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ORIGINAL ARTICLE

# Prevalence and determinants of noise-induced hearing loss among workers in the automotive industry in China: A pilot study

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## Abstract

**Objective:** Data on noise-induced hearing loss (NIHL) in the automotive industry are rare. This pilot study aimed to investigate the prevalence and determinants of NIHL among workers in the automotive industry in China.

**Methods:** A cross-sectional survey was conducted with 6557 participants from the automotive industry. The questionnaire survey was administered, and individual noise exposure level ($L_{Aeq.8h}$) and hearing loss level were measured.

**Results:** Of participants, 96.43% were male; the median age was 27.0 years and 28.82% had NIHL defined as adjusted high-frequency noise-induced hearing loss (AHFNIHL). Concerning individual noise levels ($L_{Aeq.8h}$), 62.53% exceeded 85 dB(A), which were mainly concentrated in various jobs, including metal cutting, surface treatment, stamping, welding, grinding, assembly, plastic molding, and forging. Each typical noise source generated its own unique temporal waveform shape with the type of non-Gaussian noise. Of workers, 53.15% regularly used hearing protector devices (HPD), and the proportion of regular HPD use increased with $L_{Aeq.8h}$. The trend test showed that the prevalence of AHFNIHL in male workers significantly increased with an increase in $L_{Aeq.8h}$ at <94 dB(A) and cumulative noise exposure (CNE) in each age group ($P < 0.05$ or $P < 0.01$). A logistic regression analysis showed that CNE and HPD usage frequency were important factors contributing to AHFNIHL.

**Conclusions:** CNE and HPD usage frequency were the determinants for NIHL. Much more human surveys are needed to understand the prevalence and determinants of NIHL in the automotive industry in China.

KEYWORDS
automotive industry, determinants, hearing loss, noise, prevalence

# 1 | INTRODUCTION

Noise-induced hearing loss (NIHL), known as the second leading cause of sensorineural hearing loss after presbycusis, is a leading occupational disease today. The World Health Organization (WHO) estimated that 466 million people globally had disabling hearing loss in the world[1] and 16% of the disabling hearing loss in adults might be attributed to occupational exposure to noise.[2] NIHL can diminish the ability to communicate with the surrounding world and monitor environmental sounds, leading to an increasing risk of injury and reduced productivity.[3] Outside the workplace, those with NIHL can suffer from communication interference,[4] nonauditory health effects including cognitive impairment and sleep disturbance, and adverse cardiovascular health.[5] The National Institute of Occupational Safety and Health (NIOSH) in the United States estimated that 12.2% of work-related accidents in 2008 were associated with NIHL, resulting in a huge economic impact of an estimated $242.4 million dollars annually.[6]

Currently, approximately 12% of the United States working population have hearing difficulty and about 24% of them were caused by occupational exposure to noise.[7] The US population occupationally exposed to hazardous noise reached 22 million.[7] In Korea, from 2002 to 2005, the environmental noise levels of 22.7%-29.6% workplaces exceeded the occupational exposure limit (OEL) and the individual noise levels for 16.2%-22.9% of workers exceeded the OEL.[8] A total of 4483 Korean workers were reported as suspected cases of NIHL, accounting for 92.9% of total suspected occupational diseases.[8] In China, there were 1220 reported cases of occupational noise-induced deafness (NID) in 2016 with an annual growth rate of 24.2% from 2014.[9,10] Thus far, the detailed data with regard to prevalence of NIHL in China, especially from specific industries such as the automotive industry, have rarely been reported.

The automotive industry in China has been the largest in the world by output of motor vehicle since 2010.[11] The number of automobile manufacturing enterprises in China reached 14 493 in 2006.[12] Therefore, there might be a substantial number of workers who were exposed to high levels of noise and at a high risk of NIHL in the automotive industry in China. Tao et al[13] reported a hearing loss prevalence of 38.9% among 517 workers, who were exposed to 80.1-118.4 dB(A) noise levels, in an automobile manufacturing company in China. Wang et al[14] found that in a sample of 728 workers from automobile manufacturing factories, 11.4% experienced high-frequency hearing loss with more than 50 dB threshold shift at 3-6 kHz frequencies. In Malaysia, Tahir et al[15] found that the incidence of NIHL in the manufacturing population was 139 per 100 000; among them, those workers in the factories manufacturing motor vehicle parts had a relatively high incidence of NIHL (eg 32%). Tan et al[16] reported that the highest noise levels reached 90.8 dB(A) in an automotive plant in Pahang, Malaysia. In Thailand, the percentage of hearing loss in either ear or both ears among welders from factories manufacturing automobile parts were 23.33% and 8.33%, respectively, and the noise exposure levels ranged from 80.8 to 97.0 dB(A).[17] Despite the different definitions of NIHL and diverse methods to determine individual noise exposure, these studies indicated that the occupational population in the automotive industry were exposed to hazardous noise levels, which put them at a high risk for NIHL.

Considering the lack of epidemiological data on hearing loss in the automotive industry, this pilot study aimed to investigate the following contents using a cross-sectional survey: (a) the prevalence of NIHL associated with noise exposure; (b) the dose-response relationship between noise exposure and NIHL; and (c) the potential determinants for NIHL among the workers in the automotive industry.

# 2 | PARTICIPANTS AND METHODS

## 2.1 | Selection of participants

A total of 6557 workers were selected from an original pool of 8836 from 4 automotive manufacturing factories and 18 auto part manufacturing or powertrain factories in the Wuhan area, Hubei province of China. The Wuhan area is one of the seven automotive manufacturing bases in China. In this study, the 4 automotive and 18 auto part manufacturing factories were chosen at random from the total of 7 automotive and 180 auto part manufacturing factories, respectively. These specific manufacturing enterprises had many typical features of other enterprises in this automotive manufacturing base, such as similar types of work, production processes, noise exposure levels, as well as control measures. The inclusion criteria for the subjects were as follows: (a) no history of prior employment in a high noise environment, (b) a minimum of 1 year of employment at the current job, (c) no military service or shooting activities, (d) no family history of hearing loss, (e) no history of ear disease, (f) no history of the exposure to organic solvents, and (g) no use of ototoxic drugs. All participants were introduced to the purpose of and procedures to be followed in this study by an occupational physician and were asked to sign an informed consent form.

## 2.2 | Questionnaire survey

Each participant was required to complete a health-related information questionnaire, which was administered through a face-to-face interview for quality control. The following information was collected: general personal information (age, sex, etc); occupational history (factory, type of work, length of employment, duration of daily noise exposure, and history of hearing protector devices (HPD) use); personal life habits (eg, shooting and smoking); and overall health conditions (eg, history of ear disease and use of ototoxic drugs).

## 2.3 | Audiometric testing

Each participant was given a general physical and an otological examination. Pure tone audiometry was performed in an audiometric booth, where baseline noise was 30 dB, as measured by experienced physicians using pure tone audiometers (Madsen, OB40, Copenhagen, Denmark). The audiometers were calibrated according to the ISO 8253 (2010) standards. Hearing thresholds were determined at frequencies of 0.5, 1, 2, 3, 4, and 6 kHz in each ear, and at least 16 hours after the participants' last occupational noise exposure based on an occupational standard in China (eg, The Diagnosis Criteria of Occupational Noise-Induced Deafness, GBZ49-2014). Hearing threshold levels (HTLs) at each frequency were adjusted by subtracting averaged hearing threshold levels in age- and sex-matched population adapted from ISO 1999:2013 Annex A. High-frequency hearing thresholds (HFHTs) were defined as the average hearing threshold at 3, 4, and 6 kHz in both ears. An adjusted high-frequency NIHL (AHFNIHL) was defined as one or more of the adjusted HTLs, in either ear, at 3, 4, or 6 kHz being equal to or greater than 30 dB HL.[18] In addition, the prevalence of noise-induced deafness (NID), as a serious type of hearing loss, was also investigated based on type of work. The NID was classified into mild, moderate, and severe degrees based on the occupational health standard in China (GBZ49-2014).

## 2.4 | Noise exposure measurement

The shift-long personal noise exposure level was measured for each participant using a personal noise dosimeter (Aihua, Model AWA5610B, Hangzhou, China). Before the measurement, each dosimeter was calibrated using a Model AWA6221 Sound Level Calibrator (Aihua Instruments, Hangzhou, China). The participants were required to wear the dosimeter throughout an entire work shift. The dosimeters were equipped with a ½-inch microphone and placed at the level of the participants' collars. The dynamic range of the dosimeters was 40-140 dB(A). The noise data collected in the dosimeter were entered in an IBM computer for subsequent analysis. The equivalent continuous A-weighted sound pressure level over 8 hours ($L_{Aeq.8h}$) was calculated with a software package designed for the dosimeter for each measurement. The $L_{Aeq.8h}$ is defined as

$$L_{Aeq.8h} = L_{Aeq.Te} + 10 * \lg\left(T_e / T_0\right) \quad (1)$$

where $L_{Aeq.8h}$ is the equivalent continuous A-weighted noise exposure level normalized to an 8-hour working day in decibels; $L_{Aeq.Te}$ is the actual A-weighted sound pressure level over the entire work shift; $T_e$ is the actual working time during the entire work shift in hours; and $T_0$ = 8 hours. The cumulative noise exposure (CNE), a composite noise exposure index,[19] was used to quantify the noise exposure for each participant. The CNE is defined as

$$CNE = 10 \lg \left[\frac{1}{T_{ref}} \sum_{i=1}^{n} (T_i \times 10^{\frac{L_{Aeq.8h_i}}{10}})\right] \quad (2)$$

where $L_{Aeq.8hi}$ is the equivalent continuous A-weighted noise exposure level normalized to an 8-hour working day, in decibels, occurring over the time interval Ti in years; with a total of n different noise levels (ie, different working tasks/environments) that the participants were exposed to during their employment history; and $T_{ref}$ = 1 year. As all participants in this study were restricted to being exposed to only one occupational noise environment, n was set as equal to 1 and $T_1$ was simplified as T. Thus, for all the participants in this study, n = i=1 and Equation (2) can be reduced to:

$$CNE = L_{Aeq.8h} + 10 \log T \quad (3)$$

In addition, the temporal waveform of typical noise sources was recorded to understand the waveform shape using ASV5910-R digital recorders (Hangzhou Aihua Instruments Co.) operating continuously with a 32-bit resolution at a 48-kHz sampling rate. The ASV5910-R digital recorder is a digital audio recorder that can record high-fidelity sound.

## 2.5 | Statistics

A chi-square test was applied to analyze the correlation between the category of work and AHFNIHL. The Cochran-Armitage Trend Test was performed to analyze the trend between (a) the proportion of workers using HPD regularly and noise exposure level; (b) the prevalence of AHFNIHL and $L_{Aeq.8h}$; and (c) the prevalence of AHFNIHL and CNE. Logistic regression analysis was used to determine the influence of age, CNE, and HPD usage on the prevalence of AHFNIHL, and their odds ratios (OR) and 95% confidence intervals (CI) were calculated. Female subjects were not included in the logistic regression analysis because of their very low percentage in the total subjects. The statistical difference was considered significant when $P < 0.05$.

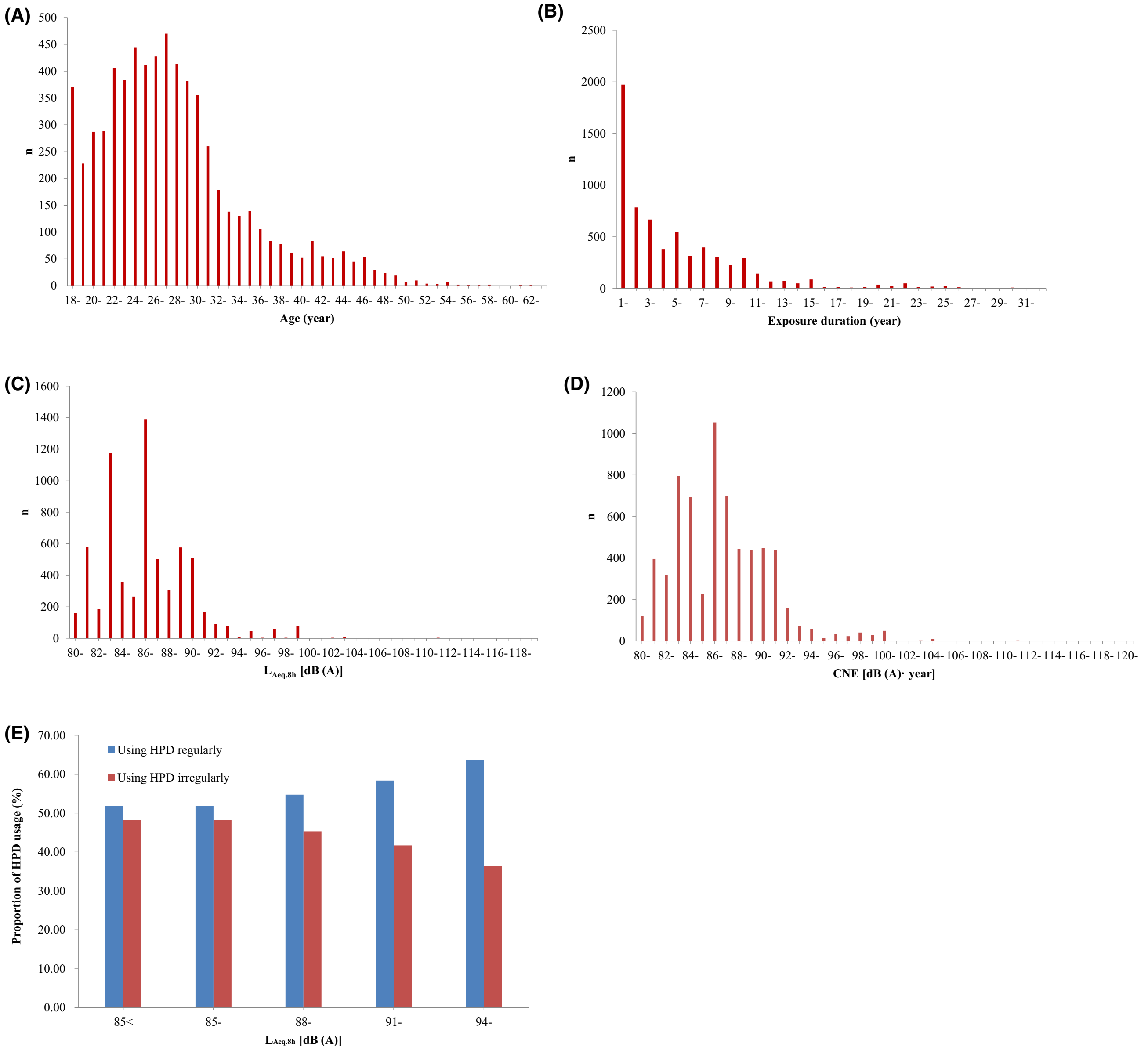


**FIGURE 1** Distribution of important factors. A, Age, median age was 27.0 y; (B) exposure duration, mean noise exposure duration of workers was 5.2 years; (C) $L_{Aeq.8h}$, mean $L_{Aeq.8h}$ was 86.0 dB(A), ranging from 80 to 119.1 dB(A); (D) cumulative noise exposure (CNE), ranging from 80.1 to 120.1 dB(A)·year with a median level of 86.7 dB(A)·year; and (E) relationship between hearing protector device (HPD) usage and $L_{Aeq.8h}$: 53.15% of exposed workers regularly use HPD. The proportion of workers using HPD regularly increased with the increasing $L_{Aeq.8h}$

# 3 | RESULTS

## 3.1 | Prevalence of NIHL associated with noise exposure

Figure 1A shows that of the 6,557 participants almost all were male (96.43%) and the age ranged from 18 to 63 years with a median of 27.0 years. The proportion of male workers in welding from automotive manufacturing factories was the highest (99.93%), when compared with only 66.67% in metal cutting and assembly from auto part manufacturing factories. The median age of workers in metal cutting from auto part manufacturing factories was the highest, at 32.5 years, compared with only 23.0 years in assembly from auto part manufacturing factories. Figure 1B shows that the mean duration of noise exposure for workers was 5.2 years (median: 3.5 years; 25th-75th percentile: 1.7-7.0 years). The median exposure duration of workers in metal cutting from auto part manufacturing factories was the highest, at 6.6 years, compared with only 2.1 years in assembly from auto part manufacturing factories. As shown in Figure 1E, the trend test showed that the proportion of workers using HPD regularly increased significantly with increasing $L_{Aeq.8h}$ ($Z = 3.7216$, $P = 0.0002$). The percentage of the participants who regularly used HPD (53.15%) was higher than that of those who did not use it regularly (46.85%). Table 1 further shows the distributions of general information of participants based on the type of work.

**TABLE 1** Distribution of general information of participants based on type of work (n = 6557)

| Category of workers | | | Sex n (%) | | Age (y) | Exposure duration (y) | Frequencies of HPD usage n (%) | | Duration of HPD usage (y) | Smoking n (%) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Factory | Type of work | n (%) | Male | Female | Median (IQR) | Median (IQR) | Regularly | Irregularly | Median (IQR) | Yes | No |
| Automotive manufacturing | Stamping | 398 (6.07) | 397 (99.75) | 1 (0.25) | 28.7 (25.0-35.1) | 6.0 (2.5-12.0) | 209 (52.51) | 189 (47.49) | 5.0 (2.0-9.0) | 212 (53.27) | 186 (46.73%) |
| | Welding | 2829 (43.14) | 2827 (99.93) | 2 (0.07) | 27.0 (23.0-30.4) | 3.9 (1.7-6.8) | 1818 (64.26) | 1011 (35.74) | 2.0 (1.0-5.0) | 1598 (56.49) | 1231 (43.51%) |
| | Grinding | 965 (14.72) | 953 (98.76) | 12 (1.24) | 24.0 (20.0-29.0) | 3.4 (1.0-7.0) | 347 (35.96) | 618 (64.04) | 0.0 (0.0-4.0) | 507 (52.54) | 458 (47.46%) |
| | Assembly | 312 (4.76) | 301 (96.47) | 11 (3.53) | 23.0 (20.5-26.5) | 2.1 (1.0-5.4) | 73 (23.40) | 239 (76.60) | 0.0 (0.0-2.0) | 151 (48.40) | 161 (51.60%) |
| Auto part manufacturing | Casting | 65 (0.99) | 59 (90.77) | 6 (9.23) | 27.0 (25.0-30.0) | 3.8 (1.4-8.0) | 32 (49.23) | 33 (50.77) | 3.0 (1.0-4.0) | 29 (44.62) | 36 (55.38%) |
| | Plastic molding | 29 (0.44) | 22 (75.86) | 7 (24.14) | 29.0 (25.0-32.0) | 3.8 (3.0-5.6) | 20 (68.97) | 9 (31.03) | 2.0 (1.0-3.0) | 13 (44.83) | 16 (55.17%) |
| | Stamping | 290 (4.42) | 283 (97.59) | 7 (2.41) | 30.0 (26.0-36.0) | 5.8 (3.5-8.8) | 167 (57.59) | 123 (42.41) | 5.0 (3.0-8.0) | 158 (54.48) | 132 (45.52%) |
| | Forging | 178 (2.71) | 148 (83.15) | 30 (16.85) | 30.0 (26.0-37.0) | 3.2 (1.6-7.5) | 94 (52.81) | 84 (47.19) | 2.0 (0.0-4.0) | 66 (37.98) | 112 (62.92%) |
| | Welding | 409 (6.24) | 385 (94.13) | 24 (5.87) | 29.0 (25.0-37.0) | 3.9 (1.7-6.8) | 225 (55.01) | 184 (44.99) | 2.0 (1.0-5.0) | 220 (53.79) | 189 (46.21%) |
| | Metal cutting | 24 (0.37) | 16 (66.67) | 8 (33.33) | 32.5 (29.0-41.0) | 6.6 (3.0-5.6) | 9 (37.50) | 15 (62.50) | 3.0 (0.0-8.0) | 8 (33.33) | 16 (66.67%) |
| | Assembly | 358 (5.46) | 249 (66.67) | 109 (30.45) | 30.0 (26.0-37.0) | 3.5 (2.0-7.3) | 173 (48.32) | 185 (51.68) | 2.0 (1.0-5.0) | 127 (35.47) | 231 (64.53%) |
| | Surface treatment | 98 (1.49) | 84 (85.71) | 14 (14.29) | 30.0 (26.0-35.0) | 5.3 (2.8-8.7) | 55 (56.12) | 43 (43.88) | 2.0 (1.0-5.0) | 42 (42.86) | 56 (57.14%) |
| Powertrain | Powertrain | 602 (9.18) | 599 (99.50) | 3 (0.50) | 24.0 (21.0-26.0) | 2.3 (1.0-3.3) | 263 (43.69) | 339 (56.31) | 1.0 (0.0-2.0) | 284 (47.18) | 318 (52.82%) |
| Total | | 6557 (100%) | 6323 (96.43) | 234 (3.57) | 27.0 (23.0-31.0) | 3.5 (1.7-7.0) | 3485 (53.15) | 3072 (46.85) | 2.0 (0.0-5.0) | 3415 (52.08) | 3142 (47.92) |

Abbreviations: HPD, hearing protector devices; IQR: interquartile range.

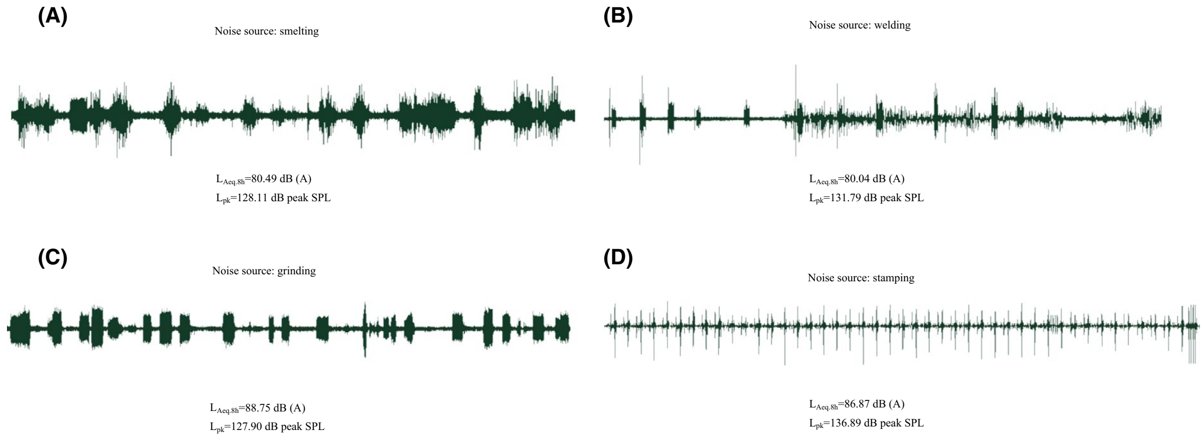


**FIGURE 2** The noise temporal waveform from typical noise sources: (A) smelting; (B) welding; (C) grinding; and (D) stamping. Each typical noise source was able to generate its own unique temporal waveform shape. The non-Gaussian noise consisted of a background noise embedded with a temporally complex series of randomly occurring high-level noise transients

The population who had a highest percentage of regular HPD usage (68.97%) was from the plastic molding location in auto part manufacturing factories, compared with only 23.40% in the assembly location from automotive manufacturing factories. The participants had used HPDs for an average of 3.0 years (median: 2.0; 25th percentile: 0.0; 75th percentile: 5.0). The highest median years (5.0 years) of HPD usage of workers were concentrated in the stamping locations from automotive manufacturing factories and auto part manufacturing factories. The population with the highest percentage of smoking (56.49%) was those who came from welding location in automotive manufacturing factories.

Figure 2A-D show the noise temporal waveforms from several typical noise sources, such as smelting, welding, grinding, and stamping. Each typical noise source was able to generate its own unique temporal waveform shape. One common characteristic among them was that they were all non-Gaussian noise consisting of a background noise embedded with a temporally complex series of randomly occurring high-level noise transients. The average difference between noise peak level ($L_{pk}$) and $L_{Aeq.8h}$ reached 47.14 dB(A).

Table 2 lists each participant's $L_{Aeq.8h}$ and CNE, which served as parameters for noise exposure level. In this study, 62.53% of workers' $L_{Aeq.8h}$ exceeded the legislated OEL value of 85 dB(A). These workers were mainly concentrated in several working locations, such as metal cutting, surface treatment, stamping, welding, grinding, assembly, plastic molding, forging, casting, and powertrain. Figure 1C illustrates that the mean $L_{Aeq.8h}$ for all participants was 86.0 dB(A), which varied from a low level of 80.0 dB(A) to as much as 119.1 dB(A). Figure 1D shows that CNE ranged from 80.1 to 120.1 dB(A)·year with a median level of 86.7 dB(A)·year.

The median HFHTs among all workers was 16.67 dB(A) and the prevalence of AHFNIHL was 28.82%. The prevalence of NID was 0.32% with 21 cases of NID including 17 with mild NID and 4 with moderate NID. The difference in the prevalence of AHFNIHL among the various categories of workers was statistically significant ($P < 0.0001$). At the factory level, the prevalence of AHFNIHL in participants from auto part manufacturing factories was the highest (41.14%), followed by that in workers from powertrain factories (31.56%) and automotive manufacturing factories (24.49%). In terms of the type of work, the highest prevalence of AHFNIHL (53.79%) came from welders with the highest threshold shift of 20.83 dB HL. Other types of workers, such as those in grinding, assembly, casting, stamping, forging, metal cutting, surface treatment, and powertrain had a similar threshold shift of about 18 dB HL.

## 3.2 | Dose-response relationship between noise exposure and NIHL

Figure 3A-D demonstrate the dose-response relationship between noise exposure and prevalence of AHFNIHL among male workers of different ages and work durations. The Cochran-Armitage Trend Test depicted in Figure 3A-C showed that there were increasing trends between the prevalence of AHFNIHL and $L_{Aeq.8h}$ at $L_{Aeq.8h}$ <94 dB(A) in the male workers under different combinations of exposure duration and age (except for a combination of exposure duration ≥6 years and age < 30 years) ($P < 0.05$). The Cochran-Armitage Trend Test depicted in Figure 3D also showed that there were increasing trends between the prevalence of AHFNIHL and CNE in the male workers in each age group ($P < 0.01$). The prevalence of AHFNIHL at 94 ≤ CNE < 100 and CNE > 94 dB(A)·year were 37.75% and 38.26%, respectively.

**TABLE 2** Distributions of noise exposure levels, HFHTs, AHFNIHL, and NID among workers based on type of work (n = 6557)

| Category of workers | | LAeq.8h [dB(A)] | LAeq.8h ≥ 85 dB (A) | CNE [dB(A)·year] | HFHTs (dB HL) | AHFNIHL | NID[a] |
|---|---|---|---|---|---|---|---|
| Factory | Type of work | Median (IQR) | n (%) | Median (IQR) | Median (IQR) | n (%) | n (%) |
| Automotive manufacturing | Stamping | 88.3 (83.9-89.2) | 219 (55.03) | 89.2 (84.4-90.2) | 15.50 (11.50-19.17) | 88 (22.11) | 3 (0.75) |
| | Welding | 86.1 (84.7-88.3) | 2099 (74.20) | 86.9 (85.1-89.1) | 15.83 (12.50-20.00) | 638 (22.55) | 1 (0.03) |
| | Grinding | 88.4 (84.2-89.9) | 702 (72.25) | 89.1 (84.8-90.6) | 18.33(14.33-21.67) | 296 (30.67) | 1 (0.10) |
| | Assembly | 86.0 (81.9-86.0) | 223 (71.47) | 86.2 (81.9-86.7) | 17.50 (14.17-20.00) | 81 (25.96) | 0 (0.00) |
| Auto part manufacturing | Casting | 83.5 (82.1-84.0) | 16 (24.62) | 83.7 (82.3-85.0) | 18.50 (15.00-20.83) | 17 (26.15) | 0 (0.00) |
| | Plastic molding | 85.6 (84.1-88.4) | 19 (65.52) | 86.3 (85.3-88.8) | 16.00 (15.00-19.17) | 4 (13.79) | 0 (0.00) |
| | Stamping | 93.6 (87.5-97.3) | 261 (90.00) | 94.5 (88.4-97.8) | 17.67 (14.17-22.33) | 121 (41.72) | 2 (0.69) |
| | Forging | 82.0 (81.8-86.9) | 54 (30.34) | 82.9 (82.0-86.9) | 18.00 (14.33-22.50) | 68 (38.20) | 1 (0.56) |
| | Welding | 85.5 (83.4-87.8) | 238 (58.19) | 86.5 (83.6-88.5) | 20.83 (16.67-26.00) | 220 (53.79) | 9 (2.20) |
| | Metal cutting | 87.0 (87.0-92.0) | 23 (95.83) | 87.8 (87.5-92.5) | 18.25 (16.08-23.42) | 9 (37.50) | 0 (0.00) |
| | Assembly | 81.9 (81.9-84.2) | 49 (13.69) | 82.9 (82.1-84.9) | 18.50 (15.17-22.50) | 124 (34.64) | 0 (0.00) |
| | Surface treatment | 88.9 (86.8-91.7) | 93 (94.90) | 89.4 (87.9-92.1) | 17.58 (14.17-22.50) | 34 (34.69) | 1 (1.02) |
| Powertrain | Powertrain | 83.3 (83.3-84.5) | 104 (17.28) | 83.8 (83.3-84.5) | 17.50 (15.00-19.17) | 190 (31.56) | 3 (0.50) |
| Total | | 86.0 (83.7-88.9) | 4100 (62.53) | 86.7 (84.0-89.5) | 16.67 (13.33-21.00) | 1890 (28.82) | 21 (0.32) |

Abbreviations: HFHTs, high-frequency hearing thresholds; AHFNIHL, adjusted high-frequency noise-induced hearing loss; IQR, interquartile range; NID, noise-induced deafness.

[a]Noise-induced deafness was defined as the average hearing threshold at 3, 4, and 6 kHz in both ears being equal to or greater than 40 dB HL and the weighted hearing threshold at 0.5, 1, 2, and 4 kHz in better ear being equal to or greater than 26 dB HL.

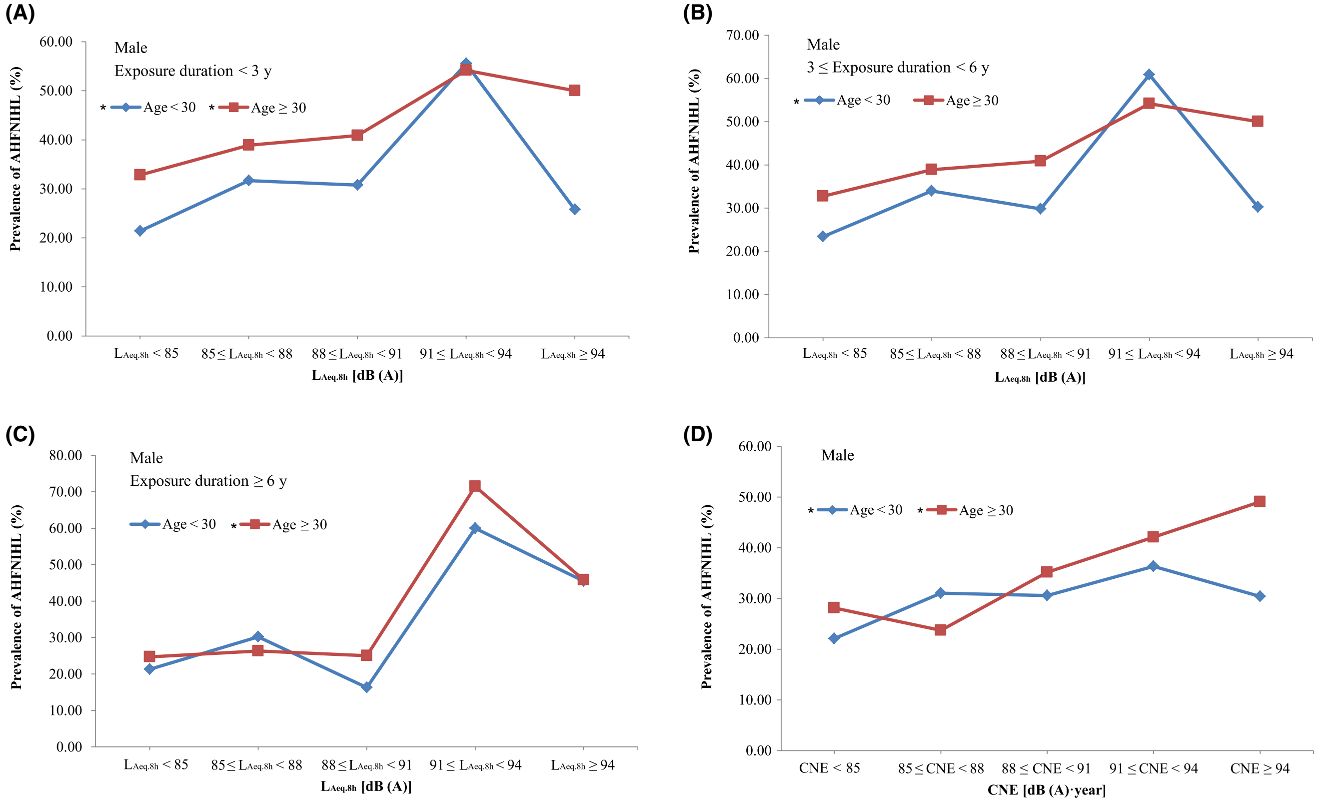


**FIGURE 3** The dose-response relationship between noise exposure and noise-induced hearing loss (NIHL) in the male workers. (A) Exposure duration <3 y; (B) 3 ≤ exposure duration <6 y; (C) exposure duration ≥6 y; and (D) cumulative noise exposure (CNE). The Cochran-Armitage Trend Test in (A-C) showed there were increasing trends between the prevalence of adjusted high-frequency noise-induced hearing loss (AHFNIHL) and $L_{Aeq.8h}$ at $L_{Aeq.8h}$ <94 dB(A) under different combinations of exposure duration and age (except for a combination of exposure duration ≥6 years and age <30 years) ($P < 0.05$). The trend test in (D) showed there was an increasing trend between the prevalence of AHFNIHL and CNE at each age group ($P < 0.01$)

**TABLE 3** Logistic regression analysis of factors affecting AHFNIHL among male subjects (n = 6323)

| | Univariate | | Multivariate | |
|---|---|---|---|---|
| | | | Model 1 | Model 2 |
| Variable | OR (95% CI) | AIC | OR (95% CI) | OR (95% CI) |
| Age | 1.022 (1.014-1.029) | 7598.54 | 1.012 (1.004-1.020) | 1.001 (0.993-1.010) |
| CNE | 1.059 (1.045-1.074) | 7560.81 | 1.061 (1.046-1.077) | 1.096 (1.078-1.115) |
| Frequency of HPD usage (ref.= irregularly) | 0.513 (0.460-0.573) | 7484.96 | 0.501 (0.448-0.561) | 0.496 (0.441-0.558) |
| | | | 7401.10 | 7162.57 |

VIF = age (1.050); CNE (1.048); frequency of HPD usage (1.008).
Model 1 did not involve adjusting; Model 2 was adjusted by the type of work.
Significant interactive effects were found in model 2 between (1) frequency of HPD usage and CNE (b = 0.1118, $P < 0.0001$), and (2)frequency of HPD usage and jobs, such as the stamping (b = 1.6845, $P = 0.0025$), grinding (b = 1.0517, $P = 0.0440$) and assembly (b = 1.3323, $P = 0.0308$) locations in automotive manufacturing factories, and the stamping (b = 1.1769, $P = 0.0358$) and welding (b = 1.6404, $P = 0.0027$) locations in auto part manufacturing factories.
Abbreviations: AHFNIHL, adjusted high-frequency noise-induced hearing loss; CNE, cumulative noise exposure; HPD, hearing protector devices; AIC, Akaike information criterion, as an estimator of the relative information lost by a given model; VIF, The variance inflation factor, quantifying the severity of multicollinearity in an ordinary least squares regression analysis.

## 3.3 | Determinants for NIHL

Table 3 presents the results of the univariate and multivariate logistic regression analysis for several important factors influencing AHFNIHL among workers. Two models were fitted in the multivariate analysis. Model 1 did not require adjusting of any variables while the category of workers was adjusted for in model 2. The variance inflation factor

(VIF) for all variables were very low (as shown in Table 3) and implied little or no multicollinearity. All variables were included in the multivariate analysis. Based on the Akaike information criterion (AIC), the best-fitted model (ie, the model with the lowest AIC) in the multivariate analysis was model 2. The results showed that CNE and frequency of HPD usage were the determinants of AHFNIHL among male workers. The frequency of HPD usage showed a protective effect on the odds of having AHFNIHL (OR: 0.496; 95% CI: 0.441-0.558). An increase in CNE by 1 dB(A)·year could result in 9.6% increase in the odds of AHFNIHL (OR: 1.096; 95% CI: 1.078-1.115). Significant interactive effects were observed between frequency of HPD usage and CNE, and frequency of HPD usage and jobs in model 2.

## 4 | DISCUSSION

The average individual noise exposure level in the automotive industry in this study was 86.0 ranged from 80.0 to 119.1 dB(A), which was consistent with a preliminary study on Chinese male workers (N = 517) employed in an auto manufacturing factory, who were exposed to noise levels from 80.1 to 118.4 dB(A).[13] A Malaysian study also showed that the noise exposure level in automotive filter factories was over 91.0 dB(A).[15] About 63% participants in this study exposed to high levels of noise environment, exceeding the OEL of 85 dB(A) recommended by the WHO.[20] In addition, there were significant differences in the proportion of participants exposed to noise levels above 85 dB(A) from the same type of work in different factories in this study. For example, the proportion of participants exposed to noise levels above 85 dB(A) in stamping from auto part manufacturing factories (90.00%) was considerably higher than that of their counterparts from automotive manufacturing factories (55.03%). The difference may be due to the relatively backward production technology for auto parts.[21] These findings indicated that the majority of workers from the automotive industry in China were exposed to high levels of industrial noise.

Our data show that the prevalence of NIHL among workers in the automotive industry in China was 28.82% based on AHFNIHL, which indicated that a high percentage of workers in the industry exposed to high levels of industrial noise were suffering from hearing loss. The result was supported by a prevalence of 23.33% reported in Thailand's automobile manufacturing industry.[17] Moreover, it was found that the prevalence of AHFNIHL was associated with the category of factories and type of work. The prevalence of AHFNIHL in auto part manufacturing factories was higher than those in powertrain and automotive manufacturing factories. This was because the production technology and automation level of the auto part manufacturing factories were relatively more backward than the other two types of factories. Different types of work might have different noise exposure conditions, leading to different prevalence of AHFNIHL among workers. It was important to note that in the auto part manufacturing factories, there was still the highest prevalence (53.79%) of NIHL among welders with relatively high frequency of HPD usage (55.01%) and at average levels of exposure duration and age. This might be attributed to co-exposure to heavy metals during welding activities to some extent, which may have a synergistic effect on hearing loss with noise exposure.[22] The median HFHTs among all workers was 16.67 dB(A), which was relatively lower than the one (30.7 dB) reported in a China' study on an automobile manufacturing company by Wang et al[23] This may be due to the difference of adjustment method by age and sex for HTLs.

The noise type in the automotive industry was the non-Gaussian noise judged from the waveforms of noise. Workers exposed to a non-Gaussian noise (complex noise) consisting of a Gaussian background noise that was punctuated by a temporally complex series of randomly occurring high-level noise transients[24] might suffer from considerably greater hearing loss than those exposed to the Gaussian noise.[25-28] The prevalence of AHFNIHL in the specific population exposed to complex noise at $94 \leq \text{CNE} < 100$ dB(A)·year was 37.75%, which was relatively higher than that in the Gaussian noise group (11.10%) at $95 \leq \text{CNE} < 100$ dB(A)·year in Xie's study.[24] Further studies were needed to investigate how to classify the complex noise using a reasonable metric, such as kurtosis, in order to accurately evaluate the NIHL associated with complex noise.

The age distribution showed that more than half of participants were below 30 years. NIHL was not significantly associated with age, which was consistent with the outcome reported in a study among commercial fishermen.[29] However, another study from Malaysia showed a different pattern, which reported that the NIHL was significantly associated with the age group of 40 years and above.[30] Further studies are necessary to identify if age is an independent risk factor of NIHL after offsetting age-related hearing loss through the adjustment of age.[31] In terms of smoking habit, the options set in the questionnaire were "yes" and "no." After statistical analysis using the chi-square test, no significant correlation was found between smoking habit and AHFNIHL ($P > 0.05$, data were not shown in the results), which indicated that smoking was not the determinant for NIHL. In addition, because male workers made up the majority of the study subjects, the logistic analysis in Table 3 was performed only among the male subject. In order to observe the role of gender in the prevalence of AHFNIHL among manufacturing workers, a stratification analysis was performed under controlling the influence of age, CNE, and HPD usage even with the small sample size of women. The result showed that there was not a significant difference in AHFNIHL between male and female, indicating that sex might not be a determinant on AHFNIHL (data were not shown in the results).

The present study suggested that the prevalence of NIHL increased with the increasing noise energy levels including CNE and $L_{Aeq.8h}$. These findings were supported by previous studies. A study by Zhao et al[18] revealed that the prevalence of AHFNIHL among workers exposed to both non-Gaussian noise and Gaussian noise increased with CNE. Another study[32] in a petrochemical enterprise also showed that the prevalence of AHFNIHL increased with CNE. Based on the equal energy hypothesis (EEH) theory, the prevalence of AHFNIHL also increased with the $L_{Aeq.8h}$ level at <94 dB(A) under different conditions of exposure duration and age.

In our study, the proportion of workers with NIHL was higher among those who did not wear HPD regularly. According to the multivariate analysis, the regular use of HPD decreased the odds of NIHL, which was consistent with the outcome of previous studies.[33-35] The percentage of workers regularly wearing HPD was only 53.15% since they were required to wear it. However, the data on HPD usage were obtained from employees' self-report, which could lead to reporting bias and social desirability effects.[36] Thus, the frequency of HPD usage could be overestimated in this study. The frequency of HPD varies from one job to another, and a significant interactive effect was also observed between frequency of HPD usage and jobs. We noticed that among workers exposed to noise levels above 94 dB(A), 63.64% reported wearing HPD regularly, a much higher proportion than those exposed to less than 94 dB(A). Similar results were also found in a study of the Dutch construction industry.[37] The phenomenon that the prevalence of NIHL appeared to decline when $L_{Aeq.8h}$ ≥94 dB(A) indicated that HPD might exert a protective effect on NIHL at higher noise exposure levels. Workers in areas with a higher noise exposure might be bothered more by noise and consequently be more conscious about the use of HPD, while for those in areas with a low noise level, the use of HPD could interference with communication, leading to a reluctance to wear HPD.[38] A significant interactive effect observed between frequency of HPD usage and CNE could also indicate that HPD usage may particularly work well for some level of noise.

One limitation for this study was that the majority of participants were male and young workers aged less than 40 years. Additionally, their exposure durations were usually smaller than 10 years. As a result, the representativeness of the sample in the automotive industry might be insufficient. The development of NIHL among the workers might be at an early stage, which might lead to an uneven distribution of the degree of hearing loss. It is necessary to increase the sample size for further investigation.

## 5 | CONCLUSIONS

Based on these findings, the following conclusions can be drawn: (a) approximately 63% of workers in different types of work were exposed to harmful noise levels with the prevalence of AHFNIHL of 28.82%; (b) HPD usage has a protective effect on the development of NIHL in workers especially exposed to high levels of noise; (c) the prevalence of AHFNIHL in male workers significantly increased with an increase in $L_{Aeq.8h}$ at <94 dB(A) level and in CNE; and (d) CNE and HPD usage were important determinants contributing to the prevalence of AHFNIHL. NIHL is a public health problem in the automotive industry in China. Hearing protection programs should be improved to protect workers from hearing loss. Further human investigations with large-scale samples in automobile manufacturing industries are needed to verify these findings.

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## DISCLOSURE

*Approval of the research protocol*: The study protocol was approved by the Medical Ethical Review Committee of the National Institute of Occupational Health and Poison Control in the Chinese Center for Disease Control and Prevention on May 9, 2018 (approval number: 201808); *Informed consent*: Each subject in this study had signed the informed consent; *Registry and registration number of the study/trial*: N/A; *Animal studies*: N/A; *Conflict of interest*: None declared.

## AUTHOR CONTRIBUTIONS

Yali Chen collected and analyzed the data, and wrote the manuscript; Weijiang Hu and Meibian Zhang conceived the ideas and led the writing; Wei Qiu and Xin Sun contributed greatly to the study design and manuscript review; Xin Wang, Yiwen Dong, and Zhenlong Chen contributed to the data collection and field investigation.

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