CoDAS
ISSN 2317-1782 (Online version)

Original Article
Artigo Original

High-frequency auditory thresholds in normal hearing adults

Limiares de audibilidade de altas frequências em indivíduos adultos normo-ouvintes

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Keywords

Hearing
Adult
Auditory Threshold
Audiometry
Normal Hearing Individuals

ABSTRACT

Purpose: Evaluate high-frequency auditory thresholds, seeking to compare responses between the ears, to verify the correlation between hearing level and aging and analyze frequency responses in normal hearing adults. **Methods:** This is a prospective, quantitative, transversal study conducted with a convenience sample. Study participants were 60 individuals aged 18 to 58 years (mean=25.82) with auditory thresholds within normality standards (250-8000 Hz) and normal results in acoustic immittance measurements. High-frequency pure-tone hearing thresholds were determined using an Interacoustics AS10HF audiometer with electrodynamic high-fidelity KOSS R/80 headphones, with thresholds expressed in dBNPS. **Results:** Hearing thresholds showed an increase for the right ear with statistical significance at the 10, 11 and 14 kHz frequencies and a tendency to significance at 13 kHz. As of the 14 kHz frequency, a progressive increase directly proportional to the frequency was observed bilaterally, with the thresholds increasing proportionally to age advancement for all frequencies. **Conclusion:** High-frequency auditory thresholds progressively increase proportionally to frequency and age advancement in normal hearing individuals, with higher values for the right ear.

Descritores

Audição
Adulto
Limiar Auditivo
Audiometria
Normo-ouvintes

RESUMO

Objetivo: Avaliar os limiares auditivos nas altas frequências, buscando comparar as respostas entre as orelhas, verificar a correlação do nível de audibilidade com o aumento da idade e analisar as respostas por frequência para adultos normo-ouvintes. **Método:** Este estudo foi prospectivo, quantitativo e transversal, com amostra por conveniência. Fizeram parte da amostra 60 sujeitos, com idade entre 18 e 58 anos, média de idade de 25,8 anos, com limiares auditivos dentro dos padrões de normalidade de 250 a 8000 Hz e normalidade de resultados nas medidas de imitância acústica. Para a pesquisa das altas frequências foi utilizado o equipamento de modelo AS10 HF da marca Interacoustics com fones de ouvido do tipo KOSS R/80 e com limiares expressos em dBNPS. **Resultados:** Quanto aos limiares de audibilidade há um aumento para a orelha direita, com significância estatística em 10, 11 e 14 kHz e uma tendência à significância em 13 kHz, assim como a partir da frequência de 14 kHz há um aumento progressivo diretamente proporcional à frequência bilateralmente e quanto maior for a idade dos indivíduos, maiores serão os limiares para todas as frequências. **Conclusão:** Os limiares de audibilidade de altas frequências tornam-se maiores com um aumento progressivo proporcional ao avanço de frequência e idade de indivíduos normo-ouvintes com valores mais elevados para a orelha direita.

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Received: August 12, 2017

Accepted: November 27, 2017

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Financial support: nothing to declare.

Conflict of interests: nothing to declare.

INTRODUCTION

Behavioral tests aim to assess the auditory system from its peripheral to central portions, and demonstrate the effective response of individuals to what they hear. Pure-tone audiometry (PTA) is a behavioral, psychoacoustic procedure standardized to describe auditory sensitivity, called conventional audiometry, and tests the frequencies between 250 Hz and 8 kHz. The normality standard for conventional audiometry is established from the tritonal mean of hearing thresholds at the 500 Hz and 1 and 2 kHz frequencies smaller than 25 dBNA[1,2].

High-frequency audiometry (HFA) can be used in combination with conventional audiometry in the monitoring of hearing. Recognized since the 1960s, but little used in clinical practice today, this procedure enables evaluation of pure-tone air-conduction hearing thresholds from 9 to 20 kHz. This assessment enables the verification of impairment by lesion at the cochlear duct base before there is involvement of the frequencies tested by conventional audiometry, and it can also be used in the auditory monitoring of individuals at risk of hearing impairment development, because they are the first frequencies to be involved, assisting with early detection of hearing losses caused by ototoxic drugs, prolonged exposure to noise, presbycusis, sequelae of otitis, etc.

HFA can also provide subsidies for speech comprehension difficulties in noisy environments, because high frequencies are necessary for the decoding of speech signals, discrimination of consonant sounds, and recognition of speech[3-5].

The importance of this study lies on the fact that there has been scientific research using HFA since 1929, with Fletcher as one of the pioneers, introducing it clinically in the early 1960s, showing that hearing impairment could not be detected by conventional audiometry (250 Hz to 8 kHz) alone[3]. Although the use of HFA has been facilitated in recent years because the marketed audiometers began to incorporate frequencies higher than 8 kHz[4,6], it is still little used due to lack of literary consensus regarding its results, making knowledge regarding normality and impairment obscure, with studies showing a wide variation of methodologies applied, and also to the fact that most of the results already obtained are responses at the sound pressure level[7].

Several studies indicate that there is still no consensus regarding calibration standards for high frequencies. There are differences in the calibration of the equipment used, in the methodologies applied, in the results found, and in their interpretation, according to the population assessed[8,9].

Therefore, it is essential that further serial and consistent studies addressing the patterns of auditory thresholds at high frequencies be conducted with individuals without hearing complaints from different age groups. In view of these considerations, the present study aims to analyze the results of high-frequency hearing thresholds, at the sound pressure level, in individuals with no otological complaints aged 18-58 years.

METHODS

All procedures and evaluations were conducted at the Audiology outpatient clinic of a university hospital with collaboration of the undergraduate and graduate students of the Speech-Language Pathology course. This prospective, cross-sectional, quantitative study was approved by the Research Ethics Committee of the aforementioned Institution under protocol no. 25933514.1.0000.5346.

The study sample was composed of individuals selected according to the following eligibility criteria: understanding of the procedures; aged 18-59 years; hearing thresholds within normality limits, that is, up to 25 dBHL at all frequencies of Conventional Pure-tone Audiometry (250 to 8000 Hz) in both ears[1]; type A tympanometry curve and contralateral acoustic reflexes present bilaterally, without otological and audiological complaints.

The sample was formed by convenience according to the individuals scheduled at the Audiology outpatient clinic. After clarification about the study objectives and procedures, all participants signed an Informed Consent Form (ICF) and authorized the use of data.

After application of the inclusion criteria, the study sample consisted of 60 individuals, 11 men (18.3%) and 49 women (81.7%), aged 18-58 years (mean=25.8; median=23; standard deviation=8.5).

The volunteers underwent the following assessments

Visual Examination of the External Auditory Meatus (VEEAM)

Aimed at verifying the presence of cerumen and/or other factors that could impede or hinder the passage of sound and, consequently, the audiometric procedures. When necessary, participants were referred to an otorhinolaryngologist.

Pure-tone Audiometry (PTA)

Aimed to determine the air-conduction hearing thresholds at the 0.25 to 8 kHz frequencies and bone-conduction hearing thresholds (when necessary) at the 0.5 to 4 kHz frequencies, performed in a sound-treated room (according to the ANSI S3.1-1991 standard on environmental noise level). Individuals were positioned in the sound-treated room with the headphones properly placed and were asked to raise one of the hands when an acoustic stimulus (even if weak) was heard. When positioning the headphones, special care was taken to obtain adequate fit in order not to interfere with the examination accuracy because of the resonance characteristics of the external auditory meatus, as well as to avoid the possibility of its collapse.

Logoaudiometry

Aimed at monaurally determining the Speech Recognition Threshold (SRT) and Speech Recognition Percentage Index (SRPI), with the first and the latter using lists of dissyllabic and monosyllabic words, respectively. For the SRPI, 40 dB were added to the mean frequencies of 500, 1000 and 2000 Hz, and comfort level analysis was performed. Participants were asked to repeat the words spoken by the researcher as they understood them[10]. All the basic audiological examinations were conducted in a sound-treated room using a 2-channel clinical audiometer (Otometrics, Madsen Itera II) and headphones (TDH-39P, Telephonics).

Acoustic Immittance Measures (MIA)

Aimed to verify the integrity and functioning of the middle ear and central auditory pathway (superior olivary complex - stapedial reflexes), MIA were taken using a middle ear analyzer (Interacoustics, AT 235) and the tympanometry curve and acoustic reflexes were measured with the 226 Hz probe tone. The reflexes were analyzed at the 500-4000 Hz frequencies bilaterally in the contralateral mode. Only individuals with type A tympanometry curve[11] and presence of contralateral acoustic reflexes were sampled.

High-frequency audiometry (HFA)

Frequencies ranging from 9 to 18 kHz were assessed using an Interacoustics AS10HF audiometer with KOSS headphones, with thresholds expressed in dBNPS. As in the PTA procedure, participants were trained prior to the examination. Also as in the PTA, special care was taken when positioning the headphones to obtain adequate fit in order not to interfere with the examination accuracy because of the resonance characteristics of the external auditory meatus, as well as to avoid the possibility of its collapse.

Data were analyzed by descriptive statistics and parametric and non-parametric tests.

RESULTS

The hearing thresholds assessed were neither summed nor grouped, thus Figure 1 shows the distribution of the study sample regarding gender, where higher incidence of the female gender can be observed.

Table 1 enables verification of statistically significant differences between the ears for each frequency assessed. It is possible to observe that the right ear presents higher hearing thresholds than

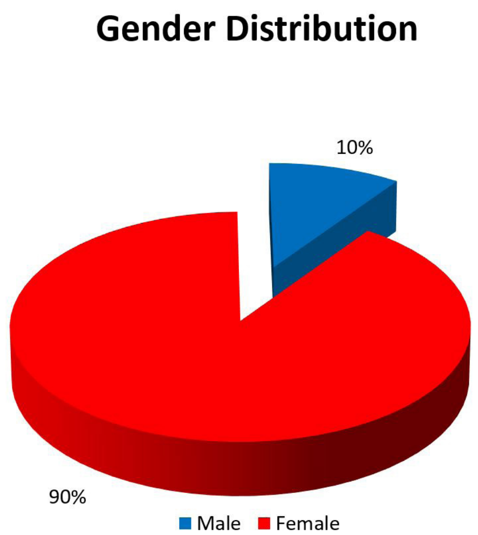

Figure 1. Gender distribution

Table 1. Comparison between hearing thresholds per ear

AC frequency		Mean	Median	SD	CV	Min	Max	N	CI	*p*-value
9kHz	RE	15.7	15	10.9	70%	0	45	60	2.8	0.263
	LE	14.3	15	8.7	61%	0	40	60	2.2	
10kHz	RE	16.9	15	10.1	60%	0	65	60	2.6	**0.016***
	LE	13.9	15	9.5	68%	0	55	60	2.4	
11kHz	RE	9.6	5	12.4	129%	0	80	60	3.1	**0.006***
	LE	6.5	5	9.3	143%	0	55	60	2.3	
12kHz	RE	6.8	0	13.8	203%	0	85	60	3.5	0.156
	LE	5.6	0	12.2	218%	0	75	60	3.1	
13kHz	RE	14.0	10	19.3	138%	0	115	60	4.9	0.092**
	LE	11.8	5	17.5	148%	0	95	60	4.4	
14kHz	RE	29.8	25	21.9	73%	0	115	60	5.5	**0.028***
	LE	26.5	20	21.7	82%	0	105	60	5.5	
15kHz	RE	34.3	30	23.3	68%	0	100	60	5.9	0.510
	LE	33.1	25	24.2	73%	0	105	60	6.1	
16kHz	RE	45.6	45	21.3	47%	15	100	60	5.4	0.345
	LE	43.8	37.5	25.1	57%	0	105	60	6.3	
17kHz	RE	58.3	57.5	22.5	39%	10	105	60	5.7	0.534
	LE	57.2	55	23.1	40%	15	110	60	5.9	
18kHz	RE	70.6	75	21.1	30%	20	105	60	5.3	0.183
	LE	68.3	70	19.4	28%	30	100	60	4.9	

*Significant values ($p \leq 0.05$); **Tendency to significance (up to 5 percentage points above the α value adopted)

Captions: AC: air-conduction; RE: right ear; LE: left ear; kHz: kilohertz; SD: standard deviation; CV: coefficient of variation ; Min: minimum; Max: maximum; N: number of individuals in the sample; CI: confidence interval the left ear, with statistical significance at the 10, 11 and 14 kHz frequencies and a tendency to significance at 13 kHz. Although no statistically significant difference is observed at the other frequencies, higher values are also presented for the right ear.

Table 2 presents the sum of the hearing thresholds for both ears per frequency. As of the frequency of 14 kHz, a progressive increase in the hearing thresholds directly proportional to frequency is observed.

Table 3 shows that auditory thresholds increase with age advancement for all frequencies, except for 9 and 10 kHz in the right ear, which presented a tendency to significance.

In Table 4, it can be verified that the greater the age, the higher the hearing thresholds at all frequencies for the left ear. For all tests, the null hypothesis rejection level was set at 0.05 or 5%, with significant values indicated by an asterisk.

Table 2. Complete description for air-conduction frequency

AC frequency	Mean	Median	SD	CV	Q1	Q3	Min	Max	N	CI
9kHz	15.0	15	9.9	66%	10	20	0	45	120	1.8
10kHz	15.4	15	9.9	64%	10	20	0	65	120	1.8
11kHz	8.0	5	11.0	137%	0	10	0	80	120	2.0
12kHz	6.2	0	13.0	209%	0	5	0	85	120	2.3
13kHz	12.9	10	18.4	142%	0	16.25	0	115	120	3.3
14kHz	28.2	25	21.7	77%	15	40	0	115	120	3.9
15kHz	33.7	30	23.7	70%	15	50	0	105	120	4.2
16kHz	44.7	42.5	23.2	52%	25	60	0	105	120	4.1
17kHz	57.8	55	22.7	39%	40	75	10	110	120	4.1
18kHz	69.5	75	20.2	29%	55	85	20	105	120	3.6

Captions: AC: air-conduction; kHz: kilohertz; SD: standard deviation; CV: coefficient of variation; Q1: first quarter; Q3: third-quarter; Min: minimum; Max: maximum; N: number of individuals in the sample; CI: confidence interval

Table 3. Correlation between age groups and air-conduction (AC) intensity for the right ear

	RE	Mean	Median	SD	CV	Min	Max	N	CI	*p*-value
9kHz	18 to 30 years	14.4	15	10.0	70%	0	40	49	2.8	0.055**
	31 to 58 years	21.4	20	13.4	63%	0	45	11	7.9	
10kHz	18 to 30 years	15.7	15	7.2	46%	0	30	49	2.0	0.051**
	31 to 58 years	22.3	20	17.8	80%	0	65	11	10.5	
11kHz	18 to 30 years	7.1	5	7.0	98%	0	30	49	2.0	0.001*
	31 to 58 years	20.5	15	22.6	111%	0	80	11	13.4	
12kHz	18 to 30 years	3.9	0	5.6	145%	0	25	49	1.6	<0.001*
	31 to 58 years	20.0	10	27.3	136%	0	85	11	16.1	
13kHz	18 to 30 years	9.9	5	10.4	105%	0	35	49	2.9	<0.001*
	31 to 58 years	32.3	20	35.0	109%	0	115	11	20.7	
14kHz	18 to 30 years	25.1	25	15.3	61%	0	70	49	4.3	<0.001*
	31 to 58 years	50.9	45	33.2	65%	10	115	11	19.6	
15kHz	18 to 30 years	29.1	25	17.1	59%	0	70	49	4.8	<0.001*
	31 to 58 years	57.7	55	32.4	56%	5	100	11	19.2	
16kHz	18 to 30 years	40.6	40	16.5	41%	15	75	49	4.6	<0.001*
	31 to 58 years	67.7	75	26.4	39%	25	100	11	15.6	
17kHz	18 to 30 years	54.2	55	19.0	35%	15	95	49	5.3	0.002*
	31 to 58 years	76.8	90	27.9	36%	10	105	11	16.5	
18kHz	18 to 30 years	67.3	70	20.6	31%	20	105	49	5.8	0.011*
	31 to 58 years	85.0	90	18.0	21%	50	100	11	10.7	

*Significant values ($p \leq 0.05$); **Tendency to significance

Captions: RE: right ear; kHz: kilohertz; SD: standard deviation; Min: minimum; Max: maximum; CV: coefficient of variation; N: number of individuals in the sample; CI: confidence interval

Table 4. Correlation between age groups and air-conduction (AC) intensity for the left ear

	LE	Mean	Median	SD	CV	Min	Max	N	CI	*p*-value
9kHz	18 to 30 years	13.2	10	8.2	62%	0	35	49	2.3	0.039*
	31 to 58 years	19.1	15	9.4	49%	5	40	11	5.6	
10kHz	18 to 30 years	12.4	15	7.0	56%	0	25	49	2.0	0.010*
	31 to 58 years	20.5	15	15.4	75%	5	55	11	9.1	
11kHz	18 to 30 years	4.6	5	5.6	121%	0	20	49	1.6	<0.001*
	31 to 58 years	15.0	10	16.1	107%	0	55	11	9.5	
12kHz	18 to 30 years	3.0	0	4.7	158%	0	20	49	1.3	<0.001*
	31 to 58 years	17.3	10	24.2	140%	0	75	11	14.3	

*Significant values ($p \leq 0.05$)

Captions: LE: left ear; kHz: kilohertz; SD: standard deviation; Min: minimum; Max: maximum; CV: coefficient of variation; N: number of individuals in the sample; CI: confidence interval

Table 4. Continued...

	LE	Mean	Median	SD	CV	Min	Max	N	CI	*p*-value
13kHz	18 to 30 years	8.6	5	9.0	105%	0	35	49	2.5	**0.002***
	31 to 58 years	26.4	10	33.8	128%	0	95	11	20.0	
14kHz	18 to 30 years	21.0	20	14.4	68%	0	60	49	4.0	**<0.001***
	31 to 58 years	50.9	50	31.1	61%	5	105	11	18.4	
15kHz	18 to 30 years	27.3	25	18.4	67%	0	65	49	5.2	**<0.001***
	31 to 58 years	58.6	65	30.9	53%	15	105	11	18.3	
16kHz	18 to 30 years	37.9	30	20.6	55%	0	80	49	5.8	**<0.001***
	31 to 58 years	70.5	75	26.6	38%	20	105	11	15.7	
17kHz	18 to 30 years	52.3	50	20.3	39%	15	95	49	5.7	**<0.001***
	31 to 58 years	78.6	90	23.6	30%	40	110	11	13.9	
18kHz	18 to 30 years	64.3	65	17.8	28%	30	95	49	5.0	**<0.001***
	31 to 58 years	86.4	95	16.1	19%	55	100	11	9.5	

*Significant values ($p \leq 0.05$)

Captions: LE: left ear; kHz: kilohertz; SD: standard deviation; Min: minimum; Max: maximum; CV: coefficient of variation; N: number of individuals in the sample; CI: confidence interval

DISCUSSION

Regarding the sample profile, of the 60 participating individuals, 49 (90%) were women and 11 (10%) were men (Figure 1). This has been a recurrent fact in several studies conducted with young individuals in which the sample is composed by convenience[9,12,13]. Pinheiro, Viacava, and Brito[14] collected a sample with 70% of women and 30% of men and reported that the greater occurrence of the female gender in clinical audiology research may be due to the fact that women seek health care more often, which may have contributed for the results found it.

Although most samples are composed by females, there is no consensus in the literature regarding better hearing quality of women compared with that of men, but the opposite has not yet been observed in any study. Moreover, no statistically significant results have been observed in the investigation of high-frequency auditory thresholds in adults without hearing complaints aged 18-29 years of both genders[7]. Similarly, another study that addressed high-frequency audiometry in normal hearing adults presented a sample comprising 67% of women and 33% of men[15].

Comparison of hearing thresholds between ears showed higher values at all frequencies for the right ear, with statistically significant difference only for the 10, 11 and 14 kHz frequencies (Table 1). Sá, Lima, Tomita, Frota, Santos, and Garcia[7] conducted the same comparison between individuals aged 18-29 years with no otological complaints and found statistically significant difference at the 11 and 12 kHz frequencies, partially corroborating the results of this study.

Other authors[16,17] did not report statistical difference when comparing hearing thresholds between the ears. A survey that analyzed the difference between high-frequency hearing thresholds in 14 individuals aged 19-56 years with a complaint of tinnitus, found no statistically significant difference between the right and left ears, as well as regarding location of the tinnitus complaint[4]. Another research with the objective of analyzing and correlating the audiometric findings at the 9-16 kHz frequencies in 125 adolescents with harmful hearing habits verified neither difference between the ears, nor influence at high frequencies due to exposure to high sound pressure levels[18]. A study that evaluated whether there were differences between the ears in 74 individuals aged 18-30 years without auditory complaints, found no statistically significant difference between hearing thresholds[6].

Table 2 shows that hearing threshold values increased with increasing frequencies, with greater sensitivity as of 14 kHz. Corroborating the findings of this study, Carvallo, Koga, Carvalho, and Ishida[6] studied 74 individuals aged 18-30 years without auditory complaints and confirmed the tendency of worsening thresholds with increasing frequency. A study that investigated 187 individuals exposed to occupational noise and 52 individuals not exposed to noise reported that, in the group exposed to noise, the high-frequency pure-tone hearing thresholds were higher than those in the group not exposed to noise, with more accentuated difference observed in pure-tone thresholds as of the 14 kHz frequency[19]. Another survey[20] also described worsening of pure-tone auditory thresholds in both ears with increased high frequencies, more pronounced as of the 14 kHz frequency.

Zeigelboim, Oliveira, Marques, and Jurkiewicz[15] performed high-frequency audiometry in 30 normal hearing individuals and compared the hearing thresholds of the frequencies surveyed; the authors observed that, as frequency increased, there was a decrease in auditory acuity in both ears for both genders. The same study verified stability in the auditory levels between the 9-12500 Hz frequencies, with decline from the frequency of 14 kHz in both ears.

Research addressing the influence of tinnitus in 30 female individuals aged 19-56 years verified that the higher the frequency assessed, the worse the hearing threshold, both for the group with a complaint of tinnitus and the control group[4]. Therefore, corroborating the aforementioned studies, this result is probably due to cochlear tonotopy, because the higher the frequency, the less stimulation that will reach the basal region of the cochlea responsible for high frequency.

At practically all frequencies in both ears, statistically significant mean difference with decreased sensitivity to perceive and detect pure tone for the 31-58-year age group was observed (Tables 3 and 4), except for the 9-10 kHz frequencies in the right ear (Table 3). Thus, the high-frequency hearing thresholds were higher in older individuals, probably as a result of loss of auditory sensitivity due to the aging process. Silva and Feitosa[21] performed high-frequency audiometry in 64 individuals divided into two groups: one composed of the 25-35-year age group and another of the 45-55-year age group, and verified that the greater the age, the higher the responses to the hearing thresholds, with more significant difference at the higher frequencies (8 to 16 kHz). The same was reported by Figuerêdo and Corona[4] in their study conducted with 30 individuals aged 19-56 years analyzing pure-tone thresholds by conventional audiometry: the control group composed of older individuals showed influence of age on their hearing thresholds, evidencing a decrease in auditory sensitivity with increasing thresholds in all statistically significant frequencies.

A study comparing age and auditory sensitivity in 347 workers found that those over 40 years of age presented a significantly higher mean of the sum of the responses to high-frequency audiometry (HFA) compared with that of workers under the age of 40 years[22].

Analysis of the auditory sensitivity at high frequencies in 125 adolescents aged 12-17 years with harmful hearing habits (use of MP3 player) demonstrated no correlation between use of MP3 player and auditory thresholds, and a division into 12-14 and 15-17-year age groups showed an increased mean for higher thresholds in the group composed of older individuals for all frequencies tested, except for 11,200 Hz[18]. Although characterization of high-frequency thresholds by age group in adolescence shows worse responses in the older age group[23,24], there is no agreement on the exact period that this reduction begins[25,26].

Aiming to investigate the hearing thresholds of dentists, dentist's assistants, and dental prosthesis technicians, 108 professionals aged 17-59 years were evaluated. No altered exams were identified for the three groups tested by conventional audiological examination; however, complementary audiological assessment such as HFA indicated greater sensitivity in the early detection of hearing impairments, considering that hearing loss in this population affects the frequencies that are not tested in conventional examinations[27].

The present study, following the clinical criteria for normal sensitivity, identified all participants as individuals with hearing thresholds within normality; however, sensitivity to high frequencies was diminished with age advancement. These findings corroborate the literature and indicate that HFA can be used clinically for the early diagnosis of auditory aging.

The fact that there was a lower prevalence in perceiving and detecting pure tone at high frequencies could be explained by the anatomy and dynamics of the cochlea, the so-called cochlear tonotopy, previously mentioned in this study. Some studies suggest that there is greater hearing sensitivity with age advancement at high frequencies than at lower frequencies[28,29]. These findings corroborate the literature and indicate that HFA can be used for clinical diagnosis because of the possibility to distinguish auditory sensitivity between youth and adults when normal results are observed in conventional audiometry.

CONCLUSION

Analysis of the response to high-frequency thresholds of normal hearing individuals aged 18-58 years showed that auditory thresholds progressively increase proportionally to frequency and age advancement, with higher values for the right ear.

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Author contributions

SJO and LCLS were responsible for the study design, collection and analysis of data, and writing of the manuscript; MVG and AFS were the study advisers, and were responsible for the writing and approval of the manuscript.