BMJ Open

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Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-027152
Article Type:	Research
Date Submitted by the Author:	09-Oct-2018
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Keywords:	hearing loss, hearing thresholds, lifestyle factors, environmental factors

Population-based cross-sectional study on the hearing threshold levels and hearing loss among people in Zhejiang, China

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Word count: 2662 words in Main Text; 215 words in Abstract

Total figures: 4 **Total tables:** 3

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ABSTRACT

Objectives: Hearing loss, as a common chronic condition in humans, is increasingly gaining attention. Relevant research in China is relatively scarce, so we conduct a population-based study to investigate the prevalence of hearing loss among age groups, genders, and ears in Zhejiang province, China.

Study design: A Population-based cross sectional study.

Participants: 3754 participants aged 18-98 years and living in Zhejiang Province, China.

Outcome measures: Pure-tone audiometric thresholds were measured at frequencies of 0.125–8 kHz for each subject. All participants were asked to complete a structured questionnaire, in the presence of a healthcare official.

Results. The prevalence of speech-frequency and high-frequency hearing loss was 27.9% and 42.9%, respectively, in Zhejiang. There were significant differences in auditory thresholds at most frequencies among the age groups, genders, and ears. In addition to the common factors affecting both types of hearing loss, significant correlation was found between personal income and speech-frequency hearing loss (odds ratio [OR]=0.69, 95% confidence interval [CI]: 0.52-0.92), and between hyperlipidaemia and high-frequency hearing loss (OR=1.45, 95% CI: 1.02-2.07).

Conclusion. The prevalence of hearing loss was high among people living in Zhejiang, particularly males, and in the left ear. Moreover, hearing thresholds increased with age. Several lifestyle and environment factors, which can be influenced by awareness and education, were significantly associated with hearing loss.

Key words: hearing loss, hearing thresholds, lifestyle factors, environmental factors.

Strengths and limitations of this study.

To the best of our knowledge, this is a study conducted in Zhejiang, China, involving a large population, with data from a wide band of hearing frequencies.

The study found that several lifestyle and environment factors, which can be influenced by awareness and education, were significantly associated with hearing loss.

Medical covariates were collected based on self-reported diagnosis, and specific values were not analysed as these data were not collected completely.

1. Introduction

Hearing loss, the most common sensory deficit in humans[1], is increasingly gaining attention; the World Health Organization estimated that the prevalence of hearing loss increased from 42 million in 1985 to 360 million in 2011.[2] According to a US study, more than 36 million people (16–17% adolescents) suffered from varying degrees of hearing loss.[3] Moreover, Twardella et al. reported that the prevalence of hearing loss among adolescents in Germany was approximately 2.4%.[4] Although the literature on hearing loss has gradually increased, these studies were either conducted in countries other than China, or the number of participants was small.[5] In addition, the hearing test did not cover a wide band of frequencies.[6]

As a common chronic condition in humans, hearing loss affects communication and can, therefore, affect the quality of life of the individual. Furthermore, it has substantial direct and indirect societal costs.[7] Moreover, in the 25-year Global Burden of Disease study, hearing loss was the second most common non-fatal disease affecting the quality of life of Chinese individuals.[8] However, the exact mechanisms of hearing loss remain unclear. Thus, there is an urgent need to study the prevalence of hearing loss and its related risk factors. Several studies have reported that hearing function is associated with age, sex, heredity, and environmental factors (such as noise exposure and heavy metal exposure) [9, 10], but similar research in China is still relatively scarce.

Hence, in the present study, data of audiometric measurements and responses to structured questionnaires were collected to investigate the prevalence of hearing loss in adults in Zhejiang, China; while other Chinese studies were conducted elsewhere, this is the first study to be conducted in Zhejiang with a large sample size and wide band of frequencies. An epidemiological study can well describe the hearing threshold levels and hearing loss in the Chinese population, and provide some data that can be used to develop interventions for preventing early hearing loss as well as for further investigation.

2. Methods

Study Areas and Participants

A study using a multi-stage stratified cluster random sampling method was conducted in the Zhejiang province from September 2016 to June 2018. Five healthcare centres were selected as follows: 1 in Jiangshan, 1 in Jiaxing, and 3 in Hangzhou (Tonglu county, Baiyang community, and Sijiqing community). Complete audiometric examination data and questionnaire data of 3754 participants (1900 males and 1854 females) (18–98 years old) were analysed. The participants were divided into 3 age groups: the young group (18–44 years old, mean age=34.19±6.35), the middle group (45–59 years old, mean age=51.82±4.34), and the old group (60–98 years old, mean age=68.07±7.14).[11]

The whole process of study was approved by the Ethics Committee of Hangzhou Normal University. All subjects provided written informed consent and the study had been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments and local government policies.

Audiometry test

First, otoscopic examination was performed for each participant by an otolaryngologist to detect any ear pathology potentially affecting hearing function. Participants who had an ear disease (such as otitis externa, otitis media, or cerumen impaction) or abnormal ear structure were excluded from the analysis. All pure-tone air conduction hearing thresholds were measured by trained researchers using audiometers (AT235; Interacoustics AS, Assens, Denmark) with standard headphones (TDH-39; Telephonic Corporation, Farmingdale, USA). Each subject was specifically instructed to press a handheld response key as soon as they heard a tone of a frequency between 0.125 and 8 kHz (0.125, 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz) over an intensity range of -10 to 110 dB in a soundproof booth with background noise of less than 20 dB(A). All facilities were calibrated before use, and similar to the study conducted by Wang et al.[5], we conducted the testing by beginning at 1 kHz, continuing to higher test frequencies and then returning to 1 kHz, followed by testing lower frequencies.[5] We computed the pure-tone average (PTA) at speech frequencies (0.5, 1, 2, and 4 kHz; speech-PTA), and at high frequencies (3, 4, 6, and 8 kHz; high-PTA).[12] Hearing loss was defined as a PTA of ≥26 dB in the better ear,[9] which is consistent with the WHO definition of clinically significant hearing loss,[13] and this can identify patients with bilateral hearing loss and related functional impairments.[14]

Covariates

All participants were asked to complete a structured questionnaire, in the presence of a healthcare official, covering demographic variables, audiometric information, lifestyle and environmental factors, as well as issues related to various risk factors and diseases. Education level was categorized as elementary school or less, middle school graduation, high school graduation, and college or more. Average monthly income was classified into 3 categories (low: ≤4000 RMB; middle: 4001–6000 RMB; high: ≥6001 RMB). Based on the history of cigarette smoking status, participants were categorized as follows: self-reported non-smokers (smoking less than 1 cigarette a day on average for less than 1 year), former smokers (cessation of smoking since the past 6 months or more), and current smokers (smoking at least one cigarette a day for more than 1 year). Based on drinking history, participants were also categorized as follows:

self-reported non-drinkers (less than once per week), former drinkers (abstinence for more than 6 months), and current drinkers (alcohol consumption at least once a week for more than 6 months). If a participant indicated an exposure to loud noise in the workplace at least once a week, then the participant was considered to experience occupational noise exposure. If the participant had been exposed to loud noise outside of work (e.g., loud music or power tools) at least once a week, then the participant was considered to be exposed to recreational noise. Self-reported medical information, mainly about hypertension, hyperlipidaemia, diabetes, and hypercholesterolemia, was also collected.

Statistical analysis

The study used Epidata 3.1 (The Epidata Association, Odense, Denmark) for survey data entry and check and error correction (double entry and validation). SPSS (version 19.0 for Windows; SPSS, Inc., Chicago, USA) was used to conduct all statistical analyses, and the results were graphed using the SigmaPlot 12.0 software package (Systat Software International., Chicago, USA). A Kolmogorov-Smirnov normality test was performed to examine the distribution of each variable. Data were presented as proportions, mean±standard deviation (SD), or median (interquartile range), according to the original data distribution. The Student's t-test and chi square test were used to compare differences between the groups. In addition, the differences between the left and right ear were analysed using the paired t-test, and the Bonferroni correction for pairwise comparisons. Logistic regression was used to estimate the association between hearing loss and the variables (as categorical variables), after adjustment for age and gender. All reported probability values were two-tailed, and a P value of less than 0.05 was considered statistically significant.

3. Results

Comparison of hearing thresholds among different populations

The PTA for all age groups at speech frequency and high frequency is shown in Figure 1 and Figure 2, respectively. There were significant differences between the left and right ear (when age was over 60 years, P<0.05) with respect to PTA, both in speech frequency and high frequency, and the hearing of the right ear was better than that of the left ear.

There were significant differences between the male and female participants in the young, middle, and old group (especially at 3, 4, 6, and 8 kHz, P<0.05, data not shown) (Figure 3). In general, compared with men, women had better hearing. Table 1 and Table S1 (comprising original PTA data) show that significant differences in hearing loss were found among the three selected areas. The prevalence of hearing loss in Hangzhou was the highest (33.3% for speech-frequency, and 53.9% for high-frequency hearing loss). Moreover, Figure 4 shows the PTA at the examined frequencies (0.125 to 8 kHz) among men and women in the different age groups. There were significant differences among age groups for both ears (P<0.05) at all frequencies. PTA was the highest in the old group, and lowest in the young group.

Table 1. Hearing loss in different areas.

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	Total, %	Male, %	Female, %	Total, %	Male, %	Female, %
Jiangshan	24.4 (304/1247)	30.2 (209/691)	17.1 (95/556)	39.0 (486/1247)	48..8 (337/691)	26.8 (149/556)
Jiaxing	24.8 (277/1088)	29.1 (155/533)	20.7 (115/555)	33.2 (361/1088)	36.6 (195/533)	29.9 (166/555)
Hangzhou	33.3 (472/1419)	34.9 (236/676)	31.8 (236/743)	53.9 (765/1419)	58.7 (397/676)	49.5 (368/743)
P	<0.001	0.061	<0.001	<0.001	<0.001	<0.001

The correlation between hearing loss and covariates

Of the 3754 eligible participants, a total of 1046 (27.9%) had speech-frequency hearing loss, and 1612 (42.9%) had high-frequency hearing loss. Table 2 shows the results of the comparison of the sociodemographic characteristics of the participants affected by hearing loss at speech-frequency and high-frequency. Participants with hearing loss group were on average 17 years older than those without hearing loss. Furthermore, there was a higher proportion of men in the hearing-loss group than in the normal-hearing group (speech-frequency, 57.4% versus 48.0%, $P<0.001$; high-frequency, 57.6% versus 45.3%, $P<0.001$). In addition, education, personal income, noise exposure, smoking status, and drinking status were significantly associated with both types of hearing loss (all $P<0.001$). As for medical covariate data, there was a significant correlation between hearing loss and presence of hypertension, hyperlipidaemia, diabetes, and hypercholesterolemia (all $P<0.001$, for speech-frequency and high-frequency hearing loss).

Table 2. Characteristics of study participants

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	No	Yes	*P*	No	Yes	*P*
Number	2708	1046		2142	1612	
Age, years	45.28±13.56	61.97±12.38	<0.001	42.83±12.92	59.37±12.68	<0.001
Gender, % (men)	48.0	57.4	<0.001	45.3	57.6	<0.001
Education, %						
≤ Elementary school	7.2	23.9		5.5	20.3	
Middle school	20.6	28.9		17.5	30.1	
High school	27.4	26.5		28.0	26.0	
≥ College	44.8	20.7	<0.001	49.1	23.5	<0.001
Income: low/middle/high, %	37.1/44.7/18.2	55.2/32.2/12.6	<0.001	34.9/46.9/18.2	51.7/33.7/14.6	<0.001
Smoking: non/former/current, %	79.0/4.6/16.4	62.2/11.8/26.0	<0.001	83.1/3.5/13.4	62.6/10.7/26.7	<0.001
Drinking: non/former/current, %	83.9/1.4/14.7	69.1/2.6/28.3	<0.001	86.5/1.4/12.1	70.9/2.1/27.0	<0.001
Occupational noise exposure, %	36.5	46.7	<0.001	35.7	44.2	<0.001
Recreational noise exposure, %	21.4	31.3	<0.001	20.5	28.9	<0.001
Hypertension, %	13.7	43.7	<0.001	10.2	37.8	<0.001
Hyperlipidemia, %	4.9	13.6	<0.001	3.3	12.7	<0.001
Diabetes, %	3.2	12.4	<0.001	1.8	11.0	<0.001
Hypercholesterolemia, %	2.0	5.2	<0.001	1.7	4.4	<0.001

After adjustment for age and gender, a logistic regression analysis was performed to estimate the correlation between hearing loss and independent variables (Table 3). Education was associated with speech-frequency hearing loss with borderline significance (*P*=0.064). High personal income was found to have a significant negative correlation with hearing loss (odds ratio [OR]=0.69, 95% confidence intervals [CI]: 0.52–0.92, *P*=0.025). The adjusted ORs for the comparison of current smokers and non-smokers and current drinkers and non-drinkers were 1.43 (95% CI: 1.11–1.85) (*P* for trend=0.007) and 1.44 (95% CI: 1.15–1.82) (*P* for trend=0.004), respectively. The results showed that both types of noise exposures were risk factors for hearing loss. As for common chronic diseases, no significant association was found between presence of hyperlipidaemia or hypercholesterolemia and hearing loss (for hyperlipidaemia, OR=1.03, 95% CI: 0.75–1.41, *P*=0.848; for hypercholesterolemia, OR=1.31, 95% CI: 0.81–2.12, *P*=0.275). Hearing loss was associated with diabetes with borderline significance (OR=1.39, 95% CI: 0.99-1.95, *P*=0.061), and hypertension was found to be significantly associated with hearing loss (OR=2.28, 95% CI: 1.87–2.79, *P*<0.001).

Moreover, smoking, drinking, occupational noise, recreational noise, hypertension, and diabetes were risk factors for high-frequency hearing loss, whereas a high education level was a protective factor. In contrast with speech-frequency hearing loss, hyperlipidaemia was positively associated with hearing loss (OR=1.45, 95% CI: 1.02–2.07, *P*=0.039), while no significant association was found between income and hearing loss. The effects of smoking and hypertension on hearing loss were the greatest (for smoking, OR=2.08, 95% CI: 1.63–2.65; for hypertension, OR=2.17, 95% CI: 1.76–2.68).

Table 3. Logistic regression analysis of all the correlations of hearing loss

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	Yes/Total	ORs (95% CIs)	*P*-trend	Yes/Total	OR (95% CI)	*P*-trend
Education						
≤ Elementary school	250/445	1 (Reference)		328/445	1 (Reference)	
Middle school	302/860	0.75 (0.57-0.98)		486/860	0.93 (0.70-1.25)	
High school	277/1018	0.73 (0.55-0.97)		419/1018	0.65 (0.48-0.87)	
≥ College	217/1431	0.66 (0.48-0.90)	0.064	379/1431	0.60 (0.43-0.82)	<0.001
Income						
Low	577/1581	1 (Reference)		834/1581	1 (Reference)	
Middle	337/1547	0.80 (0.65-0.99)		543/1547	0.82 (0.67-0.99)	
High	132/626	0.69 (0.52-0.92)	0.025	235/626	0.89 (0.69-1.16)	0.129
Smoking						
non-	651/2789	1 (Reference)		1009/2789	1 (Reference)	
former-	123/248	1.50 (1.07-2.11)		173/248	1.85 (1.30-2.64)	
current-	272/717	1.43 (1.11-1.85)	0.007	430/717	2.08 (1.63-2.65)	<0.001
Drinking						
non-	723/2995	1 (Reference)		1143/2995	1 (Reference)	
former-	27/65	1.64 (0.87-3.09)		34/65	1.13 (0.60-2.13)	
current-	296/694	1.44 (1.15-1.82)	0.004	435/694	1.38 (1.10-1.74)	0.022
Occupational noise						
no	557/2277	1 (Reference)		899/2277	1 (Reference)	
yes	489/1477	1.35 (1.12-1.62)	0.001	713/1477	1.29 (1.08-1.54)	0.004
Recreational noise						
no	719/2848	1 (Reference)		1134/2825	1 (Reference)	
yes	327/906	1.39 (1.13-1.70)	0.002	461/896	1.39 (1.14-1.70)	0.001
Hypertension						
no	589/2926	1 (Reference)		1003/2926	1 (Reference)	
yes	457/828	2.28 (1.87-2.79)	<0.001	609/828	2.17 (1.76-2.68)	<0.001

Hyperlipidemia						
no	904/3479	1 (Reference)		1407/3479	1 (Reference)	
yes	142/275	1.03 (0.75-1.41)	0.848	205/275	1.45 (1.02-2.07)	0.039
Diabetes						
no	916/3538	1 (Reference)		1435/3538	1 (Reference)	
yes	130/216	1.39 (0.99-1.95)	0.061	177/216	1.82 (1.21-2.75)	0.004
Hypercholesterolemia						
no	992/3647	1 (Reference)		1541/3647	1 (Reference)	
yes	54/107	1.31 (0.81-2.12)	0.275	71/107	1.01 (0.60-1.69)	0.983

Note: analysis were adjusted for gender and age. Age was represented by categorical variables.

4. Discussion

This cross-sectional study, conducted in a large population and based on a cohort of local individuals in the Zhejiang province, provides information about the hearing threshold levels and prevalence of hearing loss among the people in Zhejiang, China. Based on the standard definition (a PTA of ≥26 dB in the better ear), we estimated that 27.9% of the participants had speech-frequency hearing loss, which is far lower than the prevalence reported in other Chinese studies i.e., those conducted by Bu[15] and Gong[6] (59.93% and 58.85%). The difference probably resulted from the geographic distribution of the population surveyed. Consistent with other studies[5, 16, 17], women often had a lower PTA than men, at most frequencies (from 1 to 8 kHz), in both the left and right ear. Among these examined frequencies, significant differences were found between the young, middle and old groups for PTA (P<0.001), suggesting that the hearing threshold increases with age, both in males and females.[18] Furthermore, Sommer reported that a 1-year increase in age would raise the risk of hearing loss by 15%.[14]

Right ear dominance for PTA was identified in this study. Especially in participants older than 60 years, the right ear had better hearing ability than the left, which can be explained from the perspective of neurology. The ascending auditory projections pass through the brainstem and end in the cerebral cortex of the ipsi- and contra-lateral hemispheres, with a predominant representation on the side opposite to the ear.[19] In brief, the sound collected through the right ear is formed in the left hemisphere, and vice versa. Therefore, based on the anatomical characteristics of the human brain, right ear input is directly transferred to the speech perception areas in the left hemisphere, whereas stimuli to the left ear have to be transferred initially to the right hemisphere, from which it is transferred to the left hemisphere through the corpus callosum.[19] Some studies have also identified the right ear dominance in certain populations,[20-22] which in turn, supports the above theoretical basis. In contrast, another study in Switzerland suggested that PTA has no significant differences between both ears.[23]

Hangzhou had the highest prevalence of hearing loss among the three selected areas. As a modern city with a highly developed economy, Hangzhou is filled with industrial noise, whereas the other two regions have a slightly less-developed economy, with less industrial noise. This is similar to inferences made by Wang et al.[5] Meanwhile, consistent with previous studies, noise exposures (including occupational noise and recreational noise) were found to be risk factors for hearing loss,[6, 24, 25] while education and personal income were protective factors. Highly educated people have a better knowledge of health, and people with high personal income can prevent hearing loss by using low-noise devices or by avoiding high-noise workplaces.

Our results support the evidence that smoking and drinking have associations with the risk of hearing loss.[26, 27] Cruickshanks et al.[28] estimated that current smokers were 1.69 times more likely to have hearing loss than non-smokers (95% CI: 1.31–2.17), which is similar to the results obtained in our study (1.66-fold, 95% CI: 1.24–2.22). Similarly, a multi-centre study conducted by Fransen et al.[29] reported that smoking significantly increased high-frequency hearing loss in a dose-dependent fashion.

Among the factors evaluated in the present study, hypertension had the strongest effect. The risk of hearing loss was 2 times higher in people with hypertension than in those without hypertension. Similar results were also found in other studies.[30, 31] Our study only found borderline association between diabetes and hearing loss, similar to the equivocal results from other studies.[32, 33] A likely explanation for these inconsistent results is that hearing loss is only weakly associated with diabetes, whose effects may be masked by other strong factors (e.g. age[6]). Another explanation is that the number of participants with diabetes is small in this study.

The limitations of this study should be considered. First, owing to the cross-sectional study nature, a causal relationship could not be established. Second, medical covariates were collected based on self-reported diagnosis, and specific values were not analysed as these data were not collected completely. Third, similar to the study conducted by Choi[34], we cannot rule out potential residual confounding by the presence of a noisy environment that were not captured by the binary variables of occupational and recreational noise.

In conclusion, the differences based on age and gender in hearing threshold levels and hearing loss were identified. Older men living in modern cities filled with industrial noise should pay more attention to their hearing status. We found a right ear dominance throughout all audiometric parameters. Harmful habits, like smoking and drinking, and ambient noise (including occupational and recreational noise) are associated with hearing loss. Educating and advising individuals to maintain good general health and fitness would have benefits for hearing preservation.[26] Furthermore, we found evidence that hypertension may accelerate the occurrence of hearing loss via a different pathophysiological mechanism. Hearing loss is a multifactorial condition that is a result of multiple intrinsic and extrinsic factors acting on the ears, and further prospective studies, with a multi-centre approach and wider ranges of exposure, are required to confirm the related risk factors.

We hope that our data can provide information on hearing loss for the development of national public health policies, and can help identify some related factors for early intervention. Evidently, our country attaches lesser importance to hearing loss than other developed countries, and we simultaneously hope to arouse the government's attention to this condition.

Author Contributors DW and HZ are joint first authors. DW edited the article, oversaw data analysis and preparation of supplementary files. HZ conducted the statistical analysis, interpretation and drafted the article. HM and LZ contributed to collecting prevalence estimates and preparation of supplementary files. LY and LX originated the study and designed the analysis, and both of them are coinvestigators and approved the final version of the article.

Funding This work was supported by the Zhejiang Key Research and Development Program (grant number 2015C03050), and the Major Science and Technology Innovation Project of Hangzhou (grant number 20152013A01).

Competing interests All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/coi_disclosure.pdf and declare: Lei Yang and Liang-Wen Xu had financial support from the Zhejiang Key Research and Development Program and the Major Science and Technology Innovation Project of Hangzhou for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous 3 years; no other relationships or activities that could appear to have influenced the submitted work.

Ethics approval The study was approved by the Hangzhou Normal University ethics committee.

Data sharing statement No additional data are available.

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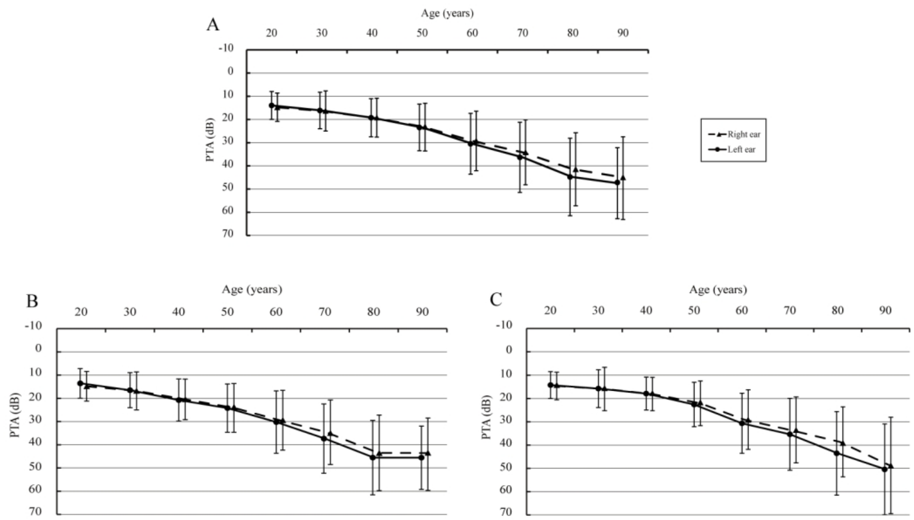
Figure legends

Figure 1. Pure-tone average for all ages at speech frequencies (0.5, 1, 2 and 4kHz) (A: total participants; B: males participants; C: female participants). The full lines indicate the hearing thresholds of left ears, and the dotted lines indicate the hearing thresholds of right ears. Bars indicate ±1 SD. '20y' old represents people aged 18-25y old, '30y' old represent people aged 26-35y old, '40y' old range is 36-45y old, '50y' old range is 46-55y old, '60y' old range is 56-65y old, '70y' old range is 66-75y old, '80y' old range is 76-85y old, and '90y' old range is 86-98y old.

Figure 2. Pure-tone average for all ages at high frequencies (3, 4, 6 and 8kHz) (A: total participants; B: males participants; C: female participants). The full lines indicate the hearing thresholds of left ears, and the dotted lines indicate the hearing thresholds of right ears. Bars indicate ±1 SD. '20y' old represents people aged 18-25y old, '30y' old represent people aged 26-35y old, '40y' old range is 36-45y old, '50y' old range is 46-55y old, '60y' old range is 56-65y old, '70y' old range is 66-75y old, '80y' old range is 76-85y old, and '90y' old range is 86-98y old.

Figure 3. Pure-tone average of different age groups (A: total participants; B: male participants; C: female participants). The left parts of the figures indicate the PTA of the left ears, and the right parts indicate the PTA of the right ears.

Figure 4. Pure-tone average of different genders (A: young group; B: middle group; C: old group). The left parts of the figures indicate the PTA of the left ears, and the right parts indicate the PTA of the right ears.



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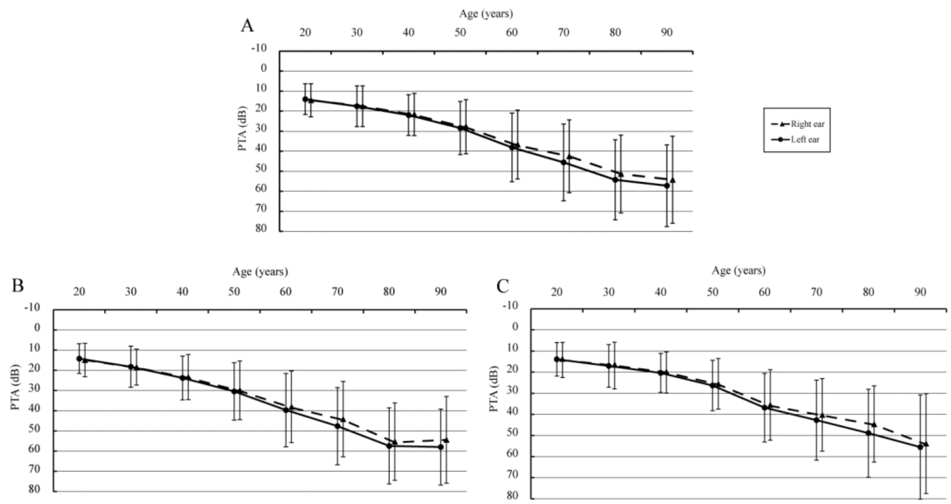

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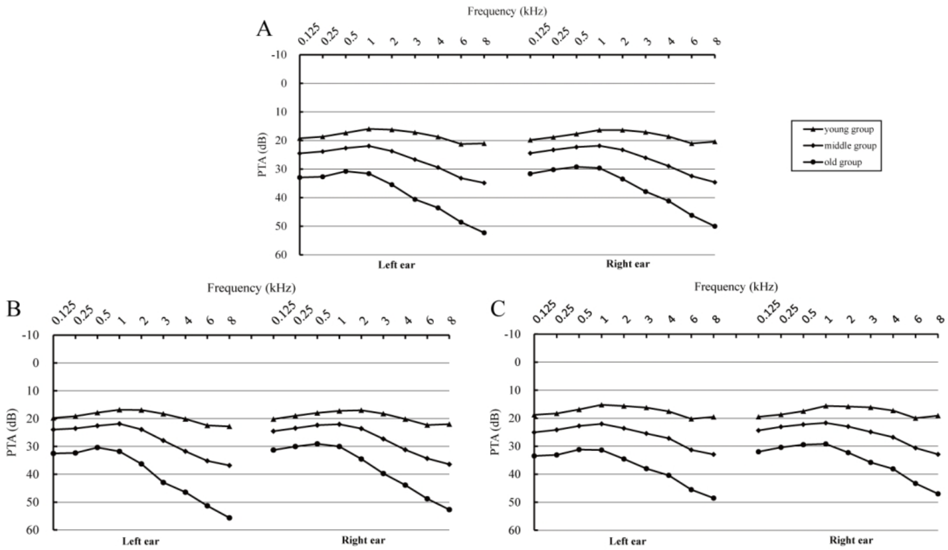

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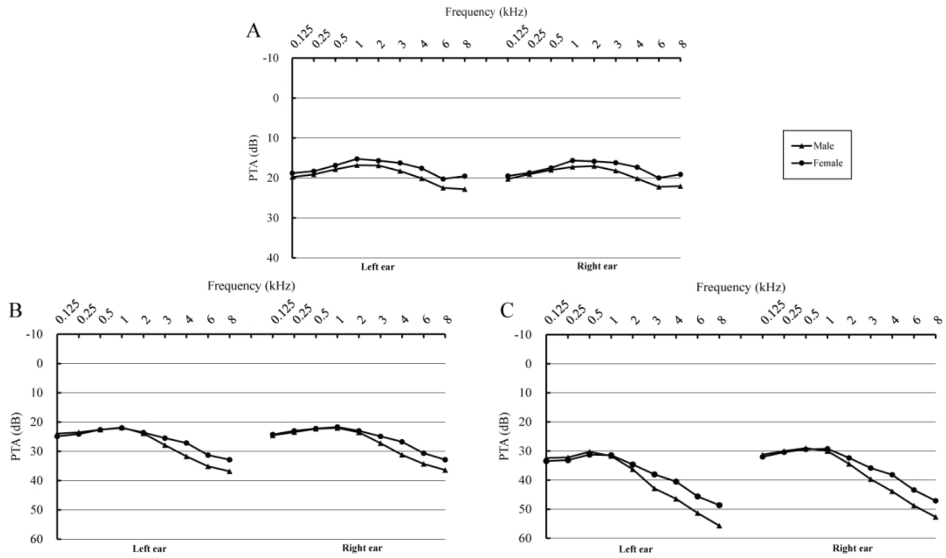

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Supplement Table 1. Differences in PTA (dB) in the better ear among areas.

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	Total	Male	Female	Total	Male	Female
Jiangshan	22.25±11.56	23.61±12.23	20.10±10.34	27.23±16.86	30.79±18.10	22.82±13.98
Jiaxing	21.23±9.91	22.39±10.02	20.11±9.68	23.09±12.09	24.33±12.10	21.90±11.98
Hangzhou	22.57±12.18	23.41±12.45	21.81±11.89	30.25±17.45	32.40±18.38	28.29±16.32
P	0.013	0.163	0.004	<0.001	<0.001	<0.001

Reporting checklist for cross sectional study.

Based on the STROBE cross sectional guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the STROBE cross sectional reporting guidelines, and cite them as:

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		Reporting Item	Page Number
Title	#1a	Indicate the study's design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	#3	State specific objectives, including any prespecified hypotheses	2
Study design	#4	Present key elements of study design early in the paper	2
Setting	#5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants.	5

	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	6
Bias	#9	Describe any efforts to address potential sources of bias	6
Study size	#10	Explain how the study size was arrived at	6
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	6
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	7
	#12b	Describe any methods used to examine subgroups and interactions	7
	#12c	Explain how missing data were addressed	7
	#12d	If applicable, describe analytical methods taking account of sampling strategy	n/a
	#12e	Describe any sensitivity analyses	n/a
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	8
	#13b	Give reasons for non-participation at each stage	n/a
	#13c	Consider use of a flow diagram	n/a
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	8

	#14b	Indicate number of participants with missing data for each variable of interest	n/a
Outcome data	#15	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	8
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8
	#16b	Report category boundaries when continuous variables were categorized	8
	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	#17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	n/a
Key results	#18	Summarise key results with reference to study objectives	9
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	12
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	9-12
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9-12
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	13

BMJ Open

Population-based cross-sectional study on the hearing threshold levels and hearing loss among people in Zhejiang, China

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-027152.R1
Article Type:	Research
Date Submitted by the Author:	16-Jan-2019
Complete List of Authors:	Wang, Dahui; Hangzhou Normal University Zhang, Huai; Hangzhou Normal University, Ma, Haiyan; Hangzhou Normal University Zhang, Long; Hangzhou Normal University Yang, Lei; Hangzhou Normal University Xu, Liangwen; Hangzhou Normal University
Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology, Ear, nose and throat/otolaryngology
Keywords:	hearing loss, hearing thresholds, lifestyle factors, environmental factors

Population-based cross-sectional study on the hearing threshold levels and hearing loss among people in Zhejiang, China

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Word count: 2912 words in Main Text; 242 words in Abstract

Total figures: 4 **Total tables:** 3

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ABSTRACT

Objectives: Hearing loss (≥26 dB threshold), as a common chronic condition in humans, is increasingly gaining attention. Relevant research in China is relatively scarce, so we conduct a population-based study to investigate the prevalence of hearing loss among age groups, genders, and ears in Zhejiang province, China.

Study design: A Population-based cross sectional study.

Participants: 3754 participants aged 18-98 years and living in Zhejiang Province, China.

Outcome measures: Pure-tone audiometric thresholds were measured at frequencies of 0.125–8 kHz for each subject. All participants were asked to complete a structured questionnaire, in the presence of a healthcare official.

Results. The prevalence of speech-frequency and high-frequency hearing loss was 27.9% and 42.9%, respectively, in Zhejiang. There were significant differences in auditory thresholds at most frequencies among the age groups, genders (male versus female: 31.6% versus 24.1% at speech-frequency; 48.9% versus 36.8% at high-frequency), and ears. In addition to the common factors affecting both types of hearing loss, significant correlation was found between personal income and speech-frequency hearing loss (odds ratio [OR]=0.69, 95% confidence interval [CI]: 0.52-0.92), and between hyperlipidaemia and high-frequency hearing loss (OR=1.45, 95% CI: 1.02-2.07).

Conclusion. The prevalence of hearing loss was high among people living in Zhejiang, particularly males, and in the left ear. Moreover, hearing thresholds increased with age. Several lifestyle and environment factors, which can be influenced by awareness and education, were significantly associated with hearing loss.

Key words: hearing loss, hearing thresholds, lifestyle factors, environmental factors.

Article Summary

Strengths and limitations of this study.

To the best of our knowledge, this is a study conducted in Zhejiang, China, involving a large population, with data from a wide band of hearing frequencies.

The study investigated whether several lifestyle and environment factors, which can be influenced by awareness and education, were related to hearing loss, and this could provide some ideas for future intervention studies.

The specific values of medical related indicators (such as systolic blood pressure, triglyceride and fasting blood-glucose) were not analysed as these data were not collected completely, hence, medical covariates were collected only based on self-reported diagnosis (as dichotomous variable, i.e., yes or no).

1. Introduction

Hearing loss, the most common sensory deficit in humans[1], is increasingly gaining attention; the World Health Organization estimated that the prevalence of hearing loss increased from 42 million in 1985 to 360 million in 2011.[2] According to a US study, more than 36 million people (16–17% adolescents) suffered from varying degrees of hearing loss.[3] Moreover, Twardella et al. reported that the prevalence of hearing loss among adolescents in Germany was approximately 2.4%.[4] Although the literature on hearing loss has gradually increased, these studies were either conducted in countries other than China, or the number of participants was small.[5] In addition, the hearing test did not cover a wide band of frequencies.[6]

As a common chronic condition in humans, hearing loss affects communication and can, therefore, affect the quality of life of the individual. Furthermore, it has substantial direct and indirect societal costs.[7] Moreover, in the 25-year Global Burden of Disease study, hearing loss was the second most common non-fatal disease affecting the quality of life of Chinese individuals.[8] However, the exact mechanisms of hearing loss remain unclear. Thus, there is an urgent need to study the prevalence of hearing loss and its related risk factors. Several studies have reported that hearing function is associated with age, sex, heredity, and environmental factors (such as noise exposure and heavy metal exposure) [9, 10], but similar research in China is still relatively scarce.

Hence, in the present study, data of audiometric measurements and responses to structured questionnaires were collected to investigate the prevalence of hearing loss in adults in Zhejiang, China; while other Chinese studies were conducted elsewhere, this is the first study to be conducted in Zhejiang with a large sample size and wide band of frequencies (0.125 to 8 kHz). An epidemiological study can well describe the hearing threshold levels and hearing loss in the Chinese population, and provide some data that can be used to develop interventions for preventing early hearing loss as well as for further investigation.

2. Methods

Study Areas and Participants

A study using a multi-stage stratified cluster random sampling method was conducted in the Zhejiang province from September 2016 to June 2018. Five healthcare centres were selected as follows: 1 in Jiangshan, 1 in Jiaxing, and 3 in Hangzhou (Tonglu county, Baiyang community, and Sijiqing community). Complete audiometric examination data and questionnaire data of 3754 participants (1900 males and 1854 females) (18–98 years old) were analysed. The participants were divided into 3 age groups: the young group (18–44 years old, mean age=34.19±6.35 [mean±standard deviation]), the middle group (45–59 years old, mean age=51.82±4.34), and the old group (60–98 years old, mean age=68.07±7.14).[11]

The whole process of study was approved by the Ethics Committee of Hangzhou Normal University. All subjects provided written informed consent and the study had been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments and local government policies.

Patient and public involvement

The role of subjects (including patients) in this study was participants. All subjects did not participate in the design, recruitment and other research work. After the completion of the study, we had called participants to elaborate on the results of this study in detail (if they indicated that they needed the results at the time of data collection).

Audiometry test

First, otoscopic examination was performed for each participant by an otolaryngologist to detect any ear pathology potentially affecting hearing function. A total of 631 participants (14.39% [631/4385]) who had an ear disease (such as otitis externa, otitis media, or cerumen impaction) or abnormal ear structure were excluded from the analysis. All pure-tone air conduction hearing thresholds were measured by trained researchers using audiometers (AT235; Interacoustics AS, Assens, Denmark) with standard headphones (TDH-39; Telephonic Corporation, Farmingdale, USA). Each subject was specifically instructed to press a handheld response key as soon as they heard a tone of a frequency between 0.125 and 8 kHz (0.125, 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz) over an intensity range of -10 to 110 dB in a soundproof booth with background noise of less than 20 dB(A). All facilities were calibrated before use, and similar to the study conducted by Wang et al.[5], we conducted the testing by beginning at 1 kHz, continuing to higher test frequencies and then returning to 1 kHz, followed by testing lower frequencies.[5] We computed the pure-tone average (PTA) at speech frequencies (0.5, 1, 2, and 4 kHz; speech-PTA), and at high frequencies (3, 4, 6, and 8 kHz; high-PTA).[12] Hearing loss was defined as speech-PTA of ≥26 dB in the better ear,[9] which is consistent with the WHO definition of clinically significant hearing loss,[13] and this can identify patients with bilateral hearing loss and related functional impairments.[14]

Covariates

All participants were asked to complete a structured questionnaire, in the presence of a healthcare official, covering demographic variables, audiometric information, lifestyle and environmental factors, as well as issues related to various risk factors and diseases. Education level was categorized as elementary school or less, middle school graduation, high school graduation, and college or more. Average monthly income was classified into 3 categories (low: ≤4000 RMB; middle: 4001–6000 RMB; high: ≥6001 RMB). Based on the history of cigarette smoking status, participants were categorized as follows: self-reported non-smokers (smoking less than 1 cigarette a day on average for less than 1 year), former smokers (cessation of smoking since the past 6 months or more), and current smokers (smoking at least one cigarette a day for more than 1 year). Based on drinking history, participants were also categorized as follows: self-reported non-drinkers (less than once per week), former drinkers (abstinence for more than 6 months), and current drinkers (alcohol consumption at least once a week for more than 6 months). If a participant indicated an exposure to loud noise in the workplace at least once a week, then the participant was considered to experience occupational noise exposure. If the participant had been exposed to loud noise outside of work (e.g., loud music or power tools) at least once a week, then the participant was considered to be exposed to recreational noise. Self-reported medical information, mainly about hypertension, hyperlipidaemia, diabetes, and hypercholesterolemia, was also collected.

Statistical analysis

The study used Epidata 3.1 (The Epidata Association, Odense, Denmark) for survey data entry and check and error correction (double entry and validation). SPSS (version 19.0 for Windows; SPSS, Inc., Chicago, USA) was used to conduct all statistical analyses, and the results were graphed using the SigmaPlot 12.0 software package (Systat Software International., Chicago, USA). A Kolmogorov-Smirnov normality test was performed to examine the distribution of each variable. Data were presented as proportions, mean±standard deviation (SD), or median (interquartile range), according to the original data distribution. The Student's t-test and chi square test were used to compare differences between the groups. In addition, the differences between the left and right ear were analysed using the paired t-test, and the Bonferroni correction for pairwise comparisons. Logistic regression was used to estimate the association between hearing loss (as binary variable, which could better represent the odds ratio of different factors in the two populations) and the variables (as categorical variables), after adjustment for age and gender. All reported probability values were two-tailed, and a *P* value of less than 0.05 was considered statistically significant.

3. Results

Comparison of hearing thresholds among different populations

The PTA for all age groups at speech frequency and high frequency is shown in Figure 1 and Figure 2, respectively. There were statistically significant differences between the left and right ear (when age was over 60 years, $P<0.05$) with respect to PTA, both in speech frequency (33.91dB versus 32.21dB [total participants, age was over 60 years]) and high frequency (42.32dB versus 40.18dB), and the hearing loss was more prevalent in the left ear.

There were significant differences between the male and female participants in the young, middle, and old group (especially at 3, 4, 6, and 8 kHz, $P<0.05$, data not shown) (Figure 3). In general, compared with men, women had better hearing (male versus female: 31.6% versus 24.1% at speech-frequency; 48.9% versus 36.8% at high-frequency [Table 1]). Meanwhile, Table 1 and Table S1 (comprising original PTA data) show that significant differences in hearing loss were found among the three selected areas. The prevalence of hearing loss in Hangzhou was the highest (33.3% for speech-frequency, and 53.9% for high-frequency hearing loss). Moreover, Figure 4 shows the PTA at the examined frequencies (0.125 to 8 kHz) among men and women in the different age groups. There were significant differences among age groups for both ears ($P<0.05$) at all frequencies. PTA was the highest in the old group, and lowest in the young group.

Table 1. Hearing loss in different areas stratified by gender and age.

Gender	Age	Speech-frequency hearing loss ≥26dB				High-frequency hearing loss ≥26dB			
		Jiangshan, %	Jiaxing, %	Hangzhou, %	*P*	Jiangshan, %	Jiaxing, %	Hangzhou, %	*P*
Male	Young	5.2 (13/249)	14.2 (27/190)	7.8 (18/230)	0.003	13.3 (33/249)	18.4 (35/190)	18.7 (43/230)	0.202
	Middle	27.0 (65/241)	24.6 (44/179)	30.8 (60/195)	0.398	52.3 (126/241)	33.5 (60/179)	67.7 (132/195)	<0.001
	Old	65.2 (131/201)	51.2 (84/164)	62.9 (158/251)	0.015	88.6 (178/201)	61.0 (100/164)	88.4 (222/251)	<0.001
Female	Young	3.9 (10/256)	4.8 (12/248)	5.3 (14/265)	0.751	7.8 (20/256)	12.1 (30/248)	14.7 (39/265)	0.046
	Middle	18.8 (38/202)	21.9 (34/155)	26.8 (59/220)	0.141	29.2 (59/202)	34.8 (54/155)	50.0 (110/220)	<0.001
	Old	48.0 (47/98)	45.4 (69/152)	63.2 (163/258)	0.001	71.4 (70/98)	53.9 (82/152)	84.9 (219/258)	<0.001
Total		24.4 (304/1247)	24.8 (270/1088)	33.3 (472/1419)	<0.001	39.0 (486/1247)	33.2 (361/1088)	53.9 (765/1419)	<0.001

The correlation between hearing loss and covariates

Of the 3754 eligible participants, a total of 1046 (27.9%) had speech-frequency hearing loss, and 1612 (42.9%) had high-frequency hearing loss. Table 2 shows the results of the comparison of the sociodemographic characteristics of the participants affected by hearing loss at speech-frequency and high-frequency. Participants with hearing loss group were on average 17 years older than those without hearing loss. Furthermore, there was a higher proportion of men in the hearing-loss group than in the normal-hearing group (speech-frequency, 57.4% versus 48.0%, $P<0.001$; high-frequency, 57.6% versus 45.3%, $P<0.001$). In addition, education, personal income, noise exposure (Table S2), smoking status, and drinking status were significantly associated with both types of hearing loss (all $P<0.001$). As for medical covariate data, there was a significant correlation between hearing loss and presence of hypertension, hyperlipidaemia, diabetes, and hypercholesterolemia (all $P<0.001$, for speech-frequency and high-frequency hearing loss).

Table 2. Characteristics of study participants

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	No	Yes	*P*	No	Yes	*P*
Number	2708	1046		2142	1612	
Age, years	45.28±13.56	61.97±12.38	<0.001	42.83±12.92	59.37±12.68	<0.001
Gender, % (men)	48.0	57.4	<0.001	45.3	57.6	<0.001
Education, %						
≤ Elementary school	7.2	23.9		5.5	20.3	
Middle school	20.6	28.9		17.5	30.1	
High school	27.4	26.5		28.0	26.0	
≥ College	44.8	20.7	<0.001	49.1	23.5	<0.001
Income: low/middle/high, %	37.1/44.7/18.2	55.2/32.2/12.6	<0.001	34.9/46.9/18.2	51.7/33.7/14.6	<0.001
Smoking: non/former/current, %	79.0/4.6/16.4	62.2/11.8/26.0	<0.001	83.1/3.5/13.4	62.6/10.7/26.7	<0.001
Drinking: non/former/current, %	83.9/1.4/14.7	69.1/2.6/28.3	<0.001	86.5/1.4/12.1	70.9/2.1/27.0	<0.001
Occupational noise exposure, %	36.5	46.7	<0.001	35.7	44.2	<0.001
Recreational noise exposure, %	21.4	31.3	<0.001	20.5	28.9	<0.001
Hypertension, %	13.7	43.7	<0.001	10.2	37.8	<0.001
Hyperlipidemia, %	4.9	13.6	<0.001	3.3	12.7	<0.001
Diabetes, %	3.2	12.4	<0.001	1.8	11.0	<0.001
Hypercholesterolemia, %	2.0	5.2	<0.001	1.7	4.4	<0.001

After adjustment for age and gender, a logistic regression analysis was performed to estimate the correlation between hearing loss and independent variables (Table 3). The correlation between education and speech-frequency hearing was not significant (*P*=0.064), although the risk of hearing loss decreased as the level of education increased. High personal income was found to have a significant negative correlation with hearing loss (odds ratio [OR]=0.69, 95% confidence intervals [CI]: 0.52–0.92, *P*=0.025). The adjusted ORs for the comparison of current smokers and non-smokers and current drinkers and non-drinkers were 1.43 (95% CI: 1.11–1.85) (*P* for trend=0.007) and 1.44 (95% CI: 1.15–1.82) (*P* for trend=0.004), respectively. The results showed that both types of noise exposures were risk factors for hearing loss. As for common chronic diseases, no significant association was found between presence of hyperlipidaemia or hypercholesterolemia and hearing loss (for hyperlipidaemia, OR=1.03, 95% CI: 0.75–1.41, *P*=0.848; for hypercholesterolemia, OR=1.31, 95% CI: 0.81–2.12, *P*=0.275). Hearing loss was associated with diabetes with borderline significance (OR=1.39, 95% CI: 0.99-1.95, *P*=0.061), and hypertension was found to be significantly associated with hearing loss (OR=2.28, 95% CI: 1.87–2.79, *P*<0.001).

Moreover, smoking, drinking, occupational noise, recreational noise, hypertension, and diabetes were risk factors for high-frequency hearing loss, whereas a high education level was a protective factor. In contrast with speech-frequency hearing loss, hyperlipidaemia was positively associated with hearing loss (OR=1.45, 95% CI: 1.02–2.07, *P*=0.039), while no significant association was found between income and hearing loss. The effects of smoking and hypertension on hearing loss were the greatest (for smoking, OR=2.08, 95% CI: 1.63–2.65; for hypertension, OR=2.17, 95% CI: 1.76–2.68).

Table 3. Logistic regression analysis of all the correlations of hearing loss

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	Yes/Total	ORs (95% CIs)	*P*-trend	Yes/Total	OR (95% CI)	*P*-trend
Education						
≤ Elementary school	250/445	1 (Reference)		328/445	1 (Reference)	
Middle school	302/860	0.75 (0.57-0.98)		486/860	0.93 (0.70-1.25)	
High school	277/1018	0.73 (0.55-0.97)		419/1018	0.65 (0.48-0.87)	
≥ College	217/1431	0.66 (0.48-0.90)	0.064	379/1431	0.60 (0.43-0.82)	<0.001
Income						
Low	577/1581	1 (Reference)		834/1581	1 (Reference)	
Middle	337/1547	0.80 (0.65-0.99)		543/1547	0.82 (0.67-0.99)	
High	132/626	0.69 (0.52-0.92)	0.025	235/626	0.89 (0.69-1.16)	0.129
Smoking						
non-	651/2789	1 (Reference)		1009/2789	1 (Reference)	
former-	123/248	1.50 (1.07-2.11)		173/248	1.85 (1.30-2.64)	
current-	272/717	1.43 (1.11-1.85)	0.007	430/717	2.08 (1.63-2.65)	<0.001
Drinking						
non-	723/2995	1 (Reference)		1143/2995	1 (Reference)	
former-	27/65	1.64 (0.87-3.09)		34/65	1.13 (0.60-2.13)	
current-	296/694	1.44 (1.15-1.82)	0.004	435/694	1.38 (1.10-1.74)	0.022
Occupational noise						
no	557/2277	1 (Reference)		899/2277	1 (Reference)	
yes	489/1477	1.35 (1.12-1.62)	0.001	713/1477	1.29 (1.08-1.54)	0.004
Recreational noise						
no	719/2848	1 (Reference)		1134/2825	1 (Reference)	
yes	327/906	1.39 (1.13-1.70)	0.002	461/896	1.39 (1.14-1.70)	0.001
Hypertension						
no	589/2926	1 (Reference)		1003/2926	1 (Reference)	
yes	457/828	2.28 (1.87-2.79)	<0.001	609/828	2.17 (1.76-2.68)	<0.001

Hyperlipidemia						
no	904/3479	1 (Reference)		1407/3479	1 (Reference)	
yes	142/275	1.03 (0.75-1.41)	0.848	205/275	1.45 (1.02-2.07)	0.039
Diabetes						
no	916/3538	1 (Reference)		1435/3538	1 (Reference)	
yes	130/216	1.39 (0.99-1.95)	0.061	177/216	1.82 (1.21-2.75)	0.004
Hypercholesterolemia						
no	992/3647	1 (Reference)		1541/3647	1 (Reference)	
yes	54/107	1.31 (0.81-2.12)	0.275	71/107	1.01 (0.60-1.69)	0.983

Note: analysis were adjusted for gender and age. Age was represented by categorical variables.

4. Discussion

This cross-sectional study, conducted in a large population and based on a cohort of local individuals in the Zhejiang province, provides information about the hearing threshold levels and prevalence of hearing loss among the people in Zhejiang, China. Based on the standard definition (speech-PTA [i.e., the average of 0.5, 1, 2, and 4 kHz hearing threshold] of ≥26 dB in the better ear), we estimated that 27.9% of the participants had speech-frequency hearing loss, which is different from the prevalence reported in other Chinese studies i.e., those conducted by Bu[15] and Gong[6] (11.7% and 58.85%). Differences in education, economics, and industrialization level due to geographical distribution of the population surveyed may be one of the reasons. On the other hand, the study by Gong et al was conducted among older adults (≥60 years), surprisingly, the prevalence of hearing loss in the elderly in our study was calculated as 58.23%, which was very close to that of Gong. Consistent with other studies[5, 16, 17], women often had a lower PTA than men, at most frequencies (from 1 to 8 kHz), in both the left and right ear. Among these examined frequencies, significant differences were found between the young, middle and old groups for PTA ($P<0.001$), confirming that the hearing threshold increases with age, both in males and females.[18] Furthermore, Sommer reported that a 1-year increase in age would raise the risk of hearing loss by 15%.[14]

Right ear dominance for PTA was identified in this study. Especially in participants older than 60 years, the right ear had better hearing ability than the left, which can be explained from the perspective of neurology. The ascending auditory projections pass through the brainstem and end in the cerebral cortex of the ipsi- and contra-lateral hemispheres, with a predominant representation on the side opposite to the ear.[19] In brief, the sound collected through the right ear is formed in the left hemisphere, and vice versa. Therefore, based on the anatomical characteristics of the human brain, right ear input is directly transferred to the speech perception areas in the left hemisphere, whereas stimuli to the left ear have to be transferred initially to the right hemisphere, from which it is transferred to the left hemisphere through the corpus callosum.[19] Some studies have also identified the right ear dominance in certain populations,[20-22] which in turn, supports the above theoretical basis. In contrast, another study in Switzerland suggested that PTA has no significant differences between both ears.[23]

Hangzhou had the highest prevalence of hearing loss among the three selected areas. As a modern city with a highly developed economy, Hangzhou is filled with industrial noise, whereas the other two regions have a slightly less-developed economy, with less industrial noise. This is similar to inferences made by Wang et al.[5] Meanwhile, consistent with previous studies, noise exposures (including occupational noise and recreational noise) were found to be risk factors for hearing loss,[6, 24, 25] while education (for high-frequency hearing loss) and personal income (for speech-frequency hearing loss) were protective factors. Highly educated people have a better knowledge of health, and people with high personal income can prevent hearing loss by using low-noise devices or by avoiding high-noise workplaces.

Our results support the evidence that smoking and drinking have associations with the risk of hearing loss.[26, 27] Cruickshanks et al.[28] estimated that current smokers were 1.69 times more likely to have hearing loss than non-smokers (95% CI: 1.31–2.17), which is similar to the results obtained in our study (1.66-fold, 95% CI: 1.24–2.22). Similarly, a multi-centre study conducted by Fransen et al.[29] reported that smoking significantly increased high-frequency hearing loss in a dose-dependent fashion.

Among the factors evaluated in the present study, hypertension had the strongest effect. The risk of hearing loss was 2 times higher in people with hypertension than in those without hypertension. Similar results were also found in other studies.[30, 31] Our study only found borderline association between diabetes and hearing loss, similar to the equivocal results from other studies.[32, 33] A likely explanation for these inconsistent results is that hearing loss is only weakly associated with diabetes, whose effects may be masked by other strong factors (e.g. age[6]). Another explanation is that the number of participants with diabetes is small in this study.

The limitations of this study should be considered. First, owing to the cross-sectional study nature, a causal relationship could not be established. Second, medical covariates were collected based on self-reported diagnosis, and specific values were not analysed as these data were not collected completely. Third, similar to the study conducted by Choi[34], we cannot rule out potential residual confounding by the presence of a noisy environment that were not captured by the binary variables of occupational and recreational noise (refer to exposure at the time of data collection). Fourth, the burden of hearing loss may be underestimated due to the exclusion of patients with ear diseases.

In conclusion, the differences based on age and gender in hearing threshold levels and hearing loss were identified. Older men living in modern cities filled with industrial noise should pay more attention to their hearing status. We found a right ear dominance throughout all audiometric parameters. Harmful habits, like smoking and drinking, and ambient noise (including occupational and recreational noise) are associated with hearing loss. Educating and advising individuals to maintain good general health and fitness would have benefits for hearing preservation.[26] Furthermore, we found evidence that among several common chronic diseases, hypertension is the most closely related to hearing loss, which requires special attention to the hearing of patients with hypertension. Hearing loss is a multifactorial condition that is a result of multiple intrinsic and extrinsic factors acting on the ears, and further prospective studies, with a multi-centre approach and wider ranges of exposure, are required to confirm the related risk factors.

We hope that our data can provide information on hearing loss for the development of national public health policies, and can help identify some related factors for early intervention. As a developing country, society is more concerned about various fatal diseases, economy and ecology, so that our country attaches lesser importance to hearing loss than other developed countries, and we simultaneously hope to arouse the government's attention to this condition.

Author Contributors DW and HZ are joint first authors. DW edited the article, oversaw data analysis and preparation of supplementary files. HZ conducted the statistical analysis, interpretation and drafted the article. HM and LZ contributed to collecting prevalence estimates and preparation of supplementary files. LY and LX originated the study and designed the analysis, and both of them are coinvestigators and approved the final version of the article.

Funding This work was supported by the Zhejiang Key Research and Development Program (grant number 2015C03050), and the Major Science and Technology Innovation Project of Hangzhou (grant number 20152013A01).

Competing interests All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/coi_disclosure.pdf and declare: Lei Yang and Liang-Wen Xu had financial support from the Zhejiang Key Research and Development Program and the Major Science and Technology Innovation Project of Hangzhou for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous 3 years; no other relationships or activities that could appear to have influenced the submitted work.

Ethics approval The study was approved by the Hangzhou Normal University ethics committee.

Data sharing statement No additional data are available.

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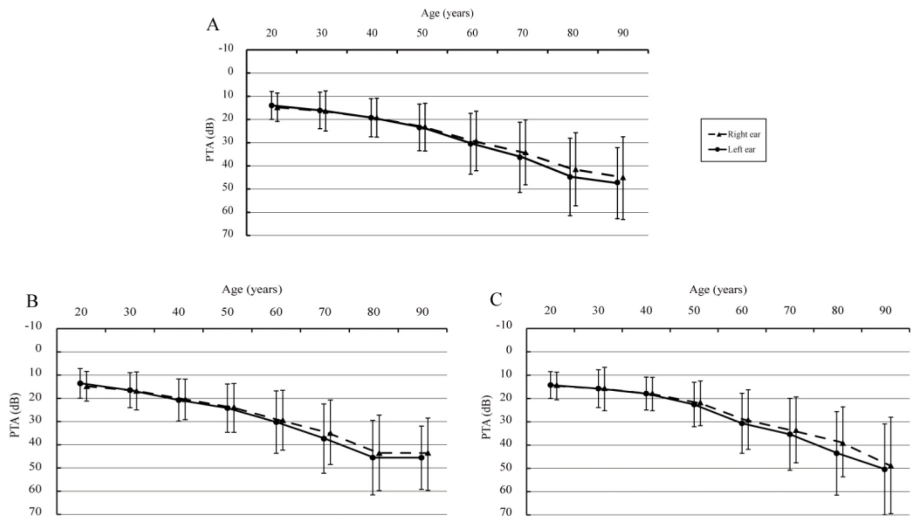
Figure legends

Figure 1. Pure-tone average for all ages at speech frequencies (0.5, 1, 2 and 4kHz) (A: total participants; B: males participants; C: female participants). The full lines indicate the hearing thresholds of left ears, and the dotted lines indicate the hearing thresholds of right ears. Bars indicate ±1 SD. '20y' old represents people aged 18-25y old, '30y' old represent people aged 26-35y old, '40y' old range is 36-45y old, '50y' old range is 46-55y old, '60y' old range is 56-65y old, '70y' old range is 66-75y old, '80y' old range is 76-85y old, and '90y' old range is 86-98y old.

Figure 2. Pure-tone average for all ages at high frequencies (3, 4, 6 and 8kHz) (A: total participants; B: males participants; C: female participants). The full lines indicate the hearing thresholds of left ears, and the dotted lines indicate the hearing thresholds of right ears. Bars indicate ±1 SD. '20y' old represents people aged 18-25y old, '30y' old represent people aged 26-35y old, '40y' old range is 36-45y old, '50y' old range is 46-55y old, '60y' old range is 56-65y old, '70y' old range is 66-75y old, '80y' old range is 76-85y old, and '90y' old range is 86-98y old.

Figure 3. Pure-tone average of different age groups (A: total participants; B: male participants; C: female participants). The left parts of the figures indicate the PTA of the left ears, and the right parts indicate the PTA of the right ears.

Figure 4. Pure-tone average of different genders (A: young group; B: middle group; C: old group). The left parts of the figures indicate the PTA of the left ears, and the right parts indicate the PTA of the right ears.



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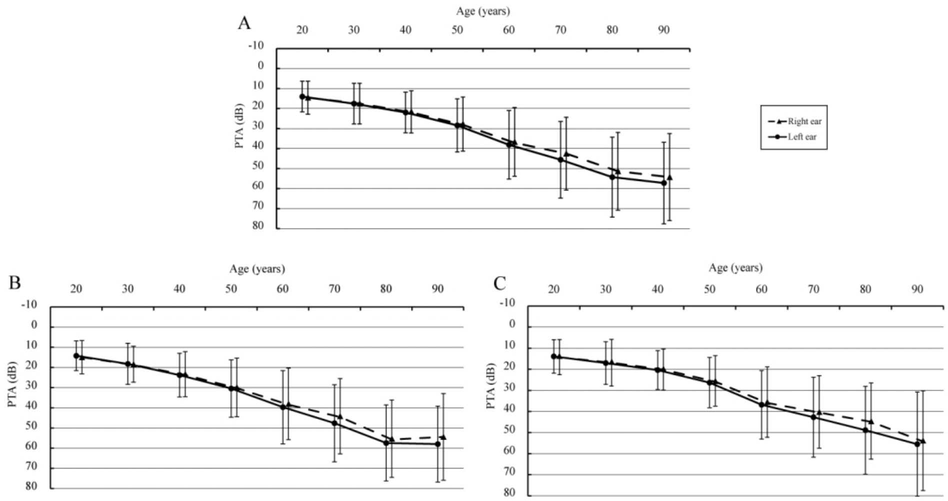

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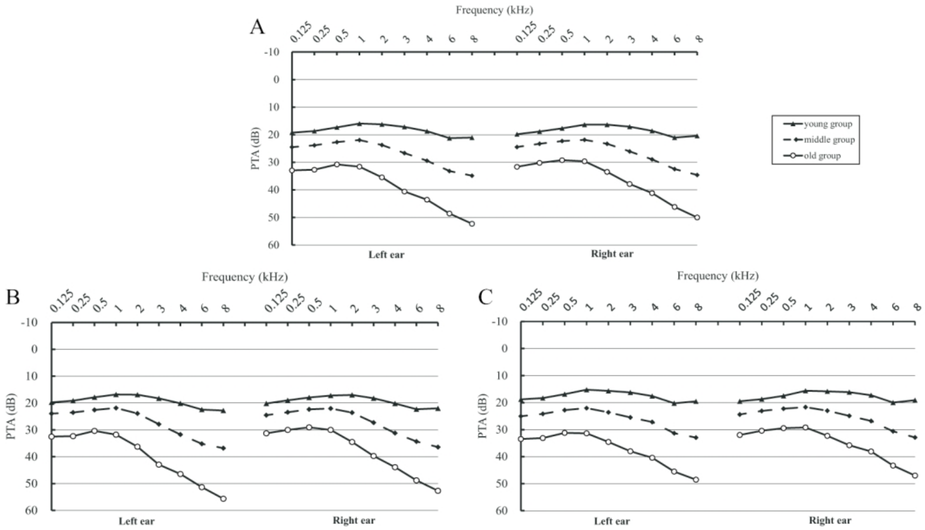
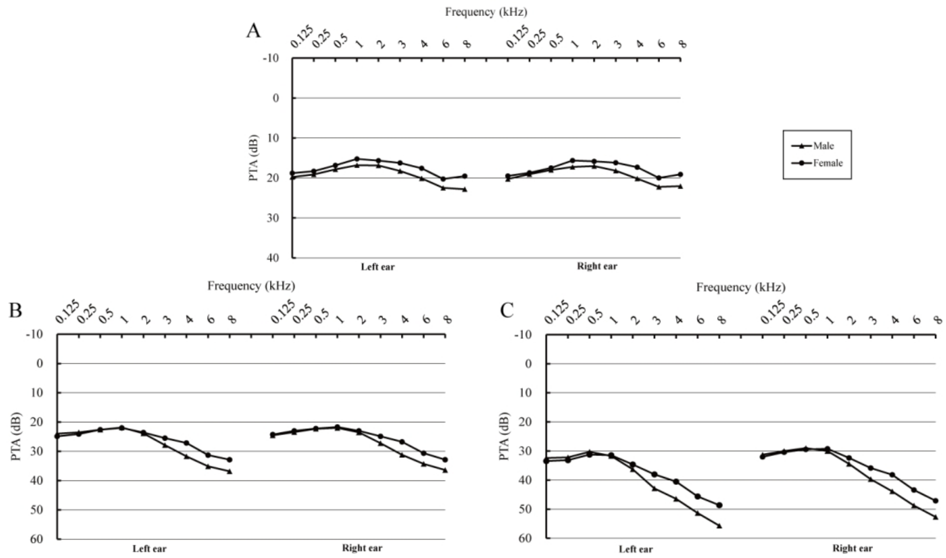


Caption: 3



4

137x82mm (300 x 300 DPI)

Supplement Table 1. Differences in PTA (dB) in the better ear among areas.

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	Total	Male	Female	Total	Male	Female
Jiangshan	22.25±11.56	23.61±12.23	20.10±10.34	27.23±16.86	30.79±18.10	22.82±13.98
Jiaxing	21.23±9.91	22.39±10.02	20.11±9.68	23.09±12.09	24.33±12.10	21.90±11.98
Hangzhou	22.57±12.18	23.41±12.45	21.81±11.89	30.25±17.45	32.40±18.38	28.29±16.32
P	0.013	0.163	0.004	<0.001	<0.001	<0.001

Supplement Table 2. Characteristics information of noise exposure.

	Exposure to occupational noise			Exposure to recreational noise		
	No	Yes	*P*	No	Yes	*P*
Number	2277	1477		2848	906	
Age group, %						
Young	38.7	37.7		39.9	33.4	
Middle	32.1	31.2		31.4	32.8	
Old	29.2	31.1	0.431	28.7	33.8	0.001
Gender, % (men)	47.9	54.8	<0.001	49.0	55.7	<0.001
Education, %						
≤ Elementary school	10.7	13.6		11.7	12.3	
Middle school	21.1	25.7		23.8	20.2	
High school	26.9	27.5		26.1	30.2	
≥ College	41.3	33.2	<0.001	38.4	37.3	0.037
Income, %						
Low	41.0	43.9		42.8	40.0	
Middle	39.3	44.1		40.4	43.6	
High	19.7	12.0	<0.001	16.8	16.4	0.222

Reporting checklist for cross sectional study.

Based on the STROBE cross sectional guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

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In your methods section, say that you used the STROBE cross sectional reporting guidelines, and cite them as:

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		Reporting Item	Page Number
Title	#1a	Indicate the study’s design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	#3	State specific objectives, including any prespecified hypotheses	2
Study design	#4	Present key elements of study design early in the paper	2
Setting	#5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants.	5

	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	6
Bias	#9	Describe any efforts to address potential sources of bias	6
Study size	#10	Explain how the study size was arrived at	6
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	6
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	7
	#12b	Describe any methods used to examine subgroups and interactions	7
	#12c	Explain how missing data were addressed	7
	#12d	If applicable, describe analytical methods taking account of sampling strategy	n/a
	#12e	Describe any sensitivity analyses	n/a
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	8
	#13b	Give reasons for non-participation at each stage	n/a
	#13c	Consider use of a flow diagram	n/a
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	8

	#14b	Indicate number of participants with missing data for each variable of interest	n/a
Outcome data	#15	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	8
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8
	#16b	Report category boundaries when continuous variables were categorized	8
	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	#17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	n/a
Key results	#18	Summarise key results with reference to study objectives	9
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	12
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	9-12
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9-12
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	13

Population-based cross-sectional study on the hearing threshold levels and hearing loss among people in Zhejiang, China

Journal:	*BMJ Open*
Manuscript ID	bmjopen-2018-027152.R2
Article Type:	Research
Date Submitted by the Author:	21-Feb-2019
Complete List of Authors:	Wang, Dahui; Hangzhou Normal University Zhang, Huai; Hangzhou Normal University, Ma, Haiyan; Hangzhou Normal University Zhang, Long; Hangzhou Normal University Yang, Lei; Hangzhou Normal University Xu, Liangwen; Hangzhou Normal University
Primary Subject Heading:	Public health
Secondary Subject Heading:	Epidemiology, Ear, nose and throat/otolaryngology
Keywords:	hearing loss, hearing thresholds, lifestyle factors, environmental factors

Population-based cross-sectional study on the hearing threshold levels and hearing loss among people in Zhejiang, China

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Word count: 2985 words in Main Text; 252 words in Abstract

Total figures: 4 **Total tables:** 3

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ABSTRACT

Objectives: Hearing loss (≥26 dB threshold in the better ear), as a common chronic condition in humans, is increasingly gaining attention. Relevant research in China is relatively scarce, so we conduct a population-based study to investigate the prevalence of hearing loss among age groups, genders, and ears in Zhejiang province, China from September 2016 to June 2018.

Study design: A Population-based cross sectional study.

Participants: 3754 participants aged 18-98 years and living in Zhejiang Province, China.

Outcome measures: Pure-tone audiometric thresholds were measured at frequencies of 0.125–8 kHz for each subject. All participants were asked to complete a structured questionnaire, in the presence of a healthcare official.

Results. The prevalence of speech-frequency and high-frequency hearing loss was 27.9% and 42.9%, respectively, in Zhejiang. There were significant differences in auditory thresholds at most frequencies among the age groups, genders (male versus female: 31.6% versus 24.1% at speech-frequency; 48.9% versus 36.8% at high-frequency), and ears. In addition to the common factors affecting both types of hearing loss, significant correlation was found between personal income and speech-frequency hearing loss (odds ratio [OR]=0.69, 95% confidence interval [CI]: 0.52-0.92), and between hyperlipidaemia and high-frequency hearing loss (OR=1.45, 95% CI: 1.02-2.07).

Conclusion. The prevalence of hearing loss was high among people living in Zhejiang, particularly males, and in the left ear. Moreover, hearing thresholds increased with age. Several lifestyle and environment factors, which can be influenced by awareness and education, were significantly associated with hearing loss.

Key words: hearing loss, hearing thresholds, lifestyle factors, environmental factors.

Article Summary

Strengths and limitations of this study.

To our knowledge, this is the first study to be conducted in Zhejiang, China, involving a large population, with data from a wide band of hearing frequencies.

The study investigated whether several lifestyle and environment factors, which can be influenced by awareness and education, were related to hearing loss, and this could provide some ideas for future intervention studies.

The specific values of medical related indicators (such as systolic blood pressure, triglyceride and fasting blood-glucose) were not analysed as these data were not collected completely, hence, medical covariates were collected only based on self-reported diagnosis (as dichotomous variable, i.e., yes or no).

1. Introduction

Hearing loss, the most common sensory deficit in humans[1], is increasingly gaining attention; the World Health Organization estimated that the prevalence of hearing loss increased from 42 million in 1985 to 360 million in 2011.[2] According to a US study, more than 36 million people (16–17% adolescents) suffered from varying degrees of hearing loss.[3] Moreover, Twardella et al. reported that the prevalence of hearing loss among adolescents in Germany was approximately 2.4%.[4] Although the literature on hearing loss has gradually increased, these studies were either conducted in countries other than China, or the number of participants was small.[5] In addition, the hearing test did not cover a wide band of frequencies.[6]

As a common chronic condition in humans, hearing loss affects communication and can, therefore, affect the quality of life of the individual. Furthermore, it has substantial direct and indirect societal costs.[7] Moreover, in the 25-year Global Burden of Disease study, hearing loss was the second most common non-fatal disease affecting the quality of life of Chinese individuals.[8] However, the exact mechanisms of hearing loss remain unclear. Thus, there is an urgent need to study the prevalence of hearing loss and its related risk factors. Several studies have reported that hearing function is associated with age, sex, heredity, and environmental factors (such as noise exposure and heavy metal exposure) [9, 10], but similar research in China is still relatively scarce.

Hence, in the present study, data of audiometric measurements and responses to structured questionnaires were collected to investigate the prevalence of hearing loss in adults in Zhejiang, China; while other Chinese studies were conducted elsewhere, this is the first study to be conducted in Zhejiang with a large sample size and wide band of frequencies (0.125 to 8 kHz). What's more, Zhejiang is a typical representative of the eastern coastal provinces of China. It has a relatively developed economy, a large population, and is one of the larger provinces in China. An epidemiological study can well describe the hearing threshold levels and hearing loss in the Chinese population, and provide some data that can be used to develop interventions for preventing early hearing loss as well as for further investigation.

2. Methods

Study Areas and Participants

A study using a multi-stage stratified cluster random sampling method was conducted in the Zhejiang province from September 2016 to June 2018. Five healthcare centres were selected as follows: 1 in Jiangshan, 1 in Jiaxing, and 3 in Hangzhou (Tonglu county, Baiyang community, and Sijiqing community). Complete audiometric examination data and questionnaire data of 3754 participants (1900 males and 1854 females) (18–98 years old) were analysed. The participants were divided into 3 age groups: the young group (18–44 years old, mean age=34.19±6.35 [mean±standard deviation]), the middle group (45–59 years old, mean age=51.82±4.34), and the old group (60–98 years old, mean age=68.07±7.14).[11]

The whole process of study was approved by the Ethics Committee of Hangzhou Normal University. All subjects provided written informed consent and the study had been performed in accordance with the ethical standards laid down in the 1964 Declaration of Helsinki and its later amendments and local government policies.

Patient and public involvement

The role of subjects (including patients) in this study was participants. All subjects did not participate in the design, recruitment and other research work. After the completion of the study, we had called participants to elaborate on the results of this study in detail (if they indicated that they needed the results at the time of data collection).

Audiometry test

First, otoscopic examination was performed for each participant by an otolaryngologist to detect any ear pathology potentially affecting hearing function. A total of 631 participants (14.39% [631/4385]) who had an ear disease (such as otitis externa, otitis media, or cerumen impaction) or abnormal ear structure were excluded from the analysis. All pure-tone air conduction hearing thresholds were measured by trained researchers using audiometers (AT235; Interacoustics AS, Assens, Denmark) with standard headphones (TDH-39; Telephonic Corporation, Farmingdale, USA). Each subject was specifically instructed to press a handheld response key as soon as they heard a tone of a frequency between 0.125 and 8 kHz (0.125, 0.25, 0.5, 1, 2, 3, 4, 6, and 8 kHz) over an intensity range of -10 to 110 dB in a soundproof booth with background noise of less than 20 dB(A). All facilities were calibrated before use, and similar to the study conducted by Wang et al.[5], we conducted the testing by beginning at 1 kHz, continuing to higher test frequencies and then returning to 1 kHz, followed by testing lower frequencies.[5] We computed the pure-tone average (PTA) at speech frequencies (0.5, 1, 2, and 4 kHz; speech-PTA), and at high frequencies (3, 4, 6, and 8 kHz; high-PTA).[12] Hearing loss was defined as speech-PTA of ≥26 dB in the better ear,[9] which is consistent with the WHO definition of clinically significant hearing loss,[13] and this can identify patients with bilateral hearing loss and related functional impairments.[14]

Covariates

All participants were asked to complete a structured questionnaire, in the presence of a healthcare official, covering demographic variables, audiometric information, lifestyle and environmental factors, as well as issues related to various risk factors and diseases. Education level was categorized as elementary school or less, middle school graduation, high school graduation, and college or more. Average monthly income was classified into 3 categories (low: ≤4000 RMB; middle: 4001–6000 RMB; high: ≥6001 RMB). Based on the history of cigarette smoking status, participants were categorized as follows: self-reported non-smokers (smoking less than 1 cigarette a day on average for less than 1 year), former smokers (cessation of smoking since the past 6 months or more), and current smokers (smoking at least one cigarette a day for more than 1 year). Based on drinking history, participants were also categorized as follows: self-reported non-drinkers (less than once per week), former drinkers (abstinence for more than 6 months), and current drinkers (alcohol consumption at least once a week for more than 6 months). If a participant indicated an exposure to loud noise in the workplace at least once a week, then the participant was considered to experience occupational noise exposure. If the participant had been exposed to loud noise outside of work (e.g., loud music or power tools) at least once a week, then the participant was considered to be exposed to recreational noise. To emphasize an important point, the volume of the noise is the subjective feeling of the participant, so if a participant felt that the sound was too loud to feel uncomfortable, then he/she was considered to be exposed to loud noise. Self-reported medical information, mainly about hypertension, hyperlipidaemia, diabetes, and hypercholesterolemia, was also collected.

Statistical analysis

The study used Epidata 3.1 (The Epidata Association, Odense, Denmark) for survey data entry and check and error correction (double entry and validation). SPSS (version 19.0 for Windows; SPSS, Inc., Chicago, USA) was used to conduct all statistical analyses, and the results were graphed using the SigmaPlot 12.0 software package (Systat Software International., Chicago, USA). A Kolmogorov-Smirnov normality test was performed to examine the distribution of each variable. Data were presented as proportions, mean±standard deviation (SD), or median (interquartile range), according to the original data distribution. The Student's t-test and chi square test were used to compare differences between the groups. In addition, the differences between the left and right ear were analysed using the paired t-test, and the Bonferroni correction for pairwise comparisons. Logistic regression was used to estimate the association between hearing loss (as binary variable, which could better represent the odds ratio of different factors in the two populations) and the variables (as categorical variables), after adjustment for age and gender. All reported probability values were two-tailed, and a *P* value of less than 0.05 was considered statistically significant.

3. Results

Comparison of hearing thresholds among different populations

The PTA for all age groups at speech frequency and high frequency is shown in Figure 1 and Figure 2, respectively. There were statistically significant differences between the left and right ear (when age was over 60 years, $P<0.05$) with respect to PTA, both in speech frequency (33.91dB versus 32.21dB [total participants, age was over 60 years]) and high frequency (42.32dB versus 40.18dB), and the hearing loss was more prevalent in the left ear.

There were significant differences between the male and female participants in the young, middle, and old group (especially at 3, 4, 6, and 8 kHz, $P<0.05$, data not shown) (Figure 3). In general, compared with men, women had better hearing (male versus female: 31.6% versus 24.1% at speech-frequency; 48.9% versus 36.8% at high-frequency [Table 1]). Meanwhile, Table 1 and Table S1 (comprising original PTA data) show that significant differences in hearing loss were found among the three selected areas. The prevalence of hearing loss in Hangzhou was the highest (33.3% for speech-frequency, and 53.9% for high-frequency hearing loss). Moreover, Figure 4 shows the

PTA at the examined frequencies (0.125 to 8 kHz) among men and women in the different age groups. There were significant differences among age groups for both ears ($P<0.05$) at all frequencies. PTA was the highest in the old group, and lowest in the young group.

Table 1. Hearing loss in different areas stratified by gender and age.

Gender	Age	Speech-frequency hearing loss ≥26dB				High-frequency hearing loss ≥26dB			
		Jiangshan, %	Jiaxing, %	Hangzhou, %	*P**	Jiangshan, %	Jiaxing, %	Hangzhou, %	*P**
Male	Young	5.2 (13/249)	14.2 (27/190)	7.8 (18/230)	0.003	13.3 (33/249)	18.4 (35/190)	18.7 (43/230)	0.202
	Middle	27.0 (65/241)	24.6 (44/179)	30.8 (60/195)	0.398	52.3 (126/241)	33.5 (60/179)	67.7 (132/195)	<0.001
	Old	65.2 (131/201)	51.2 (84/164)	62.9 (158/251)	0.015	88.6 (178/201)	61.0 (100/164)	88.4 (222/251)	<0.001
Female	Young	3.9 (10/256)	4.8 (12/248)	5.3 (14/265)	0.751	7.8 (20/256)	12.1 (30/248)	14.7 (39/265)	0.046
	Middle	18.8 (38/202)	21.9 (34/155)	26.8 (59/220)	0.141	29.2 (59/202)	34.8 (54/155)	50.0 (110/220)	<0.001
	Old	48.0 (47/98)	45.4 (69/152)	63.2 (163/258)	0.001	71.4 (70/98)	53.9 (82/152)	84.9 (219/258)	<0.001
Total		24.4 (304/1247)	24.8 (270/1088)	33.3 (472/1419)	<0.001	39.0 (486/1247)	33.2 (361/1088)	53.9 (765/1419)	<0.001

* Chi square test. $P<0.05$ indicated a significant difference in the prevalence of hearing loss among the three selected areas stratified by gender and age.

The correlation between hearing loss and covariates

Of the 3754 eligible participants, a total of 1046 (27.9%) had speech-frequency hearing loss, and 1612 (42.9%) had high-frequency hearing loss. Table 2 shows the results of the comparison of the sociodemographic characteristics of the participants affected by hearing loss at speech-frequency and high-frequency. Participants with hearing loss group were on average 17 years older than those without hearing loss. Furthermore, there was a higher proportion of men in the hearing-loss group than in the normal-hearing group (speech-frequency, 57.4% versus 48.0%, P<0.001; high-frequency, 57.6% versus 45.3%, P<0.001). In addition, education, personal income, noise exposure (Table S2), smoking status, and drinking status were significantly associated with both types of hearing loss (all P<0.001). As for medical covariate data, there was a significant correlation between hearing loss and presence of hypertension, hyperlipidaemia, diabetes, and hypercholesterolemia (all P<0.001, for speech-frequency and high-frequency hearing loss).

Table 2. Characteristics of study participants

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	No	Yes	*P*	No	Yes	*P*
Number	2708	1046		2142	1612	
Age, years	45.28±13.56	61.97±12.38	<0.001	42.83±12.92	59.37±12.68	<0.001
Gender, % (men)	48.0	57.4	<0.001	45.3	57.6	<0.001
Education, %						
≤ Elementary school	7.2	23.9		5.5	20.3	
Middle school	20.6	28.9		17.5	30.1	
High school	27.4	26.5		28.0	26.0	
≥ College	44.8	20.7	<0.001	49.1	23.5	<0.001
Income: low/middle/high, %	37.1/44.7/18.2	55.2/32.2/12.6	<0.001	34.9/46.9/18.2	51.7/33.7/14.6	<0.001
Smoking: non/former/current, %	79.0/4.6/16.4	62.2/11.8/26.0	<0.001	83.1/3.5/13.4	62.6/10.7/26.7	<0.001
Drinking: non/former/current, %	83.9/1.4/14.7	69.1/2.6/28.3	<0.001	86.5/1.4/12.1	70.9/2.1/27.0	<0.001
Occupational noise exposure, %	36.5	46.7	<0.001	35.7	44.2	<0.001
Recreational noise exposure, %	21.4	31.3	<0.001	20.5	28.9	<0.001
Hypertension, %	13.7	43.7	<0.001	10.2	37.8	<0.001
Hyperlipidemia, %	4.9	13.6	<0.001	3.3	12.7	<0.001
Diabetes, %	3.2	12.4	<0.001	1.8	11.0	<0.001
Hypercholesterolemia, %	2.0	5.2	<0.001	1.7	4.4	<0.001

Note: *P* values based on Student's t-test for continuous variables and chi square test for categorical variables, and *P*<0.05 indicated that the independent variables were statistically different between the two groups.

After adjustment for age and gender, a logistic regression analysis was performed to estimate the correlation between hearing loss and independent variables (Table 3). The correlation between education and speech-frequency hearing was not significant (*P*=0.064), although the risk of hearing loss decreased as the level of education increased. High personal income was found to have a significant negative correlation with hearing loss (odds ratio [OR]=0.69, 95% confidence intervals [CI]: 0.52–0.92, *P*=0.025). The adjusted ORs for the comparison of current smokers and non-smokers and current drinkers and non-drinkers were 1.43 (95% CI: 1.11–1.85) (*P* for trend=0.007) and 1.44 (95% CI: 1.15–1.82) (*P* for trend=0.004), respectively. The results showed that both types of noise exposures were risk factors for hearing loss. As for common chronic diseases, no significant association was found between presence of hyperlipidaemia or hypercholesterolemia and hearing loss (for hyperlipidaemia, OR=1.03, 95% CI: 0.75–1.41, *P*=0.848; for hypercholesterolemia, OR=1.31, 95% CI: 0.81–2.12, *P*=0.275). Hearing loss was associated with diabetes with borderline significance (OR=1.39, 95% CI: 0.99-1.95, *P*=0.061), and hypertension was found to be significantly associated with hearing loss (OR=2.28, 95% CI: 1.87–2.79, *P*<0.001).

Moreover, smoking, drinking, occupational noise, recreational noise, hypertension, and diabetes were risk factors for high-frequency hearing loss, whereas a high education level was a protective factor. In contrast with speech-frequency hearing loss, hyperlipidaemia was positively associated with hearing loss (OR=1.45, 95% CI: 1.02–2.07, *P*=0.039), while no significant association was found between income and hearing loss. The effects of smoking and hypertension on hearing loss were the greatest (for smoking, OR=2.08, 95% CI: 1.63–2.65; for hypertension, OR=2.17, 95% CI: 1.76–2.68).

Table 3. Logistic regression analysis of all the correlations of hearing loss

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	Yes/Total	ORs (95% CIs)	*P*-trend	Yes/Total	OR (95% CI)	*P*-trend
Education						
≤ Elementary school	250/445	1 (Reference)		328/445	1 (Reference)	
Middle school	302/860	0.75 (0.57-0.98)		486/860	0.93 (0.70-1.25)	
High school	277/1018	0.73 (0.55-0.97)		419/1018	0.65 (0.48-0.87)	
≥ College	217/1431	0.66 (0.48-0.90)	0.064	379/1431	0.60 (0.43-0.82)	<0.001
Income						
Low	577/1581	1 (Reference)		834/1581	1 (Reference)	
Middle	337/1547	0.80 (0.65-0.99)		543/1547	0.82 (0.67-0.99)	
High	132/626	0.69 (0.52-0.92)	0.025	235/626	0.89 (0.69-1.16)	0.129
Smoking						
non-	651/2789	1 (Reference)		1009/2789	1 (Reference)	
former-	123/248	1.50 (1.07-2.11)		173/248	1.85 (1.30-2.64)	
current-	272/717	1.43 (1.11-1.85)	0.007	430/717	2.08 (1.63-2.65)	<0.001
Drinking						
non-	723/2995	1 (Reference)		1143/2995	1 (Reference)	
former-	27/65	1.64 (0.87-3.09)		34/65	1.13 (0.60-2.13)	
current-	296/694	1.44 (1.15-1.82)	0.004	435/694	1.38 (1.10-1.74)	0.022
Occupational noise						
no	557/2277	1 (Reference)		899/2277	1 (Reference)	
yes	489/1477	1.35 (1.12-1.62)	0.001	713/1477	1.29 (1.08-1.54)	0.004
Recreational noise						
no	719/2848	1 (Reference)		1134/2825	1 (Reference)	
yes	327/906	1.39 (1.13-1.70)	0.002	461/896	1.39 (1.14-1.70)	0.001
Hypertension						
no	589/2926	1 (Reference)		1003/2926	1 (Reference)	
yes	457/828	2.28 (1.87-2.79)	<0.001	609/828	2.17 (1.76-2.68)	<0.001

Hyperlipidemia						
no	904/3479	1 (Reference)		1407/3479	1 (Reference)	
yes	142/275	1.03 (0.75-1.41)	0.848	205/275	1.45 (1.02-2.07)	0.039
Diabetes						
no	916/3538	1 (Reference)		1435/3538	1 (Reference)	
yes	130/216	1.39 (0.99-1.95)	0.061	177/216	1.82 (1.21-2.75)	0.004
Hypercholesterolemia						
no	992/3647	1 (Reference)		1541/3647	1 (Reference)	
yes	54/107	1.31 (0.81-2.12)	0.275	71/107	1.01 (0.60-1.69)	0.983

Note: analysis were adjusted for gender and age. Age was represented by categorical variables.

4. Discussion

This cross-sectional study, conducted in a large population and based on a cohort of local individuals in the Zhejiang province, provides information about the hearing threshold levels and prevalence of hearing loss among the people in Zhejiang, China. Based on the standard definition (speech-PTA [i.e., the average of 0.5, 1, 2, and 4 kHz hearing threshold] of ≥26 dB in the better ear), we estimated that 27.9% of the participants had speech-frequency hearing loss, which is different from the prevalence reported in other Chinese studies i.e., those conducted by Bu[15] and Gong[6] (11.7% and 58.85%). Differences in education, economics, and industrialization level due to geographical distribution of the population surveyed may be one of the reasons. On the other hand, the study by Gong et al was conducted among older adults (≥60 years), surprisingly, the prevalence of hearing loss in the elderly in our study was calculated as 58.23%, which was very close to that of Gong. Consistent with other studies[5, 16, 17], women often had a lower PTA than men, at most frequencies (from 1 to 8 kHz), in both the left and right ear. Among these examined frequencies, significant differences were found between the young, middle and old groups for PTA (P<0.001), confirming that the hearing threshold increases with age, both in males and females.[18] Furthermore, Sommer reported that a 1-year increase in age would raise the risk of hearing loss by 15%.[14]

Right ear dominance for PTA was identified in this study. Especially in participants older than 60 years, the right ear had better hearing ability than the left, which can be explained from the perspective of neurology. The ascending auditory projections pass through the brainstem and end in the cerebral cortex of the ipsi- and contra-lateral hemispheres, with a predominant representation on the side opposite to the ear.[19] In brief, the sound collected through the right ear is formed in the left hemisphere, and vice versa. Therefore, based on the anatomical characteristics of the human brain, right ear input is directly transferred to the speech perception areas in the left hemisphere, whereas stimuli to the left ear have to be transferred initially to the right hemisphere, from which it is transferred to the left hemisphere through the corpus callosum.[19] Some studies have also identified the right ear dominance in certain populations,[20-22] which in turn, supports the above theoretical basis. In contrast, another study in Switzerland suggested that PTA has no significant differences between both ears.[23]

Hangzhou had the highest prevalence of hearing loss among the three selected areas. As a modern city with a highly developed economy, Hangzhou is filled with industrial noise, whereas the other two regions have a slightly less-developed economy, with less industrial noise. This is similar to inferences made by Wang et al.[5] Meanwhile, consistent with previous studies, noise exposures (including occupational noise and recreational noise) were found to be risk factors for hearing loss,[6, 24, 25] while education (for high-frequency hearing loss) and personal income (for speech-frequency hearing loss) were protective factors. Highly educated people have a better knowledge of health, and people with high personal income can prevent hearing loss by using low-noise devices or by avoiding high-noise workplaces.

Our results support the evidence that smoking and drinking have associations with the risk of hearing loss.[26, 27] Cruickshanks et al.[28] estimated that current smokers were 1.69 times more likely to have hearing loss than non-smokers (95% CI: 1.31–2.17), which is similar to the results obtained in our study (1.66-fold, 95% CI: 1.24–2.22). Similarly, a multi-centre study conducted by Fransen et al.[29] reported that smoking significantly increased high-frequency hearing loss in a dose-dependent fashion.

Among the factors evaluated in the present study, hypertension had the strongest effect. The risk of hearing loss was 2 times higher in people with hypertension than in those without hypertension. Similar results were also found in other studies.[30, 31] Our study only found borderline association between diabetes and hearing loss, similar to the equivocal results from other studies.[32, 33] A likely explanation for these inconsistent results is that hearing loss is only weakly associated with diabetes, whose effects may be masked by other strong factors (e.g. age[6]). Another explanation is that the number of participants with diabetes is small in this study.

The limitations of this study should be considered. First, owing to the cross-sectional study nature, a causal relationship could not be established. Second, medical covariates were collected based on self-reported diagnosis, and specific values were not analysed as these data were not collected completely. Third, similar to the study conducted by Choi[34], we cannot rule out potential residual confounding by the presence of a noisy environment that were not captured by the binary variables of occupational and recreational noise (refer to exposure at the time of data collection). Fourth, the burden of hearing loss may be underestimated due to the exclusion of patients with ear diseases.

In conclusion, the differences based on age and gender in hearing threshold levels and hearing loss were identified. Older men living in modern cities filled with industrial noise should pay more attention to their hearing status. We found a right ear dominance throughout all audiometric parameters. Harmful habits, like smoking and drinking, and ambient noise (including occupational and recreational noise) are associated with hearing loss. Educating and advising individuals to maintain good general health and fitness would have benefits for hearing preservation.[26] Furthermore, we found evidence that among several common chronic diseases, hypertension is the most closely related to hearing loss, which requires special attention to the hearing of patients with hypertension. Hearing loss is a multifactorial condition that is a result of multiple intrinsic and extrinsic factors acting on the ears, and further prospective studies, with a multi-centre approach and wider ranges of exposure, are required to confirm the related risk factors.

We hope that our data can provide information on hearing loss for the development of national public health policies, and can help identify some related factors for early intervention. As a developing country, society is more concerned about various fatal diseases, economy and ecology, so that our country attaches lesser importance to hearing loss than other developed countries, and we simultaneously hope to arouse the government's attention to this condition.

Author Contributors DW and HZ are joint first authors. DW edited the article, oversaw data analysis and preparation of supplementary files. HZ conducted the statistical analysis, interpretation and drafted the article. HM and LZ contributed to collecting prevalence estimates and preparation of supplementary files. LY and LX originated the study and designed the analysis, and both of them are coinvestigators and approved the final version of the article.

Funding This work was supported by the Zhejiang Key Research and Development Program (grant number 2015C03050), and the Major Science and Technology Innovation Project of Hangzhou (grant number 20152013A01).

Competing interests All authors have completed the ICMJE uniform disclosure form at http://www.icmje.org/coi_disclosure.pdf and declare: Lei Yang and Liang-Wen Xu had financial support from the Zhejiang Key Research and Development Program and the Major Science and Technology Innovation Project of Hangzhou for the submitted work; no financial relationships with any organisations that might have an interest in the submitted work in the previous 3 years; no other relationships or activities that could appear to have influenced the submitted work.

Ethics approval The study was approved by the Hangzhou Normal University ethics committee.

Data sharing statement No additional data are available.

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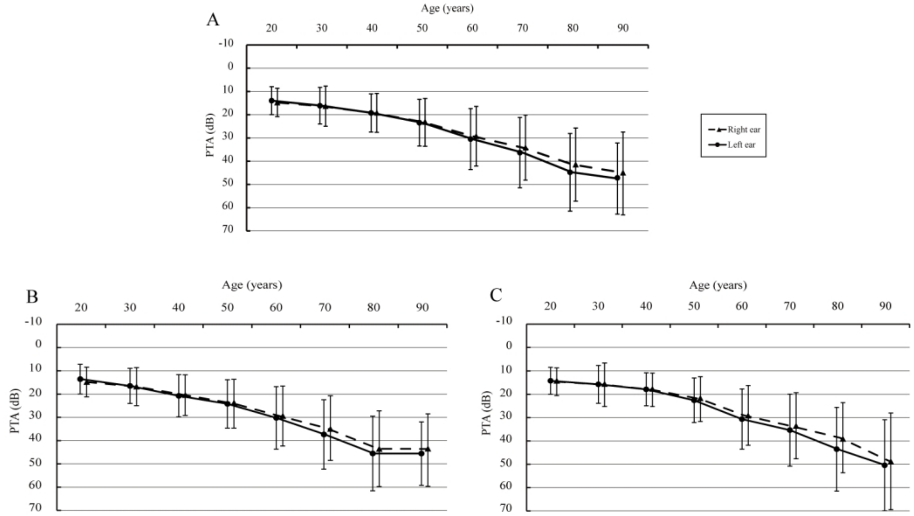
Figure legends

Figure 1. Pure-tone average for all ages at speech frequencies (0.5, 1, 2 and 4kHz) (A: total participants; B: males participants; C: female participants). The full lines indicate the hearing thresholds of left ears, and the dotted lines indicate the hearing thresholds of right ears. Bars indicate ±1 SD. '20y' old represents people aged 18-25y old, '30y' old represent people aged 26-35y old, '40y' old range is 36-45y old, '50y' old range is 46-55y old, '60y' old range is 56-65y old, '70y' old range is 66-75y old, '80y' old range is 76-85y old, and '90y' old range is 86-98y old.

Figure 2. Pure-tone average for all ages at high frequencies (3, 4, 6 and 8kHz) (A: total participants; B: males participants; C: female participants). The full lines indicate the hearing thresholds of left ears, and the dotted lines indicate the hearing thresholds of right ears. Bars indicate ±1 SD. '20y' old represents people aged 18-25y old, '30y' old represent people aged 26-35y old, '40y' old range is 36-45y old, '50y' old range is 46-55y old, '60y' old range is 56-65y old, '70y' old range is 66-75y old, '80y' old range is 76-85y old, and '90y' old range is 86-98y old.

Figure 3. Pure-tone average of different age groups (A: total participants; B: male participants; C: female participants). The left parts of the figures indicate the PTA of the left ears, and the right parts indicate the PTA of the right ears.

Figure 4. Pure-tone average of different genders (A: young group; B: middle group; C: old group). The left parts of the figures indicate the PTA of the left ears, and the right parts indicate the PTA of the right ears.



1

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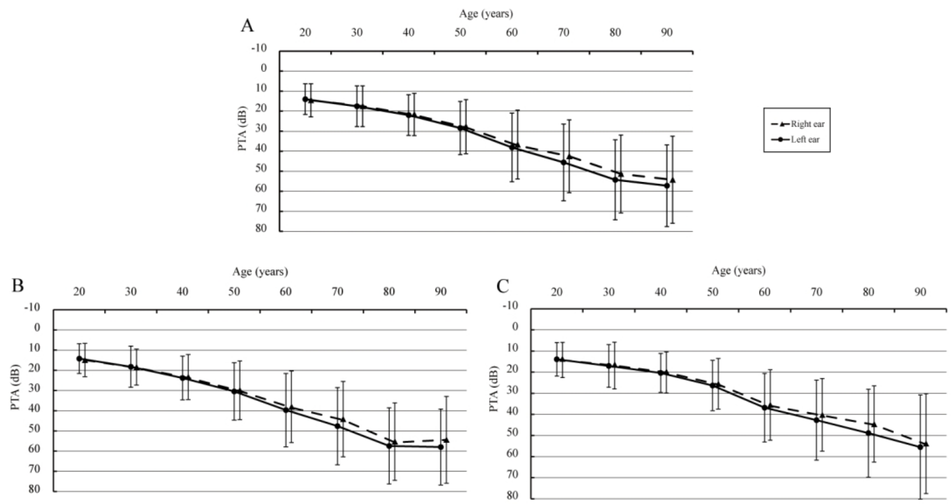

2

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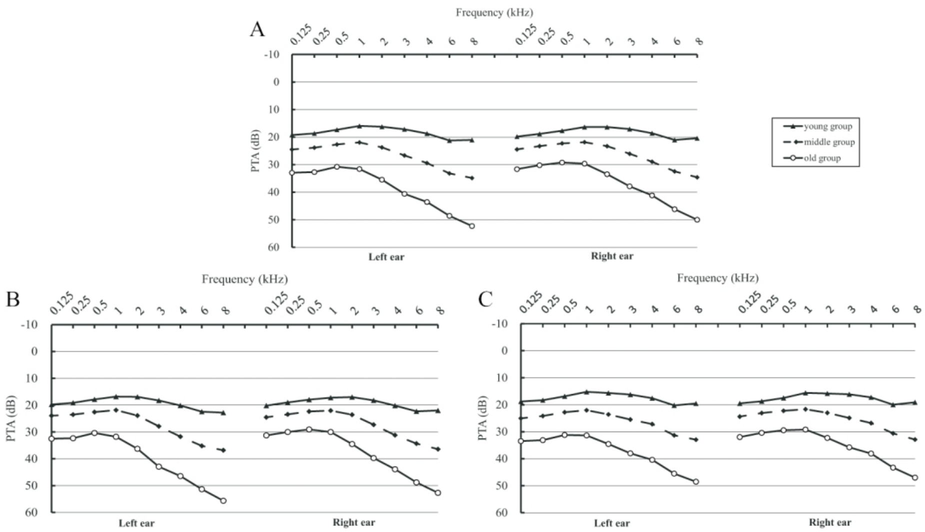
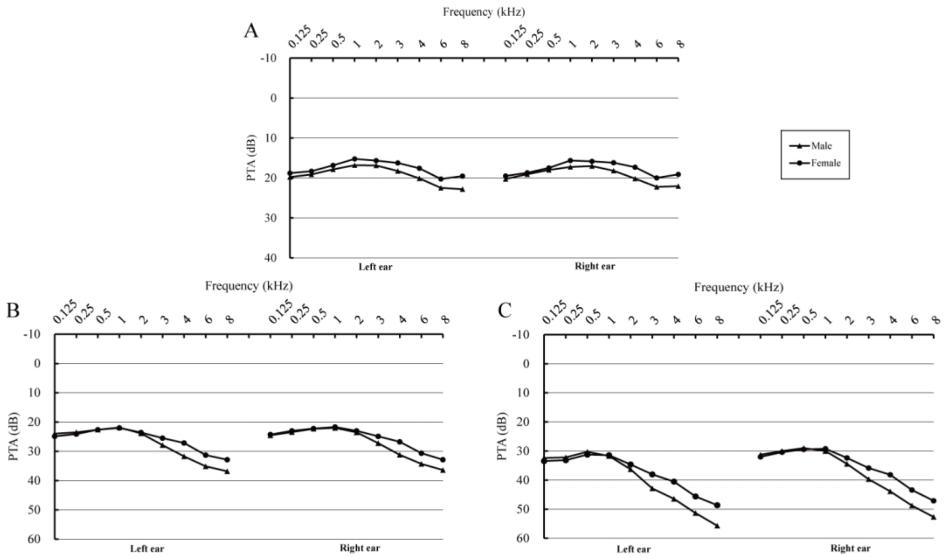

A
Frequency (kHz)
0.125 0.25 0.5 1 2 3 4 6 8 0.125 0.25 0.5 1 2 3 4 6 8
-10 0 10 20 30 40 50 60
PTA (dB)
Left ear
Right ear
young group
middle group
old group
B
Frequency (kHz)
PTA (dB)
Left ear
Right ear
C
Frequency (kHz)
PTA (dB)
Left ear
Right ear

Caption: 3



4

137x82mm (300 x 300 DPI)

Supplement Table 1. Differences in PTA (dB) in the better ear among areas.

	Speech-frequency hearing loss ≥26dB			High-frequency hearing loss ≥26dB		
	Total	Male	Female	Total	Male	Female
Jiangshan	22.25±11.56	23.61±12.23	20.10±10.34	27.23±16.86	30.79±18.10	22.82±13.98
Jiaxing	21.23±9.91	22.39±10.02	20.11±9.68	23.09±12.09	24.33±12.10	21.90±11.98
Hangzhou	22.57±12.18	23.41±12.45	21.81±11.89	30.25±17.45	32.40±18.38	28.29±16.32
P	0.013	0.163	0.004	<0.001	<0.001	<0.001

Supplement Table 2. Characteristics information of noise exposure.

	Exposure to occupational noise			Exposure to recreational noise		
	No	Yes	*P*	No	Yes	*P*
Number	2277	1477		2848	906	
Age group, %						
Young	38.7	37.7		39.9	33.4	
Middle	32.1	31.2		31.4	32.8	
Old	29.2	31.1	0.431	28.7	33.8	0.001
Gender, % (men)	47.9	54.8	<0.001	49.0	55.7	<0.001
Education, %						
≤ Elementary school	10.7	13.6		11.7	12.3	
Middle school	21.1	25.7		23.8	20.2	
High school	26.9	27.5		26.1	30.2	
≥ College	41.3	33.2	<0.001	38.4	37.3	0.037
Income, %						
Low	41.0	43.9		42.8	40.0	
Middle	39.3	44.1		40.4	43.6	
High	19.7	12.0	<0.001	16.8	16.4	0.222

Reporting checklist for cross sectional study.

Based on the STROBE cross sectional guidelines.

Instructions to authors

Complete this checklist by entering the page numbers from your manuscript where readers will find each of the items listed below.

Your article may not currently address all the items on the checklist. Please modify your text to include the missing information. If you are certain that an item does not apply, please write "n/a" and provide a short explanation.

Upload your completed checklist as an extra file when you submit to a journal.

In your methods section, say that you used the STROBE cross sectional reporting guidelines, and cite them as:

von Elm E, Altman DG, Egger M, Pocock SJ, Gotzsche PC, Vandenbroucke JP. The Strengthening the Reporting of Observational Studies in Epidemiology (STROBE) Statement: guidelines for reporting observational studies.

		Reporting Item	Page Number
Title	#1a	Indicate the study’s design with a commonly used term in the title or the abstract	1
Abstract	#1b	Provide in the abstract an informative and balanced summary of what was done and what was found	2
Background / rationale	#2	Explain the scientific background and rationale for the investigation being reported	2
Objectives	#3	State specific objectives, including any prespecified hypotheses	2
Study design	#4	Present key elements of study design early in the paper	2
Setting	#5	Describe the setting, locations, and relevant dates, including periods of recruitment, exposure, follow-up, and data collection	5
Eligibility criteria	#6a	Give the eligibility criteria, and the sources and methods of selection of participants.	5

	#7	Clearly define all outcomes, exposures, predictors, potential confounders, and effect modifiers. Give diagnostic criteria, if applicable	6
Data sources / measurement	#8	For each variable of interest give sources of data and details of methods of assessment (measurement). Describe comparability of assessment methods if there is more than one group. Give information separately for for exposed and unexposed groups if applicable.	6
Bias	#9	Describe any efforts to address potential sources of bias	6
Study size	#10	Explain how the study size was arrived at	6
Quantitative variables	#11	Explain how quantitative variables were handled in the analyses. If applicable, describe which groupings were chosen, and why	6
Statistical methods	#12a	Describe all statistical methods, including those used to control for confounding	7
	#12b	Describe any methods used to examine subgroups and interactions	7
	#12c	Explain how missing data were addressed	7
	#12d	If applicable, describe analytical methods taking account of sampling strategy	n/a
	#12e	Describe any sensitivity analyses	n/a
Participants	#13a	Report numbers of individuals at each stage of study—eg numbers potentially eligible, examined for eligibility, confirmed eligible, included in the study, completing follow-up, and analysed. Give information separately for for exposed and unexposed groups if applicable.	8
	#13b	Give reasons for non-participation at each stage	n/a
	#13c	Consider use of a flow diagram	n/a
Descriptive data	#14a	Give characteristics of study participants (eg demographic, clinical, social) and information on exposures and potential confounders. Give information separately for exposed and unexposed groups if applicable.	8

	#14b	Indicate number of participants with missing data for each variable of interest	n/a
Outcome data	#15	Report numbers of outcome events or summary measures. Give information separately for exposed and unexposed groups if applicable.	8
Main results	#16a	Give unadjusted estimates and, if applicable, confounder-adjusted estimates and their precision (eg, 95% confidence interval). Make clear which confounders were adjusted for and why they were included	8
	#16b	Report category boundaries when continuous variables were categorized	8
	#16c	If relevant, consider translating estimates of relative risk into absolute risk for a meaningful time period	n/a
Other analyses	#17	Report other analyses done—e.g., analyses of subgroups and interactions, and sensitivity analyses	n/a
Key results	#18	Summarise key results with reference to study objectives	9
Limitations	#19	Discuss limitations of the study, taking into account sources of potential bias or imprecision. Discuss both direction and magnitude of any potential bias.	12
Interpretation	#20	Give a cautious overall interpretation considering objectives, limitations, multiplicity of analyses, results from similar studies, and other relevant evidence.	9-12
Generalisability	#21	Discuss the generalisability (external validity) of the study results	9-12
Funding	#22	Give the source of funding and the role of the funders for the present study and, if applicable, for the original study on which the present article is based	13

 This checklist was completed on 08. October 2018 using http://www.goodreports.org/, a tool made by the EQUATOR Network in collaboration with Penelope.ai