Letter to the Editor

Positive Associations between Bilateral High-Frequency Hearing Loss and Hypertension Risk in Short-Term Occupational Noise Exposure

JIN Nan[1,&], ZHONG Hui Yun[2,&], YUAN Fang[1], and DENG Hua Xin[1,#]

Noise is one of the most common occupational hazards worldwide[1], and millions of workers are exposed to harmful levels of noise in the workplace[2]. Noise-induced hearing loss (NIHL) is a leading cause of occupational and recreational injury and disease[3]. There is evidence that occupational noise exposure is also associated with other health effects, such as hypertension and cardiovascular diseases, digestive disorders, behavioral disorders, and sleep disturbance[4]. Therefore, noise exposure increases the risk of non-auditory adverse outcomes.

Several epidemiological studies have investigated the associations of occupational noise exposure with blood pressure and hypertension[5], and significant positive associations have been found in cohort and cross-sectional studies[6]. However, negative associations have also been found in other studies[7]. There are limitations to noise exposure assessments. The noise pressure level in the workplace does not reflect the actual exposure to noise of each person, which might be the main reason for the inconsistent results.

Occupational NIHL is a change in perception of different sound frequencies, and initially appears at high frequencies. Bilateral high-frequency hearing loss (BHFHL) is associated with cumulative occupational noise exposure, and can serve as an early biomarker for personal exposure to occupational noise. Therefore, the objective of this study was to evaluate the associations of BHFHL with blood pressure and hypertension in Chinese workers.

This cross-sectional survey enrolled 241,006 workers exposed to occupational noise with an intensity > 80 dB (A) ($L_{EX,\ 8h}$). Recruitment was carried out in 2020 from the key occupational-disease monitoring information system of work-related noise coverage in Chongqing, China. The subjects were employees recruited in the following industries: chemical, shipbuilding, automobile, package printing, furniture making, and electronics. The workers without enough information about age, gender, height, weight, blood pressure and bilateral high-frequency tone average (BHFTA), or with chronic diseases such as cancer, cardiovascular disease, diabetes, liver and kidney diseases, or who wore auditory aids or had drug-induced deafness were excluded. About 37% (91,159) were excluded because data were not available. Finally, a total of 149,847 participants with a median age of 38.75 years (25th to 75th percentile: 29.66–47.81 years) were considered eligible. All the participants had read the informed consent form and gave written consent. The study was approved by the Research Ethics Committees of Chongqing Center for Disease Prevention and Control, and conformed to the ethical guidelines of the 1975 Declaration of Helsinki.

Trained medical personnel measured systolic blood pressure (SBP) and diastolic blood pressure (DBP) of the workers who were free from occupational noise exposure and had ≥ 12 h rest, following a standard protocol. Blood pressure was measured using a mercury sphygmomanometer on individuals in the sitting position after more than 15-min rest in the examination room. SBP and DBP were recorded as the average of three repeated measurements collected at 1-min intervals. Hypertension was defined as SBP ≥ 140 mmHg and/or DBP ≥ 90 mmHg.

The diagnostic criteria of occupational NIHL were developed on the bases of the Chinese work-related health standards (GBZ49-2014, http://www.zybw.net). The audiometer tool test was calibrated to determine the hearing loss threshold. BHFTA was calculated using the arithmetic mean of hearing thresholds at 3, 4, and 6 kHz in both ears. Normal hearing was defined according to BHFTA < 25 dB. BHFHL was defined according to BHFTA ≥ 25 dB, as mild when BHFTA was ≥ 25 to < 30 dB, medium when

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1. Department of Occupational Health and Radiation Health, Chongqing Center for Disease Control and Prevention, Chongqing 400042, China; 2. Xiejiawan Street Community Health Service Center, Chongqing 400042, China

BHFTA was ≥ 30 to < 35 dB, high when BHFTA was ≥ 35 to < 40 dB, and extremely high when BHFTA was ≥ 40 dB.

All statistical analyses were performed using SPSS 21.0 software (SPSS, Chicago, IL). Categorical variables were expressed as frequencies (%) and compared by chi-square analysis. Continuous variables were expressed as mean ± standard deviation in normally distributed data or medians (interquartile ranges) in skewed parameters. Blood pressure was evaluated by linear trend using the median value of occupational noise exposure time and BHFTA as an ordinal variable. A multiple logistic regression model was performed to assess the association between BHFHL and risk of hypertension, with appropriate adjustments for covariates including age, sex, body mass index (BMI), industry classification, enterprise size and economic type. Odds ratio (*OR*) and its 95% confidence interval (*CI*) were calculated for the risk of hypertension. Trends for risk of hypertension were assessed using the median value of BHFTA as a continuous variable in the same model. A two-side *P* value < 0.05 was considered statistically significant.

Data from 149,847 workers were included in our analysis. The general characteristics of the participants according to different groups of BHFTA are summarized in Table 1. The prevalence of extremely high BHFHL was 8.7% (13,026/149,847). Individuals with BHFHL were more likely older, male, obese, and working in small and microenterprises compared with those with normal hearing level. The prevalence of BHFHL increased stepwise across years of occupational noise exposure (*P* < 0.05).

Table 1. Demographic characteristics of hypertension of subjects with occupational noise exposure

Variables	BHFTA (dB)					*P* value
	≤ 25 (*n* = 94,432)	26–30 (*n* = 20,164)	31–35 (*n* = 13,810)	36–40 (*n* = 8,415)	> 40 (*n* = 13,026)	
Age, years	37.16 (28.89–47.17)	38.46 (29.49–47.5)	40.39 (31.04–48.35)	43.1 (32.78–49.25)	44.95 (33.77–49.8)	< 0.001
Gender, *n* (%)						< 0.001
Male	69,366 (73.46)	15,296 (75.86)	10,759 (77.91)	7,058 (83.87)	11,611 (89.14)	
Female	25,066 (26.54)	4,868 (24.14)	3,051 (22.09)	1,357 (16.13)	1,415 (10.86)	
Weight, kg (95% *CI*)	63 (56–70)	63 (56–70)	63 (56–70)	63 (56–70)	63 (56–70)	0.003
Height, cm (95% *CI*)	165 (160–170)	165 (159–170)	165 (160–170)	165 (160–170)	165 (160–170)	0.003
BMI, kg/m^2 (95% *CI*)	23.32 (21.17–25.53)	23.23 (21.14–25.48)	23.31 (21.1–25.46)	23.37 (21.22–25.53)	23.42 (21.29–25.61)	0.015
Occupational noise exposure time, years						< 0.001
< 1	39,406 (41.73)	7,281 (36.11)	4,961 (35.92)	2,778 (33.01)	4,540 (34.85)	
1–	20,134 (21.32)	4,444 (22.04)	2,689 (19.47)	1,700 (20.2)	2,283 (17.53)	
3–	15,234 (16.13)	3,894 (19.31)	2,920 (21.14)	1,644 (19.54)	2,291 (17.59)	
9–	7,594 (8.04)	1,830 (9.08)	1,216 (8.81)	789 (9.38)	1,228 (9.43)	
≥ 9	12,064 (12.78)	2,715 (13.46)	2,024 (14.66)	1,504 (17.87)	2,684 (20.6)	
Enterprise size, *n* (%)						< 0.001
Large	24,101 (25.52)	3,991 (19.79)	2,109 (15.27)	1,216 (14.45)	1,785 (13.7)	
Medium	25,266 (26.76)	5,421 (26.88)	3,570 (25.85)	2,104 (25)	3,269 (25.1)	
Small	36,728 (38.89)	8,622 (42.76)	6,596 (47.76)	4,138 (49.17)	6,489 (49.82)	
Micro	8,337 (8.83)	2,130 (10.56)	1,535 (11.12)	957 (11.37)	1,483 (11.38)	
Economic type, *n* (%)						< 0.001
Public	2,065 (10.24)	1,011 (7.32)	505 (6)	719 (5.52)	2,065 (10.24)	
Private	17,694 (87.75)	12,582 (91.11)	7,810 (92.81)	12,130 (93.12)	17,694 (87.75)	
Other	405 (2.01)	217 (1.57)	100 (1.19)	177 (1.36)	405 (2.01)	
Industry classification, *n* (%)						< 0.001
Agriculture	147 (0.16)	35 (0.17)	21 (0.15)	25 (0.3)	34 (0.26)	
Mining	2,737 (2.90)	596 (2.96)	679 (4.92)	469 (5.57)	787 (6.04)	
Manufacturing	73,185 (77.50)	15,792 (78.32)	10,595 (76.72)	6,487 (77.09)	10,041 (77.08)	
Other	18,363 (19.45)	3,741 (18.55)	2,515 (18.21)	1,434 (17.04)	2,164 (16.61)	

Note. BHFTA, bilateral high-frequency tone average; BMI, body mass index.

Hypertension prevalence was 13.1%, 14.9%, 16.1%, 20.0%, and 23.7% in normal hearing, mild, medium, high and extremely high BHFHL, respectively.

SBP and DBP of the people under different occupational noise exposure time are shown in Table 1. The median levels of SBP and DBP increased stepwise across the occupational noise exposure time. Increasing years of occupational noise exposure were significantly associated with increased SBP and DBP (both $P < 0.001$). Stratified analyses by gender were conducted, and significant linear trends were found in men and women (both $P < 0.001$).

The association between occupational noise exposure time and hypertension is shown in Table 2. Increasing years of occupational noise exposure were independently associated with an elevated risk of hypertension after adjustment of age, sex, BMI, industry classification, enterprise size and economic type (all $P < 0.05$). However, subgroup analyses revealed that the association between occupational noise exposure time and hypertension was more evident in men (both $P < 0.05$).

Table 3 shows the estimated risk of BHFTA levels for hypertension risk stratified by occupational noise exposure time. Among individuals with different duration of occupational noise exposure, there was a significant difference in the risk of hypertension between BHFTA levels. Among each duration of occupational noise exposure, increasing BHFHL was independently associated with an elevated risk of hypertension after adjustment of age, sex, BMI, industry classification, enterprise size and economic type. However, with the increase of occupational noise exposure time, the risk of hypertension in the extremely high BHFHL group decreased gradually.

To the best of our knowledge, we are the first to report that hearing loss significantly increases the

Table 2. Adjusted *OR*s (95% *CI*s) for hypertension by BHFTA levels

BHFTA (dB)	Case/participants	*OR* (95% *CI*s)		
		Model 1	Model 2	Model 3
Total				
≤ 25	12,342/82,090	1 (reference)	1 (reference)	1 (reference)
26–30	3,006/17,158	1.17 (1.12–1.22)	1.14 (1.09–1.19)	1.11 (1.06–1.16)
31–35	2,219/11,591	1.27 (1.21–1.34)	1.19 (1.13–1.25)	1.14 (1.09–1.20)
36–40	1,679/6,736	1.66 (1.57–1.75)	1.46 (1.38–1.55)	1.38 (1.31–1.47)
> 40	3,080/9,946	2.06 (1.97–2.15)	1.73 (1.66–1.81)	1.62 (1.55–1.70)
P-trend		< 0.001	< 0.001	< 0.001
Male				
≤ 25	9,900/59,466	1 (reference)	1 (reference)	1 (reference)
26–30	2,489/12,807	1.17 (1.11–1.22)	1.14 (1.09–1.20)	1.13 (1.07–1.18)
31–35	1,836/8,923	1.24 (1.17–1.31)	1.16 (1.10–1.23)	1.13 (1.07–1.19)
36–40	1,501/5,557	1.62 (1.53–1.72)	1.47 (1.38–1.56)	1.42 (1.34–1.51)
> 40	2,831/8,780	1.94 (1.85–2.03)	1.71 (1.63–1.80)	1.65 (1.57–1.73)
P-trend		< 0.001	< 0.001	< 0.001
Female				
≤ 25	2,442/22,624	1 (reference)	1 (reference)	1 (reference)
26–30	517/4,351	1.10 (1.00–1.22)	1.10 (0.99–1.22)	1.08 (0.98–1.19)
31-35	383/2,668	1.33 (1.19–1.49)	1.31 (1.17–1.47)	1.27 (1.13–1.43)
36–40	178/1,179	1.40 (1.19–1.65)	1.35 (1.15–1.59)	1.31 (1.11–1.54)
> 40	249/1,166	1.98 (1.71–2.28)	1.88 (1.63–2.17)	1.82 (1.58–2.11)
P-trend		< 0.001	< 0.001	< 0.001

Note. BHFTA: bilateral high-frequency tone average; Model 1 was bivariable analysis; Model 2 adjusted for age, sex and BMI; Model 3 adjusted for age, sex, BMI, industry classification, enterprise size and economic type.

risk of hypertension in workers with short-term occupational noise exposure. The extremely high BHFHL group who had occupational noise exposure time of < 1, 1–, 3–, 6–, and ≥ 9 years had a hypertension risk of 94%, 70%, 61%, 49%, and 47%, respectively. Several studies considered BHFHL as a good biomarker because of its association with intensity and personal noise exposure time[8,9]. This confirmed that BHFHL was a good biomarker for the risk of hypertension in short-term personal noise exposure.

In this study, we investigated the association between occupational noise exposure and hypertension among 149,847 workers in 2020 from

Table 3. Adjusted *OR*s (95% *CI*s) for hypertension according to occupational noise exposure time and BHFTA levels

Occupational noise exposure time (years)	BHFTA (dB)	Case/participants	Model 1		Model 2	
			OR (95% *CI*s)	*P* value	*OR* (95% *CI*s)	*P* value
< 1						
	≤ 25	4,056/35,350	1 (reference)		1 (reference)	
	26–30	886/6,395	1.184 (1.095–1.280)	< 0.001	1.163 (1.076–1.258)	< 0.001
	31–35	599/4,362	1.113 (1.015–1.220)	0.023	1.070 (0.976–1.174)	0.150
	36–40	411/2,367	1.319 (1.181–1.474)	< 0.001	1.258 (1.125–1.406)	< 0.001
	> 40	959/3,581	1.941 (1.791–2.102)	< 0.001	1.860 (1.716–2.016)	< 0.001
1–						
	≤ 25	2,524/17,610	1 (reference)		1 (reference)	
	26–30	630/3,814	1.124 (1.022–1.236)	< 0.001	1.114 (1.013–1.224)	0.026
	31–35	471/2,218	1.388 (1.245–1.548)	< 0.001	1.365 (1.224–1.522)	< 0.001
	36–40	388/1,312	1.836 (1.625–2.074)	< 0.001	1.805 (1.597–2.041)	< 0.001
	> 40	510/1,773	1.701 (1.526–1.896)	< 0.001	1.658 (1.486–1.850)	< 0.001
3–						
	≤ 25	2,207/13,027	1 (reference)		1 (reference)	
	26–30	624/3,270	1.099 (0.997–1.212)	0.057	1.079 (0.978–1.189)	0.129
	31–35	480/2,440	1.094 (0.982–1.220)	0.104	1.059 (0.949–1.181)	0.305
	36–40	333/1,311	1.343 (1.179–1.529)	< 0.001	1.291 (1.133–1.471)	< 0.001
	> 40	549/1,742	1.610 (1.446–1.793)	< 0.001	1.526 (1.369–1.701)	< 0.001
6–						
	≤ 25	1,230/6,364	1 (reference)		1 (reference)	
	26–30	299/1,531	0.999 (0.869–1.148)	0.988	0.968 (0.842–1.113)	0.652
	31–35	214/1,002	1.056 (0.899–1.240)	0.507	1.008 (0.857–1.184)	0.927
	36–40	156/633	1.169 (0.970–1.410)	0.101	1.081 (0.895–1.305)	0.419
	> 40	301/927	1.491 (1.289–1.726)	< 0.001	1.376 (1.187–1.595)	< 0.001
≥ 9						
	≤ 25	2,325/9,739	1 (reference)		1 (reference)	
	26–30	567/2,148	1.082 (0.976–1.200)	0.136	1.073 (0.967–1.190)	0.185
	31–35	455/1,569	1.163 (1.037–1.304)	0.010	1.138 (1.014–1.276)	0.028
	36–40	391/1,113	1.353 (1.194–1.532)	< 0.001	1.329 (1.172–1.506)	< 0.001
	> 40	761/1,923	1.474 (1.338–1.624)	< 0.001	1.444 (1.310–1.592)	< 0.001

Note. BHFTA: bilateral high-frequency tone average; Model 1 adjusted for age, sex and BMI; Model 2 adjusted for Model 1 plus industry classification, enterprise size and economic type.

the key occupational-disease monitoring information system. The results suggested that workers with mild, medium, high and extremely high BHFHL had a higher hypertension risk of 11%, 14%, 38%, and 62%, respectively. A dose–response relationship was verified between BHFHL and hypertension in both sexes after adjustment for age, sex, BMI, industry classification, enterprise size and economic type. Our results showed that the dose–response association between occupational noise exposure time, hearing loss and hypertension risk was more pronounced in male workers. Our results partly supported the Dongfeng-Tongji Cohort Study in China, in which hearing loss was an indicator for exposure to loud noise, and was associated with a higher risk of hypertension[10]. The potential reason is that male and female workers are exposed to different noise levels in the workplace. Male workers are usually exposed to higher noise pressure level compared with female workers. However, dose–response relationships were found between BHFHL and hypertension in both sexes. We found that NIHL was 47% more severe in the short-term than in the long-term exposed population. This confirmed that BHFHL was a good biomarker, which could reflect the cumulative personal noise exposure level. The possible explanation for this result is that the time of noise exposure is related to age. As a risk factor of hypertension, age can partially offset the association between NIHL and hypertension. It may also be due to the gradual adaptation of the human body to noise.

This study had several strengths. First, we enrolled > 140,000 workers, and evidence based on this large sample size is more powerful and convincing. Second, two methods were used to evaluate occupational noise exposure: noise exposure time and BHFHL, which could strengthen the effectiveness and credibility of the results by mutual confirmation. Third, subgroup analysis considering gender was performed to avoid potential confounders. In particular, BMI, one of the risk factors for hypertension, was included in the analysis. However, some limitations were also present in this study. First, it was based on a cross-sectional survey, which could not reveal the causal relationship and properly assess the associations. A prospective cohort study is needed to validate the results. Second, although some confounders such as age, gender, BMI, economic type and industry classification, were adjusted, some individual cardiovascular risk factors, such as cigarette smoking, alcohol consumption, and psychological risk factors, were not considered in the multivariable analysis. Third, this cross-sectional survey enrolled a total of 241,006 workers exposed to occupational noise, and about 37% of them were excluded because insufficient information was available regarding blood pressure or BHFTA. The excluded workers might have affected the results. Fourth, we did not collect data about noise pressure level in the working place, earplug usage and other non-occupational noise exposure of workers, such as use of headphones on the way to and from work, which are important for hearing loss. In our future research, we will collect the above-mentioned data, which could make our research more convincing.

The present study suggests that BHFHL is a good biomarker for the risk of hypertension in individuals with short-term noise exposure. A dose–response relationship was found between BHFHL and hypertension risk. Further large-scale prospective cohort studies are needed to show the cause of this association, and analyze the association of bilateral speech frequency hearing loss with blood pressure and hypertension.

[&]These authors contributed equally to this work.

[#]Correspondence should be addressed to DENG Hua Xin, Fax: 86-23-8805583, E-mail: 187357532@qq.com

Biographical notes of the first authors: JIN Nan, female, born in 1987, Associate Researcher/Master, majoring in occupational health; ZHONG Hui Yun, born in 1986, Associate Researcher/Master, majoring in public health and infectious disease control.

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