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The Effect of a High-Frequency-Hearing-Threshold Weighted Value on the Diagnosis of Occupational-Noise-Induced Deafness

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Abstract

Objective: In order to provide a theoretical basis for the revision of the current diagnostic criteria for occupational noise-induced deafness (ONID), we evaluated the degree of ONID by analyzing different high-frequency-hearing-threshold-weighted values (HFTWVs). **Methods:** A retrospective study was conducted to evaluate the diagnosis of patients with ONID from January 2016 to January 2017 in Guangdong province, China. Based on 3 hearing tests (each interval between the tests was greater than 3 days), the minimum threshold value of each frequency was obtained using the 2007 edition's diagnostic criteria for ONID. The speech frequency and the HFTWVs were analyzed based on age, noise exposure, and diagnostic classification using SPSS21.0. **Results:** 168 patients in total were involved in this study, 154 males and 14 females, and the average age was 41.18 ± 6.07. The diagnosis rate was increased by the weighted value of the high frequencies and was more than the mean value of the pure speech frequency (MVPSF). The diagnosis rate for the weighted 4 kHz frequency level increased by 13.69% (χ^2 = 9.880, P = 0.002), the weighted 6 kHz level increased by 15.47% (χ^2 = 9.985, P = 0.002), and the weighted 4 kHz + 6 kHz level increased by 15.47% (χ^2 = 9.985, P = 0.002). The differences were all statistically significant. The diagnostic rate of the different thresholds showed no obvious difference between the genders. The age groups were divided into less than or equal to 40 years old (group A) and 40 - 50 years old (group B). There were several groups with a high frequency: high frequency weighted 4 kHz (group A χ^2 = 3.380, P = 0.050; group B χ^2 = 4.054, P = 0.032), high frequency weighted 6 kHz (group A χ^2 = 6.362, P = 0.012; group B χ^2 = 4.054, P = 0.032), weighted 4 kHz + 6 kHz (group A χ^2 = 6.362 P = 0.012; B χ^2 = 4.054, P = 0.032) than those of MVPSF in the same group on ONID diagnosis rate. The differences between the groups were statistically significant. There was no significant difference between the age groups (χ^2 = 2.265, P = 0.944). The better ear's (the smaller hearing threshold weighted value) MVPSF and the weighted values for the different high frequencies were examined in light of the number of working years; the group that was exposed to noise for more than 10 years had significantly higher values than those of the average thresholds of each frequency band in the groups with 3 - 5 years of exposure (F = 2.271, P = 0.001) and 6 - 10 years of exposure (F = 1.563, P = 0.046). The differences were statistically significant. The different HFTWVs were higher than those of the MVPSF values, and the high frequency weighted 4 kHz + 6 kHz level showed the greatest difference, with an average increase of 2.83 dB. The diagnostic rate that included the weighted high frequency values was higher for the mild, moderate, and severe cases than those patients who were only screened with the pure frequency tests. The results of the comparisons of the diagnosis rates for mild ONID were as follows: the weighted 3 kHz high frequency level (χ^2 = 3.117, P = 0.077) had no significant difference, but the weighted 4 kHz level (χ^2 = 10.835, P = 0.001), 6 kHz level (χ^2 = 9.985, P = 0.002), 3 kHz + 4 kHz level (χ^2 = 6.315, P = 0.012), 3 kHz + 6 kHz level (χ^2 = 6.315, P = 0.012), 4 kHz + 6 kHz level (χ^2 = 9.985, P = 0.002), and 3 kHz + 4 kHz + 6 kHz level (χ^2 = 7.667, P = 0.002) were significantly higher than the diagnosis rate of the mean value of the PSF. There was no significant difference between the 2 groups for the moderate and severe grades (P > 0.05). **Conclusion:** Different HFTWVs increase the diagnostic rate of ONID. The weighted 4 kHz, 6 kHz, and 4 kHz + 6 kHz high frequency values greatly affected the diagnostic results, and the weighted 4 kHz + 6 kHz high frequency hearing threshold value has the maximum the effect on the ONID diagnosis results.

Keywords

Noise, Occupational Noise Deafness, Noise-Induced Hearing Loss, High Frequency Hearing Threshold Weighted Value, Diagnostic Rate

1. Introduction

Noise is an important problem in many societies, either in the workplace or outside of it [1]. When not managed effectively, it can lead to irreversible alterations in the ear structure, resulting in hearing loss. Noise is common and considered to be the second most common cause of hearing loss in adults, right after presbycusis [2]. Today, approximately 5% of the world's population suffers from noise-induced hearing loss (NIHL) acquired from industrial occupations, military duty and combat, and recreation and leisure activities. This makes NIHL the most frequent occupational disease in the United States (and probably worldwide) [3]. Researchers [4] have found that repeated exposure to hazardous noise levels might eventually result in a temporary threshold shift (TTS) in hearing, such as tinnitus and "fullness in the head", and repeated TTSs may cause permanent shifts. Damage-risk criteria provide the basis for recommending occupational noise exposure limits based on noise level and exposure duration, assuming non-occupational noise levels are low enough to allow the ear to recover. Mutai *et al.* [5] indicated that hearing loss is one of the most prevalent sensory disorders. Genetic factors are thought to account for more than half of congenital and childhood-onset hearing loss and mutations of mitochondrial DNA are associated with maternally inherited sensorineural hearing loss. The diagnostic criteria for ONID in China were revised 4 times from 1996 (GB16152-1996 Diagnostic Criteria and Management of Occupational Noise-induced Deafness) [6] to 2014 (GB49-2014 Diagnosis of Occupational Noise-induced Deafness) [7], and the largest difference was included in the 10% 4 kHz HFTWV on the basis of the 90% MVPSF. There is no uniform standard for high frequency hearing thresholds on ONID in the world. Some countries or organizations, such as WHO and ISO [8], emphasize the main frequency, and others, such as Japan [9] and the United States [10], calculate the arithmetic average or weighted value. The purpose of this study was to compare the results and degrees of ONID in light of the different HFTWVs and provide a theoretical basis for the revision of ONID diagnosis standards.

2. Materials and Methods

2.1. Research Subjects

A retrospective study was conducted to investigate the diagnosis of ONID at the Guangdong Provincial Hospital for Occupational Disease Prevention and Treatment from January 2016 to January 2017. The minimum threshold value of each frequency was obtained using the diagnostic criteria of the 2007 standards for ONID [11]. The pure tone audiometry with a binaural high frequency (3 kHz, 4 kHz, and 6 kHz) threshold average value was greater than or equal to 40 dB. Basic patient information was collected, including gender, age, length of exposure to noise, cumulative noise exposure, posts, and industry. The cases were screened using the inclusion criteria and exclusion criteria. Standard GBZ/T189.8 [12] set a limit of more than 80 dB (A) as the time-weighted average (TWA) for an 8-hour work day/40-hour work week exposure to noise (85 dB (A)). The subjects in this study were working in the manufacturing, mining, and transportation industries with exposure to continuous noise at more than 85 dBA (according to the results of the noise monitoring). They did not regularly use hearing protection devices.

2.2. Inclusion Criteria

We selected cases where there had been continuous exposure to noise for more than 3 years in men aged 18 to 50 years old and women aged 18 to 45 years old. Based on the outcomes of the 3 hearing tests, the results of the pure tone hearing threshold were consistent with the characteristics of pure sensorineural hearing loss (the basic symmetry of the left and right audiometric curves). We obtained the minimum hearing threshold value of each frequency for each test interval when the patient stayed in the hospital longer than 3 days. The object of this study was to investigate cases that were discussed by the occupational disease diagnosis team.

2.3. Exclusion Criteria

The patients included in this study met the following criteria: they had a history of ear disease affecting the pure tone hearing threshold (including drug poisoning deafness, traumatic deafness, familial deafness, infectious disease-deafness, or sudden deafness), and had been diagnosed as having mixed deafness, conductive deafness, false deafness, or exaggerated hearing loss. The men had to be over 50 years old and the women had to be over 45 years old or younger than 18 years old.

2.4. Research Group

There were 168 cases of eligible cases, which were combined into 8 groups according to the weighted different high frequency hearing threshold, MVPSF group (Speech Frequency), weighted 3 kHz high frequency group (3 kHz), weighted 4 kHz high frequency group (4 kHz), weighted 4 kHz high frequency group (4 kHz), weighted 6 kHz high frequency group (6 kHz), weighted 3 kHz + 4 kHz high frequency group (3 kHz + 4 kHz), weighted 3 kHz + 6 kHz high frequency group (3 kHz + 6 kHz), weighted 4 kHz + 6 kHz high frequency group (4 kHz + 6 kHz), weighted 3 kHz + 4 kHz + 6 kHz high frequency group (3 kHz + 4 kHz + 6 kHz).

2.5. Pure Tone Audiometry

The audiometry tests were performed by an experienced doctor who has been practicing for many years. Hearing was assessed in the range of pure tone thresholds from 0.5 to 6 kHz, according to the GB/T16403 standard for Acoustics and Audiometric Test Methods for Basic Pure Tone Air and Bone Conduction Threshold Audiometry. Audiometric tests were performed using a hearing instrument (Otometrics, Denmark, in the calibration period) in accordance with the requirements of standard GBZ49-2014 (Diagnosis of Occupational Noise-induced Deafness) in a sound-isolated chamber for all subjects. The results of the audiometry tests were adjusted by age and sex using standard GB/T7582.

2.6. Auditory Threshold Calculation Method

MVPSF refers to the average threshold for 0.5, 1, and 2 kHz of the better ear. HFTWV refers to the MVPSF multiplied by 0.9, plus a high frequency threshold value multiplied by 0.1of the better ear. Bringing into high frequency included 3 kHz, 4 kHz, 6 kHz, (3 kHz + 4 kHz)/2, (3 kHz + 6 kHz)/2, (4 kHz + 6 kHz)/2, and (3 kHz + 4 kHz + 6 kHz)/3, respectively.

2.7. Classification Basis

The values were judged based on the MVPSF or high frequency weighted value $\left(\frac{\text{HL}0.5\text{Hz}+\text{HL}1\text{kHz}+\text{HL}2\text{kHz}}{3}\times 0.9+\text{HL}_{\text{High frequency}}\times 0.1\geq 26\text{ dB}\right)$ of the better ear: 26 dB - 40 dB (HL) was mild deafness, 41 dB - 55 dB (HL) was moderate deafness, and more than 56 dB (HL) was severe deafness.

2.8. Statistical Treatment

Statistical analysis was performed using SPSS software package 21.0. A P-value of <0.05 was used as the statistical significance. The two-factor analysis of the variance was performed using the binaural speech and high frequency values, which needed to conform to a normal distribution or similar normal data. Chi square tests were carried out for the comparison of the categorical data rate by age, sex, length of service, and industry group.

3. Results

3.1. Basic Characteristics of All Subjects

We had a total of 168 cases in this research. The average age of the patients was 41.2 ± 6.1. There were 154 males aged 25 to 50 years old, and their average age was 41.5 ± 6.0. There were 14 females aged 31 to 45 years old, and their average age was 37.2 ± 5.1.All subjects were exposed to noise from 81 to 107 dB (A) for more than 3 years.

3.2. Comparison of the Diagnostic Rates of ONID between the MVPSF and HFTWVs for the Gender Groups (Table 1)

With the standard of the MVPSF (2007 Edition), 108 cases were conforming to noise deafness, accounting for 64.29% of the total number, 98 men and 10 women. The standard for the HFTWV ≥ 26 dB, and we found that the diagnostic rate of ONID was greater than that of the MVPSF: it was greater by 8.92% (χ^2 = 3.117, P = 0.077) at the weighted 3 kHz level, 8.92% (χ^2 = 3.117, P = 0.077) at the weighted 4 kHz level, 15.47% (χ^2 = 9.985, P = 0.002) at the weighted 6 kHz level, 12.50% (χ^2 = 6.315, P = 0.012) at the weighted 3 kHz + 4 kHz level, 12.50% (χ^2 = 6.315, P = 0.012) at the weighted 3 kHz + 6 kHz level, 15.47% (χ^2 = 9.985, P = 0.002) at the weighted 4 kHz + 6 kHz level, and 13.69% (χ^2 = 9.880, P = 0.002) at the weighted 3 kHz + 4 kHz + 6 kHz level. The diagnosis rate of ONID was significantly higher than that of the MVPSF after the introduction of different HFTWVs, except for the weighted 3 kHz level. The diagnosis rate showed no difference between the different HFTWVs. The diagnosis rate of different thresholds showed no significant difference between males and females.

Table 1. Comparison of the diagnostic rates of the gender groups.

Gender	N	Speech Frequency (2007 Edition)		3 kHz				4 kHz (2014 Edition)				6 kHz			
		n	%	n	%	χ^2	*P*	n	%	χ^2	*P*	n	%	χ^2	*P*
Male	154	98	63.64	112	72.73	2.933	0.087	119	77.27	6.878	0.009	122	79.22	9.164	0.002
Female	14	10	71.43	11	78.57	-	-	12	85.71	-	-	12	85.71	-	-
Total	168	108	64.29	123	73.21	3.117	0.077	131	77.98	9.880	0.002	134	79.76	9.985	0.002
χ^2-value		0.339		0.224				0.533				0.335			
P-value		0.560		0.636				0.466				0.563			

Gender	3 kHz + 4 kHz				3 kHz + 6 kHz				4 kHz + 6 kHz				3 kHz + 4 kHz + 6 kHz			
	n	%	χ^2	*P*	n	%	χ^2	*P*	n	%	χ^2	*P*	n	%	χ^2	*P*
Male	117	75.97	5.561	0.018	117	75.97	5.561	0.018	122	79.22	9.164	0.002	119	77.27	6.878	0.009
Female	12	85.71	-	-	12	85.71	-	-	12	85.71	-	-	12	85.71	-	-
Total	129	76.79	6.315	0.012	129	76.79	6.315	0.012	134	79.76	9.985	0.002	131	77.98	9.880	0.002
χ^2-value	0.683				0.683				0.335				0.533			
P-value	0.409				0.409				0.563				0.466			

-There were not enough cases in this analysis, so it was not suitable for the values to be checked by the chi square test.

3.3. Comparison of the Age Group Diagnostic Rates for the MVPSF (2007 Edition) and HFTWVs (Table 2)

The age groups were divided into patients less than 40 years old (group A) and patients who were 40-50 years old (group B). Compared with the MVPSF, the diagnosis rate was significantly higher (group A: χ^2 = 3.380, P = 0.050; group B: χ^2 = 4.054, P = 0.032) at the weighted 4 kHz level (group A: χ^2 = 6.362, P = 0.012; group B: χ^2 = 4.054, P = 0.032) and at the weighted 6 kHz level (group A: χ^2 = 6.362, P = 0.012; group B: χ^2 = 4.054, P = 0.032). At the weighted 4 kHz + 6 kHz level, the difference between the 2 groups was statistically significant, but the difference for the other levels was not significantly different. There was no significant difference of totality between the 2 groups (χ^2 = 2.265, P = 0.944). A respective comparison between groups A and B at different frequencies found that the diagnosis rate of ONID with weighted different high-frequency in group B was higher than that of group A, in addition to the weighted 3 kHz with the high frequency. The difference in the ages between the 2 groups was significant. At a simple speech frequency (χ^2 = 5.407, P = 0.016), we found the following values: at the weighted 4 kHz level (χ^2 = 3.976, P = 0.036), at the weighted 3 kHz + 4 kHz level (χ^2 = 5.788, P = 0.012), and at the weighted 3 kHz + 4 kHz + 6 kHz level (χ^2 = 5.788, P = 0.012).

3.4. Comparisons of the Mean between the Speech Frequency and Different HFTWVs in the Working Years Group (Table 3, $\bar{x} \pm s$)

The patients were divided into 3 groups according to the years of noise exposure: 3 - 5 years, 6 - 10 years, and greater than 10 years. The better ear's mean value of

Table 2. Comparison of the diagnostic rates of the age groups.

Age	N	Speech Frequency (2007 Edition)		3 kHz				4 kHz (2014 Edition)				6 kHz			
		n	%	n	%	χ^2	*P*	n	%	χ^2	*P*	n	%	χ^2	*P*
≤40	67	36	53.73	43	64.18	1.511	0.219	47	70.15	3.830	0.050	50	74.63	6.362	0.012
41 - 50	101	72	71.29	59	58.42	3.670	0.055	84	83.17	4.054	0.032	84	83.17	4.054	0.032
χ^2-value		5.407		0.561					3.976				1.82		
P-value		0.016		0.279					0.036				0.125		

Age	3 kHz + 4 kHz				3 kHz + 6 kHz				4 kHz + 6 kHz				3 kHz + 4 kHz + 6 kHz			
	n	%	χ^2	*P*	n	%	χ^2	*P*	n	%	χ^2	*P*	n	%	χ^2	*P*
≤40	45	67.16	2.528	0.112	47	70.15	3.830	0.050	50	74.63	6.362	0.012	45	67.16	2.528	0.112
41 - 50	84	83.17	4.054	0.032	82	81.19	2.733	0.068	84	83.17	4.054	0.032	84	83.17	4.054	0.032
χ^2-value		5.788				2.754				1.820				5.788		
P-value		0.012				0.071				0.125				0.012		

Table 3. Comparison of the different frequency means of the working years groups ($\bar{x} \pm s$).

Working years	N	Speech frequency	3 kHz	4 kHz	6 kHz	3 kHz + 4 kHz	3 kHz + 6 kHz	4 kHz + 6 kHz	3 kHz + 4 kHz + 6 kHz
3 - 5	38	29.78 ± 9.83	31.70 ± 9.78	32.28 ± 9.42	32.32 ± 9.58	32.03 ± 9.58	32.07 ± 9.63	32.33 ± 9.48	32.12 ± 9.55
6 - 10	67	30.49 ± 9.28	32.31 ± 9.17	32.72 ± 8.53	33.39 ± 8.66	32.56 ± 8.83	32.90 ± 8.85	33.09 ± 8.57	32.83 ± 8.72
>10	63	31.90 ± 13.55	33.99 ± 13.04	34.47 ± 12.59	34.73 ± 12.99	34.26 ± 12.81	34.40 ± 12.98	34.74 ± 12.77	34.40 ± 12.85
Total	168	30.74 ± 11.24	32.70 ± 10.98	33.20 ± 10.54*	33.46 ± 10.80*	32.98 ± 10.75	33.13 ± 10.84*	33.57 ± 10.65*	33.14 ± 10.74*

Compared with the speech frequency mean, *$P < 0.05$.

PSF and the weighted values of the different high frequencies in relation to the number of working years for each group were compared. Those who worked more than 10 years had a significantly higher value than that of the average thresholds of each frequency band in the 3 - 5 years group (F = 2.271, $p = 0.001$) and the 6 - 10 years group (F = 1.563, $p = 0.046$); the difference was statistically significant. The MVPSF of the better ear was significantly lower than that of the high frequency values for the weighted 4 kHz level ($F = 2.464$, $P = 0.036$), 6 kHz level ($F = 2.727$, $P = 0.021$), 3 kH + 6 kHz level ($F = 2.394$, $P = 0.042$), 4 kHz + 6 kHz level ($F = 2.832$, $P = 0.020$), and 3 kHz + 4 kHz + 6 kHz level ($F = 2.401$, $P = 0.041$); the difference was statistically significant ($P < 0.05$). The different HFTWVs were higher than those of the MVPSF values, and the high frequency weighted 4 kHz + 6 kHz level showed the greatest frequency difference, with an average increase of 2.83 dB.

3.5. Effects on the Diagnostic Classification of the Different High Frequencies (Table 4)

The diagnostic rate that included the different HFTWVs was higher than that of the MVPSF values for the different grades of mild, moderate, and severe ONID.

Table 4. Comparison of the diagnostic classification between the speech frequency mean value and different high frequency values.

Frequency	N	Not diagnosed				mild				moderate				severe			
		n	%	χ^2	*P*	n	%	χ^2	*P*	n	%	χ^2	*P*	n	%	χ^2	*P*
Speech	168	60	35.71	-	-	84	50.00	-	-	15	8.93	-	-	9	5.36	-	-
3 kHz	168	45	26.79	3.117	0.077	94	55.95	1.195	0.274	19	11.31	0.524	0.469	10	5.95	0.056	0.813
4 kHz	168	33	19.64	10.835	0.001	106	63.10	5.862	0.015	18	10.71	0.302	0.582	11	6.55	0.213	0.645
6 kHz	168	34	20.24	9.985	0.002	104	61.90	4.830	0.028	20	11.90	0.797	0.372	10	5.95	0.056	0.813
3 kHz + 4 kHz	168	39	23.21	6.315	0.012	101	60.12	3.476	0.062	18	10.71	0.302	0.582	10	5.95	0.056	0.813
3 kHz + 6 kHz	168	39	23.21	6.315	0.012	99	58.93	2.700	0.100	20	11.90	0.797	0.372	10	5.95	0.056	0.813
4 kHz + 6 kHz	168	34	20.24	9.985	0.002	106	63.10	5.862	0.015	18	10.71	0.302	0.582	10	5.95	0.056	0.813
3 kHz + 4 kHz + 6 kHz	168	37	22.02	7.667	0.002	102	60.71	3.902	0.048	19	11.31	0.524	0.469	10	5.95	0.056	0.813

The diagnosis rate of mild ONID with the weighted difference high frequency was higher than that of the MVPSF: at the weighted 3 kHz high frequency level, it increased by 13.10% (χ^2 = 10.835, P = 0.001),at the weighted 4 kHz level, it increased by 11.90% (χ^2 = 9.985, P = 0.002), at the weighted 6 kHz level, it increased by 10.12% (χ^2 = 6.315, P = 0.012), at the weighted 3 kHz + 4 kHz level, it increased by 8.93% (χ^2 = 6.315, P = 0.012), at the weighted 3 kHz + 6 kHz level, it increased by 13.10% (χ^2 = 9.985, P = 0.002), at the weighted 4 kHz + 6 kHz level, it increased by 10.71% (χ^2 = 7.667, P = 0.002), and at the weighted 3 kHz + 4 kHz + 6 kHz level, it increased in addition to the weighted 3 kHz high frequency. The diagnosis rate of the moderate and severe ONID with the high frequencies was higher than that of the pure frequency, but the difference was not significant (P > 0.05).

4. Discussion

The purpose of this study was to elucidate whether the inclusion of different frequency thresholds had an effect on the ONID diagnosis; there was an attempt to illuminate the extent and magnitude of the impact, eventually providing a theoretical basis for the revision of the diagnostic criteria for ONID. Noise-induced hearing loss is a kind of progressive sensorineural hearing loss that occurs due to the long-term exposure to noise in the workplace. It includes the early loss of high frequency hearing, which is followed by difficulties with language listening. Because noise-induced hearing loss is irreversible, its early diagnosis can help prevent the development of hearing loss, especially for speech frequencies [13].

The traditional method for the early diagnosis of noise-induced hearing loss is to perform pure tone audiometry tests to screen for suspected occupational noise cases before making a definite diagnosis. Noise-induced high frequency hearing loss is the result of the interactions of multiple factors, including genetic, environmental, and personal habits. There are many studies on the genetic factors of noise-induced hearing loss. Genetic factors mainly include the gene polymorphism of ATP enzymes related to energy metabolism, rs1368402 and rs891969 loci polymorphism, rs4880 single nucleotide polymorphism, hOGG1 Cys/Cys genotype, and the sensitivity of the rs2763979 locus [14] [15]. The results of twin studies showed that monozygotic pairs were more similar with regards to noise sensitivity than dizygotic pairs, and quantitative genetic modeling indicated significant familiality. The best z-fitting genetic model provided an estimate of heritability at 36% (95% CI = 0.20 - 0.50) and when hearing impaired subjects were excluded from this, it rose to 40% (95% CI = 0.24 - 0.54) [16]. Mehrparvar *et al.* [17] noted that hearing loss was more common in high-frequency audiometry testing than conventional audiometry testing. High frequency audiometry tests are more sensitive to detecting noise-induced hearing loss than conventional audiometry tests. The early diagnosis of hearing sensitivity to noise can thus help prevent hearing loss at lower frequencies, especially speech frequencies.

The results of this study showed that most of the patients diagnosed over the past year at the hospital with ONID were male (91.7%). The average hearing loss of males was greater than that of females, but there was no significant difference between males and females. The results from a noise exposure survey [18] reported that men do most of the noisy jobs and therefore are more likely to suffer from hearing problems. Those most affected by noise (in terms of absolute magnitude) are 50-year-old men. Although 40-year-olds have already accrued as much noise-induced permanent threshold shift as any of the older groups (all exposures ended at age 40), they have very little age-related hearing loss, and therefore their impairments (aging and noise combined) are mostly too mild to reach the 25 dB HL threshold for monaural hearing impairment. By age 50, age-related hearing loss is large enough to push many people over the 25 dB threshold.

Our results show that including the high frequency hearing threshold in tests has a significant impact on the diagnosis effect of ONID. For those at the 3 kHz level, the diagnosis rate increased by 8.92% (it increased at other levels, too: 13.69% at the 4 kHz level, 15.47% at the 6 kHz level, 12.50% at the 3 kHz + 4 kHz level, 12.50% at the 3 kHz + 6 kHz level, 15.47% at the 4 kHz + 6 kHz level, and 13.69% at the 3 kHz + 4 kHz + 6 kHz level. The highest increase in diagnosis was at the 4 kHz + 6 kHz level (15.47%). This is consistent with the results of audiograms on occupational noise-induced hearing loss (ONIHL); the maximum hearing loss is usually at a high frequency of 4 kHz. Epidemiologic studies [19] have also reported that the audiometric configuration of noise-induced hearing loss shows symmetrical, mild to moderate sensorineural hearing loss mostly at 3000 and 4000 Hz.

In our study, there was no difference in the totality between males and females ($p = 0.944$). The main reason for this result is that the pure tone test results were adjusted for age and sex, so some of the hearing loss caused by age was eliminated. The test results of hearing loss were attributed to the noise-induced hearing loss. Aging and noise are generally considered the most common causes of adult hearing loss around the world. Similar studies [20] reported that the relative contributions of aging and noise are difficult to determine for the following reasons: age-related hearing loss (ARHL) and NIHL have similar pure tone audiometric features, the pure tone audiogram in early NIHL typically demonstrates notching in the 3 to 6 kHz region (8 kHz thresholds are better than those at 3 to 6 kHz), and age-related threshold shifts (typically greatest at 8 kHz) may efface the notch.

In the working years groups, our results showed that exposure to noise for more than 10 years was significantly higher than in the groups with 3 - 5 and 6 - 10 years of exposure; this result is related to the accumulation of the noise exposure. Hearing loss may gradually develop over a period of years; this occurs most rapidly during the first 6 - 10 years of exposure to noise and usually starts at high frequencies, mostly at 4000 Hz. Some studies [21] [22] found that individuals who were 30 - 60 years old and who were exposed to noise for 5 - 10 years had an increased risk of hearing loss (0.2% - 0.8%) when exposed to average daily noise levels of 80 dB (A). This risk increased to 1.4% - 4.9% with daily noise exposure levels of85 dB (A) and to 5.4% - 15.9% with daily noise exposure levels of 90 dB (A). Statistics from Attias's study in Israel [23] showed that the greatest loss usually occurs at around 4 kHz, and the earliest damage is in the highest frequencies (6 and/or 8 kHz). The average hearing loss is greater at the higher frequency ranges (4 - 8 kHz) than at the lower frequency ranges (0.25 - 2 kHz). Usually, and especially in the early stage of damage, the speech frequency area range (0.25 - 2 kHz) remains intact, with the losses starting at 3 kHz and above. In the classification of occupational noise deafness, the diagnostic rate of ONID for different frequencies for mild, moderate, and severe cases was higher than that of the average frequency. However, there were significant differences in the different high frequency tests only for mild deafness, and no significant difference in the rates for moderate and severe deafness. This result is related to the insufficient sample size. It is necessary to accumulate a greater number of moderate and severe occupational noise deafness cases to further analysis.

In summary, using HFTWVs has a great influence on the diagnosis of ONID. Whether or not the diagnosis conclusion is occupational disease is opposite to the benefit relations for the worker individual and the employer. It is important for the ONID standards to include high frequencies and how doctors can incorporate those high frequencies into hearing tests (frequency band, proportion, and methods). Deafness should be diagnosed as an occupational disease caused by noise during the production process after a certain number of years of work. An early diagnosis can protect the health and legitimate rights and interests of workers, and it can promote technological innovation at enterprises, helping them to reduce or eliminate the generation of noise sources. Therefore, we believe that high frequencies should be included in the revised diagnostic criteria for ONID; a weighted 4 kHz + 6 kHz level (10%) is the most suitable.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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