2014).[28] High-frequency NIHL (HFNIHL) was defined as an average hearing threshold of ≥40 dB for binaural high-frequency sound (3, 4 and 6 kHz) or an average hearing threshold in either ear of ≥30 dB at 3, 4 and 6 kHz. Speech-frequency NIHL (SFNIHL) was defined as an average hearing threshold of ≥26 dB in the better ear at speech frequencies of 500, 1000 and 2000 Hz. Meanwhile, NID was defined according to the average hearing threshold for high-frequency and speech-frequency sounds, progressive hearing loss, tinnitus and other symptoms, and pure-tone audiometry results for sensorineural deafness.

The exclusion criteria were as follows: (1) studies on hearing loss or deafness that was not associated with occupational exposure to noise; (2) studies on noise exposure not associated with the auditory system; (3) studies on the clinical treatment of NIHL or NID; (4) studies on the clinical diagnosis of NIHL or NID; (5) studies on animal experiments investigating NIHL or NID; (6) studies on noise in cells and genetics; (7) studies on noise with unclear or incomplete results or unclear description of subjects;or (8) books, conferences and news articles on noise exposure.

Data analysis and extraction

EndNote software was used to screen and extract the relevant literature. Information regarding the study design, type of industry, noise level and hearing loss and general information about the target population were extracted from each study for systematic review and meta-analysis. A meta-analysis is a research study that synthesises and analyses statistical data from multiple independent studies.[29] Briefly, after relevant questions were formed, the criteria for collecting and selecting literature data were established based on the research purpose. The collected literature data were then characterised and classified. Finally, comprehensive weighted average statistics (eg, overall weighted ORs were calculated based on the characteristics of the studies, including the subject characteristics (eg, sex, age and exposure duration), type of noise (complex noise vs Gaussian noise) and exposure characteristics (noise exposure vs no noise exposure, coexposure to noise and chemicals vs noise exposure).

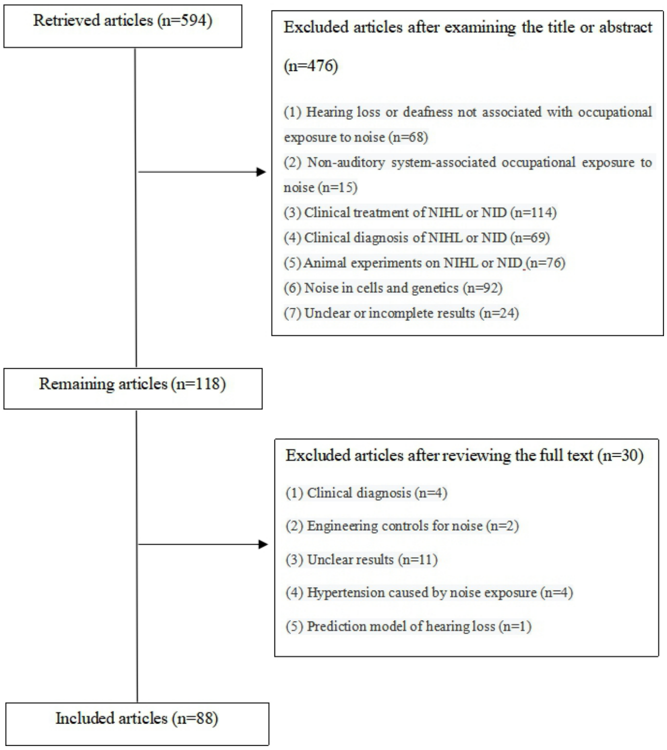

Figure 1 Flow chart of the selection of articles for meta-analysis. NID, noise-induced deafness; NIHL, noise-induced hearing loss.

A total of 594 articles were retrieved. Among them, 476 were excluded after examining the title or abstract based on the exclusion criteria. Of the 118 articles, 30 were further excluded after reviewing the full text. The remaining 88 articles, which consisted of cross-sectional studies (79.5%), cohort studies (3.4%) and hot-spot studies (17.1%) on exposure to complex noise and coexposure to noise and chemicals, were included in the systematic review and meta-analysis (figure 1).

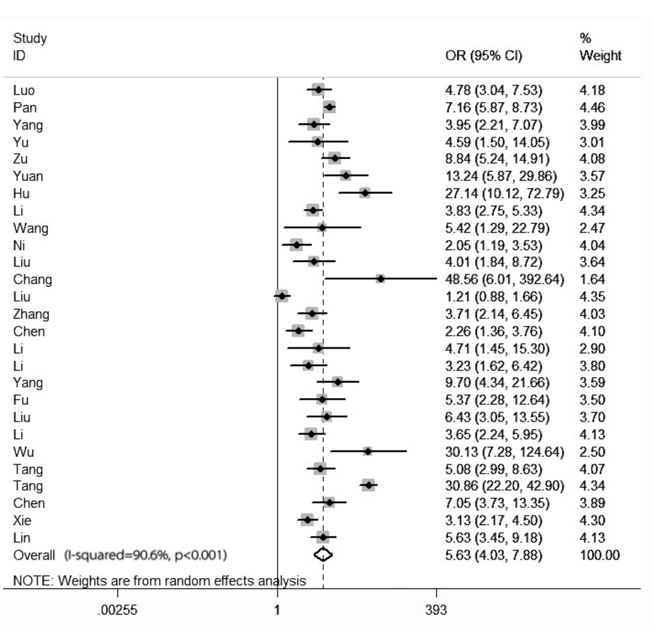

Figure 2 Forest plots of cross-sectional studies.

Patient and public involvement

No patient involved in the study.

RESULTS

Cross-sectional studies on NIHL prevalence

Online supplemental appendix table 1 describes five studies on occupational NIHL in the transportation industry (eg, ship, railway and air transportation), with a total sample size of 5810 workers. For this sector, the maximum level of noise in the workplace was reported to be 97.1 dB(A). The prevalence of HFNIHL, SFNIHL and NID among the workers was 11.6%, 5.6% and 5.9%, respectively.

Online supplemental appendix table 2 shows four studies on noise in the mining industry, with a total sample size of 2245 workers. Among the studies, the average maximum level of noise reported in the workplace was 106.2 dB(A). The prevalence of HFNIHL, SFNIHL and NID among the workers was 65.1%, 7.0% and 10.3%, respectively.

Online supplemental appendix table 3 shows a total of 34 studies with a total sample size of 34 656 workers in the manufacturing industries were analysed. The most common manufacturing industries associated with high noise exposure were typical enterprises, such as automobile manufacturing, air conditioning manufacturing and the textile industry, whose workers were mainly young male adults. The average noise level in these workplaces was 96.2±5.1 dB(A). The prevalence of HFNIHL, SFNIHL and NID was 30.9%, 8.5% and 7.1%, respectively.

Cross-sectional studies with references to NIHL prevalence

Online supplemental appendix table 4 shows a total of 27 cross-sectional studies with references to occupational NIHL. There were 18 319 workers in the exposed groups with average noise levels of 102.2±7.2 dB(A) and 7399 controls with average noise levels of 63.5±3.8 dB(A). The prevalence of HFNIHL among the exposed workers was 28.7%, which was significantly higher than that (9.9%) in the controls. The prevalence of SFNIHL was also significantly higher in the exposed groups than in the control groups. The fixed-effects model of the meta-analysis showed that the overall weighted OR for noise exposure as a risk factor for HFNIHL was 5.63 (95% CI (CI), 4.03–7.88). Moreover, the forest plot (figure 2) displayed the magnitude and uncertainty of the 95% CI of OR in each effect size in the dataset. The 95% CI of OR in each study was >1.

Typical cohort studies on NIHL incidence

Only three cohort studies dynamically investigated hearing loss in 2999 workers from the oil field, electrolytic aluminium and automobile manufacturing industries (table 1). The results showed that the incidence of

Table 1 Meta-analysis of typical cohort studies on NIHL incidence

Author	Type of factory	Population		Study duration	Years of follow-up	Noise level (max or mean)(dB(A))	NIHL incidence (%)		
		N	Exposure duration (years)				HFNIHL	SFNIHL	Average
Jing[59]	Oil field	673	1.0–30.0	2006–2010	5	106.8	30.6	3.7	17.2
Xu[60]	Electrolytic aluminium	1929	1.0–30.0	2008–2012	5	87.1±2.2	16.6	10.9	13.8
He[61]	Automobile	397	8.8±8.7	2014–2016	3	101.3	34.3	2.3	18.3
Total	–	2999	8.8±8.7	2006–2016	–	98.4±7.2	22.1	8.1	15.1

dB(A), A-weighted decibels; HFNIHL, high-frequency noise-induced hearing loss; NIHL, noise-induced hearing loss; SFNIHL, speech-frequency noise-induced hearing loss.

HFNIHL and SFNIHL in these sectors was 22.1% and 8.1%, respectively. Moreover, cumulative noise exposure (CNE) was shown to aggravate hearing loss, and the length of service was positively correlated with the incidence of hearing loss.

Hot-spot research on noise exposure and NIHL

NIHL associated with complex noise

Seven studies were about NIHL associated with complex noise versus Gaussian noise. There were no significant differences in CNE, noise level, age or sex between the Gaussian noise groups and complex noise groups (p>0.05) (table 2). The kurtosis of complex noise (33.0±51.7) was significantly higher than that of Gaussian noise (3.3±0.3). The prevalence of HFNIHL in the complex noise groups was 34.5%, which was significantly higher than that (25.6%) in the Gaussian noise groups (χ^2 test, p<0.01). The fixed-effects model of the meta-analysis showed that the overall weighted OR for complex noise affecting HFNIHL prevalence was 1.95.

NIHL associated with coexposure to noise and chemicals

Table 3 shows eight studies regarding NIHL associated with coexposure to noise and chemicals (eg, dust, benzene, welding fumes, n-hexane, hydrogen, carbon, ethylbenzene) versus exposure to noise alone. There were no significant differences in noise level, age or sex between the noise groups and coexposure groups (p>0.05). Moreover, the prevalence of coexposure to noise and chemicals was 54.2%, which was significantly higher than that of exposure to noise alone (30.3%) (χ^2 test, p<0.01). The fixed-effects model of the meta-analysis showed that the overall weighted OR for coexposure to noise and chemicals was 2.36.

Summary of the epidemiological characteristics of occupational NIHL

A total of 71 865 workers (males, 82.7%) aged 33.5±8.7 years, who had an average noise exposure duration of 9.9±8.4 years, were included in this study (table 4). Their average levels of noise exposure were 98.6±7.2 dB(A), and most of them were from the transportation, mining and manufacturing industries. Combining all the data, we found that the general prevalence of occupational NIHL during the past 26 years in China was 21.3%, of which 30.2%, 9.0% and 5.8% accounted for the prevalence of HFNIHL, SFNIHL and NID, respectively. The overall weighted ORs for noise, complex noise, coexposure to noise and specific chemicals, male sex, age and exposure duration were 5.63, 1.95, 2.36, 2.26, 1.35 and 1.75, respectively (table 5).

DISCUSSION

This study reviewed and analysed literature data on occupational NIHL in China in the past 26 years. The results showed that workers with NIHL was mainly from typical manufacturing industries (eg, textile, automobile manufacturing, metal processing).[30 31] Our findings are consistent with those in other countries. In the USA, workers at risk of occupational NIHL include those employed in construction, manufacturing, mining, agriculture, utilities, transportation and the military, as well as musicians,[5] with approximately 82% of workers with hearing loss coming from the manufacturing industries.[32] In Asia, sources of noise pollution mainly comprise the manufacturing, transportation, mining and agricultural industries.[13 33] In this study, we found that the average noise level for Chinese workers from these industries was 98.6±7.2 dB(A), which exceeds the occupational exposure limit of 85 dB(A). Noise intensity was positively correlated with the prevalence of hearing loss (overall weighted OR=5.63). The general prevalence of NIHL in China was 21.3%, of which 30.2% is related to high-frequency hearing loss. These findings suggest that the wide distribution of noise in different industries, high levels of noise exposure and long-term exposure to noise in the workplace were the main risk factors for the high prevalence of NIHL in China.

Our findings on the prevalence and characteristics of noise exposure and NIHL in China are similar to those in other countries. For instance, Soltanzadeh *et al* reported that the occupational noise level in Iran reached 90.29 dB(A), while the overall hearing threshold was 26.44±8.09 dB.[5] Kim also reported that >90% of the workplace noise

Table 2 Prevalence of NIHL associated with complex noise versus Gaussian noise

			Population				Noise level			NIHL (%)			HFNIHL prevalence	
Author	Group	Type of factory	N	Age (years)	Exposure duration (years)	Male (%)	(max or mean) (dB(A))	CNE(dB(A)·year)	Kurtosis (mean±SD)	HFNIHL	SFNIHL	NID	OR	95% CI
Liu[62]	Gaussian	Clothing	1421	32.8±6.9	3.6±2.1	79.9	93.4±5.0	99.1±8.2	–	9.2	–	6.8	0.83	0.61 to 1.11
	Complex	Hardware	957	32.5±8.3	4.1±1.8	78.0	93.1±4.2	99.0±7.8	–	7.7	–	6.3		
Xie[63]	Gaussian	Textile	26	35.7±8.2	9.8±5.9	76.9	95.1±1.3	104.0±4.4	–	38.5	7.7	–	2.53	1.04 to 6.14
	Complex	Rolling	98	37.4±6.5	9.9±7.4	84.7	94.9±4.0	103.5±6.3	–	61.2	17.4	–		
Zheng[64]	Gaussian	Machinery	399	33.6±9.9	11.6±8.6	70.2	100.0	96.8±6.0	–	56.6	25.8	–	2.94	2.06 to 4.19
	Complex	Machinery	271	30.6±8.8	10.1±8.2	86.7	102.1	104.8±5.0	–	79.3	39.1	–		
Zhang[65]	Gaussian	Machinery	202	–	–	100.0	93.4±1.5	–	–	13.4	–	0.5	9.13	5.60 to 14.89
	Complex	Machinery	212	–	–	100.0	92.7±1.0	–	–	58.5	–	6.1		
Zhao[66]	Gaussian	Textile	163	31.5±8.7	12.7±8.4	100.0	99.9±4.2	110.6±6.0	3.3±0.3	64.4	–	–	1.06	0.48 to 2.34
	Complex	Metal	32	35.1±7.2	12.3±7.1	37.5	95.2±3.1	103.2±4.2	40.0±44.0	65.6	–	–		
Xie[67]	Gaussian	Textile	163	31.7±8.7	12.7±8.4	49.7	101.2±4.7	110.3±6.1	3.2±0.3	64.4	–	–	0.74	0.48 to 1.15
	Complex	Steel	178	38.1±7.6	13.0±8.0	100	93.6±5.7	103.6±7.2	37.1±52.9	57.3	–	–		
Zhang[68]	Gaussian	Pharmaceutical	62	36.8±6.6	–	66.1	92.2±5.3	97.6±5.5	–	32.3	–	–	2.59	1.13 to 5.96
	Complex	Forging	38	32.9±5.5	–	100.0	95.2±3.9	97.0±6.4	–	55.3	–	–		
Total	Gaussian	–	2436	32.9±7.9	6.5±6.6	92.1	96.3±6.1	101.9±8.8	3.3±0.3	25.6	24.7	6.1	1.95	0.93 to 4.09
	Complex	–	1786	33.2±8.5	6.7±6.1	67.8	94.0±4.8	103.3±6.5	33.0±51.7	34.5	33.3	6.2		

CNE, cumulative noise exposure; dB(A), A-weighted decibels; HFNIHL, high-frequency noise-induced hearing loss; NID, noise-induced deafness; ;NIHL, noise-induced hearing loss; SFNIHL, speech-frequency noise-induced hearing loss.

Table 3 NIHL associated with coexposure to noise and specific chemicals

Author	Group	Type of factory	Population				Noise level (max or mean)(dB(A))	NIHL (%)			HFNIHL prevalence	
			N	Age (years)	Exposure duration (years)	Male (%)		HFNIHL	SFNIHL	NID	OR	95% CI
Zhang[69]	Noise	Automobile	1604	33.8±3.5	–	–	86.9	25.4	2.6	–	2.09	1.54 to 2.83
	Coexposure to welding fumes and noise	Tires	202	33.8±3.5	–	–	95.9	41.6	5.9	–		
Song[70]	Noise	Pharmaceutical	169	–	–	–	85	40.8	10.7	–	2.11	1.28 to 3.47
	Coexposure to benzene and noise		103	–	5.0–10.0	–	85	59.2	17.5	–		
Chen[71]	Noise	Metal components	59	33.8±5.6	13.6±5.2	–	94.0	29.2	–	–	3.89	1.75 to 8.63
	Coexposure to welding fumes and noise		65	33.7±5.2	13.6±5.7	–	100.0	61.5	–	–		
Xiong[72]	Noise	Technological	45	36.8±10.6	12.6±11.4	–	87.2	33.3	13.3	–	2.12	1.02 to 4.39
	Coexposure to n-hexane and noise	Printing	105	36.9±10.2	14.1±10.7	–	86.4	51.4	21.0	–		
Wu[73]	Noise	Petrochemical plants	52	30.0±4.0	14.7±6.2	–	81.6	24.0	–	–	1.45	0.82 to 2.57
	Coexposure to hydrogen sulfide and noise		73	29.8±4.1	14.3±6.0	–	85.5	31.5	–	–		
Wu[74]	Noise	Steel	59	33.7±5.6	14.0±4.8	84.7	92.0	28.1	11.5	–	3.83	2.18 to 6.76
	Coexposure to welding fumes and noise		65	33.7±5.2	13.6±5.7	87.7	92.0	60.0	35.4	–		
Wang[75]	Noise	Chemical products	106	29.3±5.5	11.2±9.0	69.8	103.0	17.9	–	0.0	1.87	1.09 to 3.21
	Coexposure to carbon monoxide and noise		427	30.3±8.5	9.9±6.8	89.0	104.0	29.0	–	2.3		
Zhang[76]	Noise	Power stations	290	–	–	100	84.3	56.9	–	–	2.92	2.14 to 3.98
	Coexposure to ethylbenzene and noise	Petrochemical plants	553	–	–	100	83.1	79.4	–	–		
Total	Noise	–	3001	33.6±4.1	12.9±7.9	77.6	89.3±6.4	30.3	3.9	0.0	2.36	1.92 to 2.92
	Coexposure	–	3612	33.3±5.2	11.6±7.5	90.5	91.5±7.3	54.2	15.8	2.3		

dB(A), A-weighted decibels; HFNIHL, high-frequency noise-induced hearing loss; NID, noise-induced deafness; NIHL, noise-induced hearing loss; SFNIHL, speech-frequency noise-induced hearing loss.

Table 4 Summary of the epidemiological characteristics of occupational NIHL in China

Group	Type of industry	Population					NIHL (%)			
		N	Age (years)	Exposure duration (years)	Male (%)	Noise level (max or mean)(dB(A))	HFNIHL	SFNIHL	NID	Average
Cross-sectional study[77–81]	Transportation	5810	39.9±6.8	17.9±10.6	93.0	93.0	11.6	5.6	5.9	8.9
Cross-sectional study[82–85]	Mining	2245	34.4±9.3	8.0±4.0	100.0	106.2	65.1	7.0	10.3	34.2
Cross-sectional study[44 86–118]	Manufacturing	34 656	32.6±8.9	7.9±6.3	81.6	96.2±5.1	30.9	8.5	7.1	23.1
Cross-sectional study with references[119–145]	Manufacturing	18 319	33.9±9.4	12.6±9.8	81.4	102.2±7.2	28.7	10.0	2.3	19.6
Complex noise[62–68]	Manufacturing	4222	33.0±8.2	6.6±6.4	81.8	95.2±5.6	29.4	28.7	6.2	21.0
Co-exposure[69–76]	Manufacturing	6613	33.4±4.7	12.0±7.6	84.0	90.4±7.0	39.9	6.3	1.9	25.4
Total	–	71 865	33.5±8.7	9.9±8.4	82.7	98.6±7.2	30.2	9.0	5.8	21.3

dB(A), A-weighted decibels; HFNIHL, high-frequency noise-induced hearing loss; NID, noise-induced deafness; NIHL, noise-induced hearing loss; SFNIHL, speech-frequency noise-induced hearing loss.

levels in South Korea exceeded the occupational exposure limit, and 92.9% of suspected occupational diseases were occupational NID.[34] The Centers for Disease Control and Prevention estimate that about 9 million workers are exposed to daily average sound levels of ≥85 dB(A) and about 26 million Americans experience NIHL, with a prevalence of 15%.[35 36] Rubak *et al* also found a dose–response relationship between NIHL and noise intensity among workers in Denmark, that is, a higher noise level was associated with a higher prevalence of NIHL.[37]

The occurrence of NIHL is usually affected by individual factors such as sex and age. In this study, the average age of the workers was 33.5±8.7 years, and the risk of HFNIHL increased with age. Meanwhile, sex was risk factor for HFNIHL, with its prevalence being significantly higher in men than in women. These findings are consistent with those of other studies. Most cases of occupational NID in developed areas of China occurred in young adults, with an average age of 40 years.[38 39] Some studies also showed that the prevalence of NIHL in workers with high noise exposure was significantly higher in men than in women, and the workers with NIHL comprised young and middle-aged people.[40–42] Although the hearing threshold was already adjusted for age in most studies, age might still influence the occurrence of HFNIHL.[41 43]

In this review, the average duration of noise exposure among Chinese workers was 9.9±8.4 years, which could be a significant contributing factor to the prevalence of high-frequency hearing loss (overall weighted OR=1.75). NIHL can result from the cumulative effects of increased durations and levels of noise exposure. High noise levels can damage the outer hair cells, but with continuous noise exposure, the damage can extend to the inner hair cells, supporting cells, cochlear vascularis and spiral ganglion cells.[39] Results of previous studies have shown that the general prevalence of NIHL increased with exposure duration, with the disease developing rapidly during the first 10 years of exposure, reaching a peak in 10–15 years, and then entering a plateau after 15 years.[44–46]

This study also showed that exposure to complex noise among workers led to a greater risk of hearing loss than exposure to Gaussian noise did. The kurtosis for the complex noise group was higher than that for the Gaussian noise group, and there were no significant differences in noise energy levels between both groups. The overall weighted OR for complex noise was 1.95. These findings indicate that the temporal structure of complex noise was a new determinant for NIHL. Moreover, the ORs in the machinery subgroups were 9.13 and 2.94, which were relatively higher than those in other subgroups. The reason might be related to the complexity of the temporal structure of noise generated from mechanical processes, making complex noise from the machinery industry a greater contributor to HFNIHL than complex noise from other industries.[15 47] Animal experiments have shown that complex noise was more destructive to the hearing of chinchillas than Gaussian noise, and these studies have recommended that the

Table 5 ORs for key factors influencing HFNIHL prevalence

No	Factor	Group	HFNIHL (%)	Overall weighted OR for HFNIHL	95% CI
1	Noise	Noise	28.7	5.63	4.03 to 7.88
		Control	9.9		
2	Complex noise	Complex noise	34.5	1.95	1.06 to 7.84
		Gaussian noise	25.6		
3	Coexposure	Coexposure	54.2	2.36	1.92 to 2.92
		Noise	30.3		
4	Sex	Male	17.5	2.26	1.62 to 3.19
		Female	7.2		
5	Age	Age >33 years	29.8	1.35	1.30 to 1.40
		Age ≤33 years	23.9		
6	Exposure duration	≤10 years	25.1	1.75	1.64 to 1.87
		>10 years	37.0		

HFNIHL, high-frequency noise-induced hearing loss.;

kurtosis reflecting the temporal structure of complex noise is a good parameter for classifying the effects of complex noise versus Gaussian noise.[15 16] Several epidemiological studies have also demonstrated that exposure to complex noise could lead to greater hearing loss than exposure to Gaussian noise and that the standard noise limit recommended by ISO-1999 was not within the safe threshold.[48 49] A typical impulse noise was also reported to cause more hearing damage than continuous noise.[50] Moreover, cross-sectional studies considered the kurtosis metric combined with noise energy as a good parameter for determining and preventing the hazards to hearing posed by industrial environments with high noise levels.[47 51 52]

In addition to noise, other occupational hazards might affect the hearing of workers. This study showed that combined exposure to noise and specific chemicals (eg, organic solvents, welding fumes, carbon monoxide and hydrogen sulfide) aggravated hearing loss (overall weighted OR=2.36). The combined effects might be related to auditory neurotoxicity induced by these chemicals. Animal experiments have demonstrated that solvents such as toluene, styrene, xylene and ethyl benzene could affect the auditory function through their toxic action on the organ of Corti, the auditory pathways and the middle-ear reflex.[53] Zhang *et al* reported that styrene might have an effect on the auditory system, and the combined effects of toluene, xylene, and noise could lead to a significant increase in the hearing threshold.[54] Campo *et al* found that the temporal structure of noise was able to modify the ototoxicity of styrene in experimental animals and a moderate level of styrene enhanced the cochlear damage caused by impulse noise. A pilot study showed that workers exposed to non-Gaussian noise and solvents presented a significantly worse hearing threshold than those exposed only to non-Gaussian noise.[55] A meta-analysis also showed that among 7530 industrial workers, those exposed to both noise and organic solvents had a significantly greater risk of hearing loss than those exposed to noise alone.[26] Furthermore, as previously mentioned, several epidemiological studies have shown that exposure to various organic solvents was associated with an excessive risk of developing hearing loss, with or without concurrent noise exposure, in humans.[56–58]

This study has several limitations. The number of Chinese studies focusing on SFNIHL and deafness was limited, resulting in an insufficient sample in these categories. There was also a lack of well-designed prospective studies on noise, which made it impossible to determine the incidence of NIHL in China. Only three cohort studies with 2999 subjects were included in this study, and the rest were mainly cross-sectional studies; therefore, the determination of correlation between occupational exposure factors and NIHL was limited.

CONCLUSIONS

Based on the above findings, the following conclusions could be drawn: (1) In China, a large proportion of the population exposed to occupational noise comprised young male manufacturing workers, and the average duration of exposure to harmful noise levels was >9.0 years. The general prevalence of occupational NIHL in China was 21.3%, and among the types of NIHL, HFNIHL had the highest prevalence; (2) The prevalence of HFNIHL increased with higher noise levels and higher duration of exposure and was affected by individual factors such as age and sex; (3) Exposure to complex noise and coexposure to noise and specific chemicals could increase the risk of occupational NIHL and (4) Finally, the high prevalence of occupational NIHL in China was related to the wide distribution of noise in different industries as well as high-level and long-term noise exposure.

Our findings suggest the need for additional efforts to reduce noise exposure among Chinese workers, which are made possible by carrying out industrial noise monitoring and risk assessment of hearing loss, further strengthening the implementation of hearing protection programmes for workers, and conducting well-designed epidemiological studies on industrial noise, complex noise, and coexposure to noise and chemicals.

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ORCID iD

Jiena Zhou http://orcid.org/0000-0002-6839-737X

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