The Journal of
Laryngology & Otology

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The significance of extended high-frequency audiometry in tinnitus patients with normal hearing as evaluated via conventional pure tone audiometry

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Main Article

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Cite this article: Ma X, Shen W, Yang S, Wang F. The significance of extended high-frequency audiometry in tinnitus patients with normal hearing as evaluated via conventional pure tone audiometry. *J Laryngol Otol* 2024;**138**: 381–387. https://doi.org/10.1017/S0022215123000920

Received: 24 September 2022
Revised: 15 April 2023
Accepted: 28 April 2023
First published online: 24 May 2023

Keywords:
Tinnitus; audiometry; pure-tone; extended high frequency

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Abstract

Objective. This study was designed to determine whether extended high-frequency audiometry was capable of better differentiating between participants with normal hearing who did or did not have subjective tinnitus.
Methods. A total of 96 study participants were enrolled: 36 patients with unilateral tinnitus, 28 patients with bilateral tinnitus and 32 volunteers as controls. All 96 participants exhibited normal audiometry findings and hearing thresholds. Extended high-frequency audiometry was used to evaluate these patients.
Results. There were differences between the extended high-frequency hearing thresholds of affected and unaffected ears in those with unilateral tinnitus, and in the 20–29-year-old bilateral tinnitus group, at 11.2, 12.5 and 14 kHz. Unilateral tinnitus subgroups had higher extended high-frequency hearing thresholds than those in control subjects, at all extended high frequencies.
Conclusion. Extended high-frequency audiometry can offer additional information regarding the hearing status of patients with tinnitus who exhibit normal pure tone thresholds when analysed via conventional hearing thresholds.

Introduction

Subjective tinnitus is a condition in which people hear sounds that do not correlate to external stimuli.[1] Tinnitus is thought to affect 10–15 per cent of the global adult population, with 1.6 per cent of individuals suffering from severe tinnitus that regularly distracts from other activities and 0.5 per cent of people suffering from severe tinnitus symptoms that interferes with their daily life.[2]

Clinically diagnosed hearing loss appears to co-exist in individuals who also experience tinnitus.[3] Indeed, approximately 90 per cent of tinnitus patients have hearing loss,[3–5] with loud noise exposure, ototoxic drug utilisation and ageing being the primary drivers of this loss. In the remaining 10 per cent of tinnitus patients, however, audiogram findings are normal.[6] Even though it is widely accepted that tinnitus is caused by abnormal events in the cochlea that result in an abnormal hearing state, there is little evidence in the literature to support the perception of tinnitus being exclusively related to cochlear mechanisms.[7] The mechanism of tinnitus generation in patients with normal audiograms in the conventional range (up to 8 kHz) remains unclear. One can hypothesise that possible causes of tinnitus in those patients may be linked to cochlear impairment in the most basal region, which is routinely not tested by extended high-frequency audiometry.[7]

Because most tinnitus cases are associated with hearing loss, examining the hearing state is critical for evaluating tinnitus patients. The human ear has an auditory spectrum that may exceed 20 kHz, whereas conventional audiometry only measures frequencies up to 8 kHz. According to one study, extended high-frequency audiometry is more sensitive than traditional lower frequency audiometry at identifying cochlear damage.[8] As such, the evaluation of tinnitus patients via extended high-frequency audiometry may offer more insight into the true hearing status of these patients.

In light of this, several recent studies have examined the extended high-frequency audiometry results in tinnitus patients with normal hearing in conventional hearing threshold analyses.[9–12] Some of these studies have found that tinnitus patients with normal hearing below 8 kHz exhibited decreased hearing abilities in the extended high-frequency range compared with normal individuals.[10,12] However, this finding was not universal, with one study detecting no differences between tinnitus patients and controls in the extended high-frequency range.[13] It is important to note that patients with unilateral and bilateral tinnitus were included in the same analyses, with no subgroup-based comparisons between them and healthy controls. Furthermore, previous research did not examine the relationship between age, tinnitus features and extended high-frequency audiometry results.

Given these data, we attempted to conduct a study in which patients with tinnitus were divided into unilateral and bilateral tinnitus groups. Hearing declines with age, and it is known that hearing in the extended high-frequency range is particularly age-sensitive. As a result, we opted to age-segregate patients with bilateral and unilateral tinnitus and recruit age-matched controls without tinnitus. We separated patients with tinnitus into two groups (aged 20–29 and 30–39 years old). Additionally, we recruited control subjects with a similar age range.

In contrast to the bilateral tinnitus patients and controls, who were analysed against one another in two subgroups, the unilateral tinnitus cases were examined both within the group (tinnitus ear compared with non-tinnitus ear) and between the groups (tinnitus ears compared with age-matched and ear-matched control groups).

Overall, this study aimed to clarify the relationship between extended high-frequency thresholds and tinnitus in individuals with normal audiometric thresholds in the conventional frequency range. From a clinical standpoint, it may be beneficial to evaluate the extended high-frequency thresholds of tinnitus-affected patients with 'clinically normal hearing'. From a counselling perspective, it may be necessary for the patient to understand that they do not have normal hearing or have hearing loss related to their tinnitus perception.

Materials and methods

Study participants

We enrolled 64 tinnitus patients with normal otoscopic inspection findings, average immittance audiometry results, and hearing thresholds of 25 dB HL or less at 0.25 to 8 kHz, out of a total of 2516 tinnitus patients recruited as out-patients between October 2018 and December 2019. There were 36 patients with unilateral tinnitus (17 males and 19 females; 3 were aged under 20 years, 12 were 20–29 years, 11 were 30–39 years and 10 were 40–56 years) and 28 patients with bilateral tinnitus (14 males and 14 females; 14 were aged 20–29 years and 14 were 30–39 years). Patients with tone-like tinnitus in pitch-matching analyses were included in this study. In 55.43 per cent (51 out of 92) of these ears, the tinnitus pitch was matched at 8 kHz.

In addition, we recruited 32 healthy control subjects without tinnitus who had been age-matched to the participants in the bilateral (16 participants in each age group) and unilateral (12 participants aged 20–29 years and 11 aged 30–39 years) tinnitus groups. In addition, the unilateral tinnitus group and the control group were matched according to ear side (if the tinnitus was left-sided in the patients, the left ear of the age-matched control participant was chosen).

All participants in this study had normal hearing levels of 25 dB HL or less in the 0.125–8 kHz range, at each frequency, and a normal type A tympanogram. Auditory brainstem response assays were conducted to exclude the possibility of acoustic neuromas in all subjects. The enrolled participants had no history of significant noise exposure, or otological, neurological or psychological problems. The present study was approved by the Ethics Committee of the Chinese People's Liberation Army General Hospital in Beijing, China.

Measurements and statistical analyses

All normal audiometry testing (at 0.125–8 kHz), extended high-frequency audiometry testing (at 9, 10, 11.2, 12.5, 14 and 16 kHz) and psychoacoustic tinnitus spectrum testing, which intended to match the frequency and loudness of tinnitus in each patient, were performed using a clinical audiometer (Piano; Inventis, Padova, Italy). All of these tests were conducted in a soundproof room. The conventional frequency audiometry (frequencies of 0.125–8 kHz) used supra-aural Telephonics TDH-39 earphones. The extended high-frequency audiometry was performed with the same audiometer and Sennheiser HDA 200 headphones.

Hearing thresholds were determined using a standard approach (steps: 10 dB HL down, 5 dB up, with thresholds being the lowest decibel hearing level for which responses occurred during at least 50 per cent of all ascending trials), established by the American National Standards Institute.[14]

The psychoacoustic characteristics of the tinnitus spectrum (pitch and loudness) were also assessed. Pitch matching was conducted by presenting patients with two tones and asking them to select the tone closer to the perceived sound; matches were made monaurally and the tones were repeated three times before designating a match. The choices were repeated until a match was made. Loudness matching was conducted by presenting the patient with a matched frequency tone just below the threshold, and gradually increasing the loudness of this tone in 1 dB HL increments until a match was made.[15]

This study aimed to evaluate overall hearing status that was not limited to those frequencies associated with speech comprehension. The average hearing level (in dB HL) was calculated based upon the average of all thresholds for both ears in the 0.125–8 kHz range, as measured via normal audiometry. The same approach was also used to calculate the average extended high-frequency hearing levels for all frequencies in the 9–16 kHz range.

Statistics

All statistical tests were performed using SPSS version 25.0 software (IBM, Armonk, New York, USA). Utilising Fisher's exact and chi-square tests, demographic data were compared between groups. Conventional hearing thresholds, normal audiometry and extended high-frequency thresholds were compared between patients and controls using Mann–Whitney U tests. Correlations between tinnitus properties, conventional hearing thresholds and extended high-frequency thresholds were evaluated via Pearson's correlation analyses. A p-value of less than 0.05 was the significance threshold, and all tests were two-tailed. Data in the text and tables were expressed as means ± standard deviation. Given the multiple comparisons, a Bonferroni adjustment of critical p-values was used for both extended high-frequency and normal audiometric data.

Results

Participant demographic and medical information

In total, we recruited 28 patients for the bilateral tinnitus arm of this study. These patients had a mean age of 29.46 ± 3.98 years and were subdivided into two age groups (20–29 years and 30–39 years; 14 patients per group). In addition, we recruited 36 patients with unilateral tinnitus with a mean age of 33.19 ± 11.7 years. Of these unilateral tinnitus patients,

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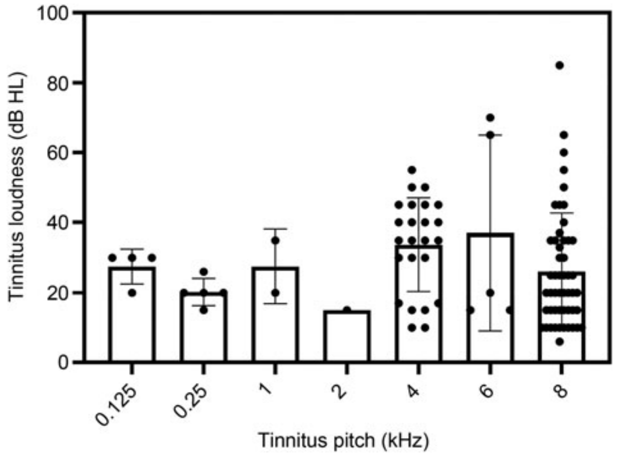

Figure 1. Tinnitus pitch and loudness values for all 92 tinnitus-affected ears. Bars represent mean ± standard deviation values; dots represent tinnitus frequency per tinnitus patient

42 per cent (15 out of 36) complained of tinnitus in the right ear, whereas 58 per cent (21 out of 36) complained of tinnitus in the left ear. The unilateral tinnitus group was further divided into two subgroups (12 patients were aged 20–29 years and 11 patients were 30–39 years). We additionally recruited 32 age-matched healthy control participants with a mean age of 29.21 ± 5.04 years, with 16 participants each in the 20–29-year and 30–39-year age groups.

Age and sex distributions did not differ significantly between the control, bilateral and unilateral tinnitus patients in the two subgroups ($p > 0.05$).

The tinnitus pitch and loudness values for all 92 tinnitus-affected ears in the present study are presented in Figure 1, which reveals that 55.43 per cent (51 out of 92) of these ears were affected by a tinnitus pitch of 8 kHz. The mean (± standard deviation) tinnitus duration in the unilateral tinnitus group was 1.08 ± 1.46 years. In the bilateral tinnitus group, tinnitus duration values in the 20–29-year and 30–39-year age groups were 0.79 ± 1.46 years and 0.80 ± 1.03 years, respectively.

Audiometry findings

This section concerns the normal pure tone audiometry and extended high-frequency audiometry findings in patients with and without subjective tinnitus. At 0.125, 0.5 and 1 kHz, we observed significant differences in conventional audiometry levels when comparing the 20–29-year-old bilateral tinnitus cases to those in the control group ($p < 0.05$). In addition, when comparing the 30–39-year group of bilateral tinnitus patients to their age-matched controls, we also detected significant differences in threshold values at 0.25 kHz ($p < 0.005$). However, no differences in conventional audiometry threshold values were detected when comparing the tinnitus and non-tinnitus ears in unilateral tinnitus patients, other than at 4 kHz (Tables 1 and 2, and Figures 2 and 3).

The hearing thresholds in the tinnitus-affected ears of patients in the 20–29-year-old unilateral group were significantly higher than those in the matched ears of the 20–29-year-old control subjects in all frequencies except 0.25 kHz. When comparing the hearing thresholds in the tinnitus ears of patients in the 30–39-year-old unilateral group with the ear- and age-matched control group, the 0.125 kHz, 4 kHz and all extended high-frequency ranges showed significant differences (Table 3 and Figure 4).

In addition, we detected substantial differences in extended high-frequency hearing thresholds between tinnitus ears and non-tinnitus ears within the unilateral tinnitus group, and between the 20–29-year old bilateral tinnitus participants and controls at 11.2, 12.5 and 14 kHz (Tables 1 and 2, and Figures 2 and 3). Additionally, significant variations between ears were found in unilateral tinnitus patients at 10 kHz ($p < 0.05$), and differences between ears were observed in the 20–29-year-old bilateral tinnitus patients at 16 kHz when compared with controls ($p < 0.05$; Tables 1 and 2, and Figures 2 and 3).

Correlation findings

We investigated the relationship between normal pure tone audiometry results, extended high-frequency audiometry findings, tinnitus duration, pitch and loudness in the tinnitus

Table 1. Comparison of hearing thresholds between bilateral tinnitus patients and controls

	20–29-year age group hearing thresholds (mean ± SD; dB HL)			30–39-year age group hearing thresholds (mean ± SD; dB HL)		
Frequency (kHz)	Bilateral tinnitus (28 ears)	Controls (32 ears)	*P*-value	Bilateral tinnitus (28 ears)	Controls (32 ears)	*P*-value
0.125	14.82 ± 5.35	9.84 ± 6.66	0.004†	15.71 ± 5.04	8.59 ± 7.54	<0.0001†
0.25	10.54 ± 4.58	8.44 ± 4.83	0.054	13.39 ± 5.62	7.34 ± 6.09	<0.0001†
0.5	10.71 ± 4.02	7.50 ± 5.96	0.046*	12.93 ± 5.00	9.22 ± 6.73	0.020*
1	8.21 ± 4.95	5.16 ± 5.00	0.032*	12.32 ± 7.51	8.13 ± 5.79	0.021*
2	6.43 ± 4.05	4.22 ± 4.77	0.071	13.21 ± 6.56	10.00 ± 7.07	0.120
4	9.29 ± 5.73	6.41 ± 7.54	0.098	13.39 ± 9.03	9.22 ± 8.24	0.073
8	11.96 ± 7.62	8.28 ± 8.09	0.079	12.68 ± 7.39	10.47 ± 8.36	0.252
9	12.68 ± 12.51	7.03 ± 7.28	0.130	14.46 ± 15.66	11.56 ± 11.46	0.557
10	17.50 ± 20.07	9.06 ± 10.51	0.129	13.75 ± 18.39	12.66 ± 10.62	0.475
11.2	21.43 ± 20.45	9.53 ± 9.45	0.018*	14.46 ± 19.07	15.16 ± 13.41	0.330
12.5	25.18 ± 21.28	13.28 ± 12.86	0.032*	22.86 ± 19.50	21.09 ± 18.39	0.726
14	28.57 ± 22.11	14.84 ± 18.34	0.023*	25.18 ± 20.12	21.56 ± 25.73	0.471
16	33.57 ± 20.99	23.87 ± 17.02	0.047*	30.36 ± 18.20	23.48 ± 20.53	0.230

P-values for Mann–Whitney U test comparisons between groups: $^{*}p < 0.05$; $^{\dagger}p < 0.005$. SD = standard deviation

https://doi.org/10.1017/S0022215123000920 Published online by Cambridge University Press

Table 2. Comparison of hearing thresholds between ears in patients with unilateral tinnitus

Frequency (kHz)	Hearing thresholds (means ± SD; dB HL) Tinnitus ears (36 ears)	Non-tinnitus ears (36 ears)	*P*-value
0.125	16.39 ± 5.43	14.58 ± 7.59	0.281
0.25	13.06 ± 6.47	12.78 ± 6.91	0.921
0.5	13.89 ± 5.62	12.64 ± 5.41	0.378
1	13.47 ± 5.83	12.08 ± 6.59	0.541
2	12.5 ± 7.51	11.39 ± 6.61	0.763
4	17.5 ± 7.61	12.08 ± 7.5	0.003†
8	17.5 ± 8.24	13.75 ± 10.38	0.125
9	36.25 ± 25.28	18.11 ± 16.03	0.002†
10	41.67 ± 24.58	21.94 ± 21.19	0.001†
11.2	42.08 ± 26.39	26.25 ± 25.25	0.015*
12.5	48.86 ± 27.06	34.17 ± 28.12	0.024*
14	41.61 ± 23.32	28.68 ± 24.60	0.026*
16	41.54 ± 15.92	35.00 ± 21.59	0.261

P-values for Mann–Whitney U test comparisons between groups: $*p < 0.05$; $^{\dagger}p < 0.005$. SD = standard deviation

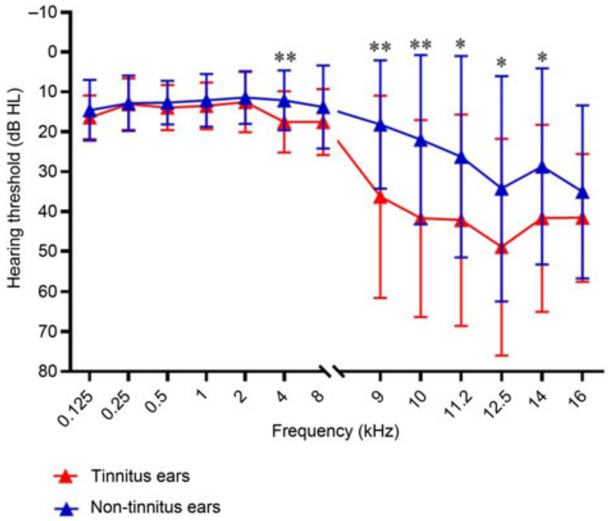

Figure 3. Conventional hearing and extended high-frequency thresholds for unilateral tinnitus group: tinnitus-affected ears compared with non-tinnitus ear side. Data represent mean ± standard deviation values. $*p < 0.05$; $**p < 0.005$

patients (Table 4). Significant correlations between tinnitus loudness and extended high-frequency findings were evident in all tinnitus groups. There were substantial correlations between the extended high-frequency results and tinnitus duration and pitch in the 20–29-year-old patients with bilateral tinnitus. In 30–39-year-old individuals with bilateral tinnitus, the normal pure tone audiometry results were correlated with the duration and loudness of the tinnitus.

Discussion

As part of the consultation and treatment process, it is crucial to identify any possible hearing loss in tinnitus patients.[5] Testing the extended high-frequency thresholds of patients with tinnitus who also have 'clinically normal hearing' may be helpful from a clinical standpoint. From a counselling perspective, it may be necessary for the patient to understand that they do not have normal hearing or hearing loss related to their tinnitus perception. Most tinnitus cases are linked to hearing loss. Even patients with normal pure tone thresholds may exhibit restricted cochlear damage or hearing loss at frequencies over 8 kHz, such that these abnormalities are overlooked upon conventional pure tone audiometry analysis.[16,17]

Given that hearing loss tends to initially manifest at higher frequencies before extending to lower frequencies,[8] extended high-frequency audiometry may be a useful tool for a more comprehensive evaluation of the hearing status of patients with tinnitus who have normal threshold values on conventional pure tone audiometry analysis. Our research confirms that unilateral tinnitus subgroups (20–29-year olds and 30–39-year olds) had higher extended high-frequency hearing thresholds than control subjects, at all extended high frequencies. The extended high-frequency hearing thresholds of the affected ears were also significantly higher than the unaffected ears in the unilateral tinnitus patients. In addition, the extended high-frequency hearing thresholds were significantly higher in the 20–29-year old bilateral tinnitus group when compared with the age-matched control group at 11.2, 12.5

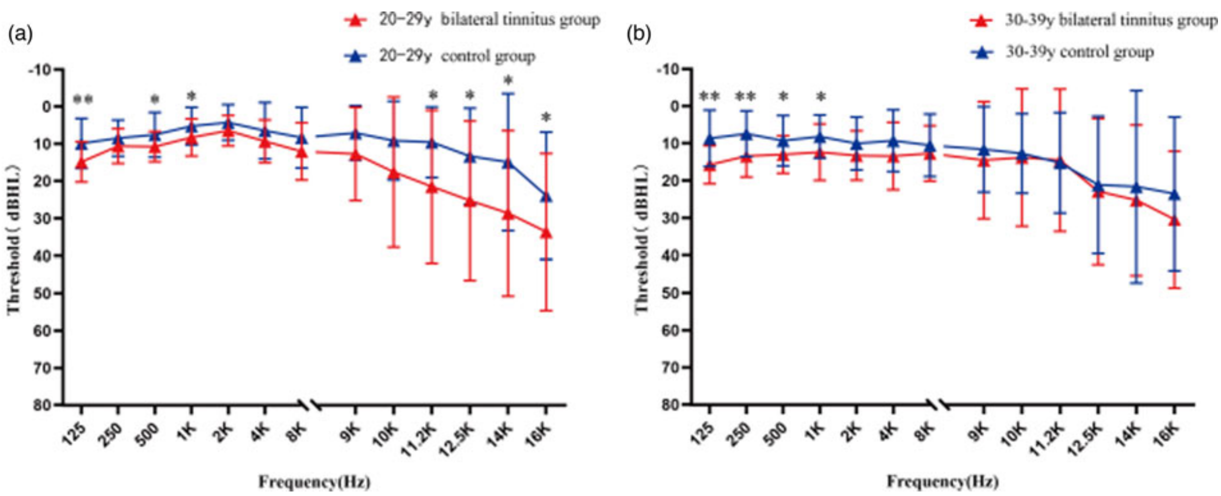

Figure 2. Conventional hearing thresholds and extended high-frequency thresholds for bilateral tinnitus group and control group: (a) 20–29-year-old groups, and (b) 30–39-year-old groups. Data represent mean ± standard deviation values. $*p < 0.05$; $**p < 0.005$. y = year

Table 3. Comparison of hearing thresholds between unilateral tinnitus patients and controls

	20–29-year age group hearing thresholds (mean ± SD; dB HL)			30–39-year age group hearing thresholds (mean ± SD; dB HL)		
Frequency (kHz)	Unilateral tinnitus (12 ears)	Controls (16 ears)	*P*-value	Unilateral tinnitus (11 ears)	Controls (16 ears)	*P*-value
0.125	16.25 ± 6.07	9.85 ± 5.36	0.006*	13.64 ± 5.04	7.38 ± 6.56	0.046*
0.25	10.8 ± 6.33	9.16 ± 4.77	0.186	11.36 ± 6.36	7.34 ± 5.78	0.069
0.5	13.33 ± 5.77	7.38 ± 5.76	0.006*	12.27 ± 10.00	9.98 ± 5.98	0.172
1	13.75 ± 6.44	5.16 ± 4.9	0.0001†	11.36 ± 3.23	8.54 ± 5.64	0.087
2	10.00 ± 7.38	4.73 ± 3.95	0.004†	10.90 ± 5.84	9.66 ± 7.84	0.704
4	15.83 ± 7.02	6.39 ± 4.96	0.001†	17.27 ± 7.86	8.68 ± 7.94	0.007*
8	15.00 ± 7.98	9.16 ± 8.09	0.018*	15.45 ± 11.06	11.03 ± 9.37	0.124
9	32.50 ± 27.5	3.98 ± 4.38	0.008*	30.91 ± 24.27	12.02 ± 11.86	0.026*
10	36.67 ± 26.83	9.32 ± 3.98	0.005*	40.45 ± 25.93	11.77 ± 9.88	0.005*
11.2	32.50 ± 24.45	9.99 ± 6.94	0.008*	38.63 ± 27.76	13.99 ± 12.62	0.020*
12.5	39.17 ± 23.44	12.39 ± 11.78	0.003†	44.54 ± 29.02	19.68 ± 17.77	0.026*
14	35.83 ± 21.30	13.94 ± 8.78	0.002†	42.27 ± 23.80	22.06 ± 16.92	0.024*
16	38.75 ± 12.45	24.77 ± 16.39	0.004†	43.18 ± 16.16	24.16 ± 19.97	0.009*

P-values for Mann–Whitney U test comparisons between groups: $^{*}p < 0.05$; $^{†}p < 0.005$. SD = standard deviation

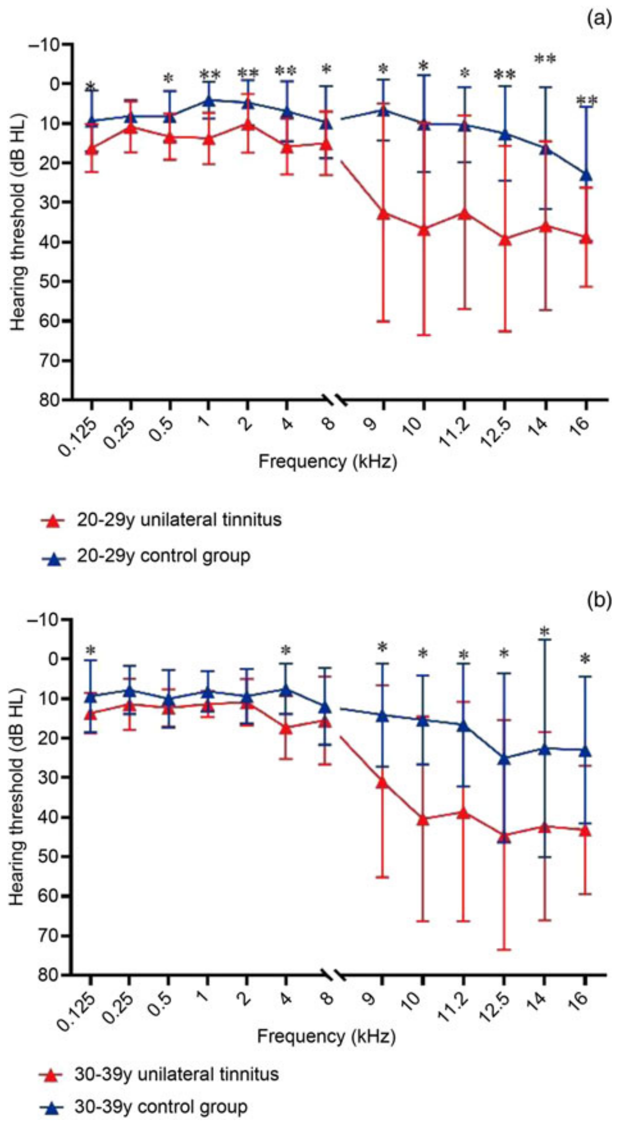

Figure 4. Conventional hearing and extended high-frequency thresholds for unilateral tinnitus group and control group: (a) 20–29-year-old groups, and (b) 30–39-year-old groups. Data represent mean ± standard deviation values. $^{*}p < 0.05$; $^{**}p < 0.005$. y = year

and 14 kHz ($p < 0.05$). Interestingly, the tinnitus group's hearing thresholds at 0.25–8 kHz were considerably higher than those of the control group, despite remaining within the normal range. In the 20–29-year-old bilateral tinnitus patients, we found statistically significant suggestive variations in conventional audiometry thresholds, compared with controls, at 0.125, 0.5 and 1 kHz ($p < 0.05$). A similar result was found when we compared patients in the 20–29-year-old unilateral tinnitus group with the matched ears of the 20–29-year-old control subjects. As a result, in patients with tinnitus and with normal audiometry findings, there is a chance of both extended high-frequency and normal audiometry hearing threshold hearing loss, which is in agreement with previous research.[18]

The pitch perceived by tinnitus patients is often associated with either the impaired frequency range or the edge of the inadequate range identified using audiograms.[19] In this study, we determined that the most common pitch perceived in the studied tinnitus patients was 8 kHz (55.43 per cent), which is on the edge of the extended high-frequency range, suggesting that damage in the extended high-frequency range can cause perceived tinnitus with a pitch at the edge of this range. Mean hearing loss has been shown to significantly correlate with tinnitus loudness.[20] We also observed a significant correlation between tinnitus loudness and extended high-frequency threshold findings in all studied groups.

In patients with unilateral tinnitus (mean age of 33.19 ± 11.7 years), we found that extended high-frequency threshold values were significantly elevated in the tinnitus ear relative to the non-tinnitus ear at 9, 10, 11.2, 12.5 and 14 kHz. Similarly, Mujdeci *et al.*[10] detected significant differences in extended high-frequency thresholds between tinnitus and non-tinnitus ears in patients of a similar age (32 ± 7.8 years) with unilateral tinnitus, at 10, 12.5, 14 and 16 kHz. Other than at 4 kHz, we observed no differences in frequency thresholds in conventional pure tone audiometry evaluations of unilateral tinnitus patients.

Human hearing progressively deteriorates with age, beginning in early adulthood, with extended high-frequency range

Table 4. Correlations between audiometry findings and tinnitus duration, pitch and loudness

		Duration		Pitch		Loudness	
Group	Audiometry parameter	r	*P*	r	*P*	r	*P*
Unilateral tinnitus group	PTA	0.003	0.986	0.006	0.970	0.092	0.594
	EHF	0.131	0.445	0.046	0.790	0.561	<0.0001†
20–29-year bilateral tinnitus group	PTA	0.010	0.953	0.105	0.595	0.124	0.528
	EHF	0.858	<0.0001†	0.820	<0.0001†	0.460	0.014*
30–39-year bilateral tinnitus group	PTA	0.411	0.030*	0.268	0.168	0.498	0.007*
	EHF	0.073	0.712	0.033	0.869	0.671	<0.0001†

P-values for Pearson's co-efficient for comparisons between groups: $^{*}p < 0.05$; $^{\dagger}p < 0.005$. r = correlation co-efficient; PTA = pure tone threshold average; EHF = extended high-frequency threshold average

hearing being particularly sensitive to the ageing process.[20,21] For this reason, we separated bilateral and unilateral tinnitus patients in the present study into two age-based subgroups. All of the extended high-frequency hearing levels in the tinnitus-affected ears of patients in both the 20–29-year-old and 30–39-year-old unilateral groups were significantly higher than those in the ear- and age-matched control subjects. Furthermore, the findings are consistent with those of Fabijańska *et al.*,[7] who found that tinnitus ears had significantly higher median hearing thresholds than control subjects at all extended high frequencies. We found differences in conventional pure tone audiometry (0.125, 0.25, 0.5 and 1 kHz) and almost all extended high-frequency threshold values (11.2, 12.5, 14 and 16 kHz) in younger (20–29-year old) bilateral tinnitus cases.

Similarly, Shim *et al.*[12] found that eight bilateral tinnitus patients with normal hearing exhibited decreased hearing ability at 10, 12.5, 14 and 16 kHz compared with healthy controls. Notably, in 20–29-year-old bilateral tinnitus patients, the average threshold of extended high frequencies significantly correlated with all tinnitus characteristics (tinnitus duration, pitch and loudness). We found no change in extended high-frequency threshold values between the older (30–39-year-old) and the 20–29-year-old bilateral tinnitus groups. The findings indicate that cochlear damage may be more prevalent in the older group than the younger group, with some frequencies in the extended high-frequency range not being determined in some of the subjects in the older group. It has also been shown that threshold values at 14 kHz can be measured in all bilateral tinnitus patients aged 20–29 years, whereas 16 kHz thresholds cannot be determined in some patients.[22] The ageing process may conceal the hearing differences in the extended high-frequency range of older (30–39-year-old) participants. Our results suggest that assessment of extended high-frequency threshold values may be particularly appropriate in tinnitus patients.

In contrast, patients aged 30–39 years with bilateral tinnitus only exhibited differences in conventional pure tone audiometry threshold values (0.125, 0.25, 0.5 and 1 kHz) relative to controls. Notably, in 30–39-year-old bilateral tinnitus patients, conventional pure tone audiometry findings were significantly correlated with tinnitus duration and loudness. However, in these 30–39-year-old bilateral tinnitus patients, extended high-frequency results were also associated with tinnitus properties. As hearing damage typically begins at higher frequencies before spreading to lower frequencies, this may suggest that cochlear damage in these older patients has progressively extended to the lowest frequencies. It is possible that both conventional pure tone audiometry and extended high-frequency range damage contributed to the perception of tinnitus in these cases.

There are multiple limitations to the present analysis. For one, we included only two age groups in our analyses of patients with tinnitus, and, as such, we may have overlooked other specific age-related results. Furthermore, our relatively small sample size may have biased our findings. The dominant tinnitus pitch's maximum frequency was 8 kHz, significantly lower than the 16 kHz obtained in extended high-frequency hearing tests; hence, it was impossible to match tinnitus pitches in the extended high-frequency region.

- Extended high-frequency audiometry can be used in evaluation of tinnitus patients with normal conventional pure tone audiometry, to provide more information about hearing status
- Unilateral tinnitus patients had higher extended high-frequency hearing thresholds than control subjects, at all extended high frequencies
- Conventional audiometry revealed differences between bilateral tinnitus patients and healthy controls at low frequencies
- Extended high-frequency hearing thresholds revealed differences between affected and unaffected ears in unilateral tinnitus patients, and in the younger bilateral tinnitus subgroup
- There was a suggestive association between tinnitus loudness and extended high-frequency results in all tinnitus groups

In addition, the bilateral tinnitus group had significantly poorer hearing than the control group in the low- to-mid frequencies in both age groups. This is a confounding variable and should be acknowledged as such. Future studies should aim to match hearing between the experimental and control groups in the conventional frequency range. Tinnitus symptoms make it hard to distinguish between test tones and tinnitus noise. In effect, the tones presented are masked when the tinnitus 'noise' is of the same pitch and of a higher intensity than the presented tone. The British Society of Audiology advocates for the use of warble tones when the clinician cannot obtain reliable test results because of tinnitus. Warble tones are far easier to distinguish from background tinnitus noise. This makes it easier for the patient and increases the accuracy of results. Unfortunately, in our study, because the hearing test is completed before the tinnitus test, we failed to use warble tones for hearing testing. When the patient's dominant frequency of tinnitus is unknown and when the clinician cannot obtain reliable test results because of tinnitus, warble tones should be included in pure tone audiometry. These deficiencies will be corrected in subsequent studies.

Conclusion

Using extended high-frequency audiometry to evaluate patients with unilateral tinnitus and young patients with bilateral tinnitus who have normal pure tone restrictions when examined with traditional pure tone audiometry could offer important information about their hearing status. It may help provide affected patients with better consultation and treatment options. From a clinical perspective, it may be worthwhile to test the extended high-frequency thresholds of patients who are affected by their tinnitus yet have 'clinically normal hearing'. However, future large-scale, multi-centre studies must expand these results to other age groups.

Acknowledgements. This work was supported by the Beijing Nova Program (grant number: Z201100006820133), the National Key Research and Development Project (grant number: 2019YFC0121302) and the National Key Research and Development Project (grant number: 2019YFC0840707).

Data availability statement. The datasets generated during and/or analysed during the current study are available from the corresponding author upon reasonable request.

Competing interests. None declared

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