The Journal of International Advanced Otology

J Int Adv Otol 2024; 20(4): 358-364 • DOI: 10.5152/iao.2024.231217

Review

Extended High-frequency Audiometry in the Elderly: A Narrative Review

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Cite this article as: Gottfriedová N, Kovalová M, Škerková M, Mrázková E. Extended high-frequency audiometry in the elderly: A narrative review. *J Int Adv Otol.* 2024;20(4):358-364.

Extended high-frequency audiometry (HFA) is considered an important tool in the detection of hearing loss. However, the values at extended high frequencies (EHF) in older adults (in both men and women) are associated with considerable uncertainty due to limited reference data. The presented review aimed to analyze hearing thresholds at EHF in adults older than 60 years. A literature search for HFA-related keyword combinations was conducted using the electronic databases PubMed, Scopus, and Web of Science. A total of 1654 records, published in the last 22 years, were identified through this search, of which only 7 articles were ultimately included in the analysis. Multiple studies have shown that significant hearing loss can be observed at EHF in older adults. Hearing thresholds in the frequency range of 9-20 kHz in the elderly varied widely across the studies. Therefore, further research in this field is needed to complete the normative data.

KEYWORDS: extended high frequencies, extended high-frequency audiometry, hearing, older adults, presbycusis

INTRODUCTION

The average life expectancy is increasing globally.[1] Hand in hand with this increase, however, comes a rise in the incidence of hearing loss.[2] Based on the reports of the World Health Organization, nearly 2.5 billion people (i.e., 1 in 4 people) are projected to have hearing problems by 2050.[2] Currently, 430 million people live with disabling hearing loss globally.[3] Approximately 30% of people over 60 years of age have hearing loss.[3] Age-related hearing loss (ARHL, presbycusis) is the most common hearing disorder and a major cause of chronic disability in older age. Age-related hearing loss can cause difficulty in speech comprehension, thereby compromising communication skills and potentially leading to social isolation and loneliness.[4] In the early stages, ARHL typically affects audibility of higher frequencies, but over time, the impairment spreads to medium and low frequencies.[4] In urban settings, hearing impairment is very common, as intense community noise exacerbates the deterioration of hearing with old age.[4]

To examine hearing thresholds, pure-tone audiometry is widely used. Based on the examined frequency range, we can distinguish between conventional audiometry (CA, frequency range of 0.125-8 kHz) and extended high-frequency audiometry (HFA, frequency range of 9-20 kHz).[5] However, some differences in the definition of HFA can be observed in the literature, as some authors consider even the "standard" frequencies of 6-8 kHz to be high frequencies.[6-10] However, the term "extended high frequencies" (EHF) is typically used for the frequency range above 8 kHz nowadays.[11,12] For the purposes of this review, we will follow this definition.

The hearing thresholds at EHF are still affected by a great deal of uncertainty, especially for the older age groups.[13] Currently, the literature on audiometry above 8 kHz, up to 20 kHz, is limited. Of the available works, most focus on young or middle-aged participants, i.e., adults under 60 years of age. Not many studies with participants over this age have been published yet, and, in effect, hearing thresholds at all EHF could not yet have been properly determined for them. The causes of the low number of such studies include the higher prevalence of moderate to severe hearing impairment in people over 65 years of age compared to younger

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Received: May 15, 2023 • **Revision Requested:** January 24, 2024 • **Last Revision Received:** May 20, 2024 • **Accepted:** May 20, 2024 • **Publication Date:** July 29, 2024
Available online at www.advancedotology.org

adults[14] or otological diseases, including tinnitus,[15] as well as cognitive impairment often present in these individuals,[16] which makes recruitment of a suitable population more difficult.

The International Organization for Standardization (ISO) provides in its Standard 7029:2017 information on the expected median values at audiometric frequencies of 9-12.5 kHz for age groups of 22-80 years.[13] However, the values at this frequency range in the age category of 80+ years are associated with considerable uncertainty in both men and women due to the aforementioned low amount of available data. At the frequency of 12.5 kHz, the same is true for all age categories from 30 years onwards. No normative data are then available for any of the EHF over 12.5 kHz.[13]

This article aims to (i) summarize the knowledge on high-frequency hearing in the elderly and organize the information gained in this area over the last 22 years. Furthermore, we aim to (ii) provide readers with hearing threshold values at EHF for the oldest age categories given the fact that normative values are not fully established for that group yet, and, lastly, (iii) to draw attention to the importance of research in this area so that the mentioned standard thresholds can be properly determined and, subsequently, updated over time.

METHODS

Search Strategy

A literature search was conducted using the electronic databases PubMed, Scopus, and Web of Science. Keyword combinations related to extended HFA in the elderly (see below) were searched.

Inclusion Criteria

Eligible literature was selected using the following criteria: (i) articles had to contain the keywords "EHFs," "HFA," "pure-tone audiometry," and had to be concerned with assessing hearing thresholds at frequencies over 8 kHz in elderly (or seniors), using extended HFA; (ii) articles had to be published between 2002 and 2024; and (iii) only articles in English were included. (iv) Regarding the age of the participants, the studies had to be performed on study groups that included elderly adults with the age range of at least 60-68 years and older; (v) only original research articles were included; and (vi) finally, only studies where the authors examined at least 3 EHFs within the range of 9-20 kHz were included.

Exclusion Criteria

From records identified through database search, duplicates found in more than one of the databases were removed, as well as book chapters, conference proceedings, manuals, and brochures. Studies assessing the impact of hearing impairment on participants' quality of life, mental well-being, social contacts, or social life, as well as studies assessing the hearing of respondents in association with their acute or chronic diseases, injury, surgery, or treatment, were excluded. We did not include studies in which the authors primarily aimed to assess therapeutic and rehabilitation methods for restoring or improving participants' hearing or assess the hearing quality in relation to the use of hearing aids. Additionally, animal studies were excluded. Finally, the articles not clearly stating the examined frequencies and/or not adequately describing measurement conditions or participants were also excluded.

RESULTS

Using the above keywords and the 2002-2024 timeframe, a total of 1654 records were identified through database search. A total of 1620 records were excluded, as they were not directly related to the issue of interest. Subsequently, 9 duplicates found in more than one of the databases were removed, as were 18 articles not meeting the above inclusion criteria. Seven articles were ultimately included in the analysis and divided into 2 subgroups according to the age of participants. The entire search process is shown in Figure 1.

Group 1 (n = 2) includes studies with participants older than 60 years only.[17,18] Group 2 (n = 5) includes studies comprising, besides the elderly group over 60 years of age (minimum age range of 60-68 years), also younger participants.[5,11,12,19,20] The most important characteristics of the identified studies classified into the groups above are summarized in Table 1.

The studies were conducted in China (n = 2),[11,12] Japan (n = 1),[20] the United States (n = 1),[18] Spain (n = 1),[5] Norway (n = 1),[17] and the Czech Republic (n = 1).[19]

The number of participants in the identified studies ranged from 37[12] to 645.[5] The age of participants ranged from 5 years[5] to 90+ years.[17] Regarding sex distribution, the proportion of men varied depending on the study type, ranging from 27%[12] to 57.4%.[11]

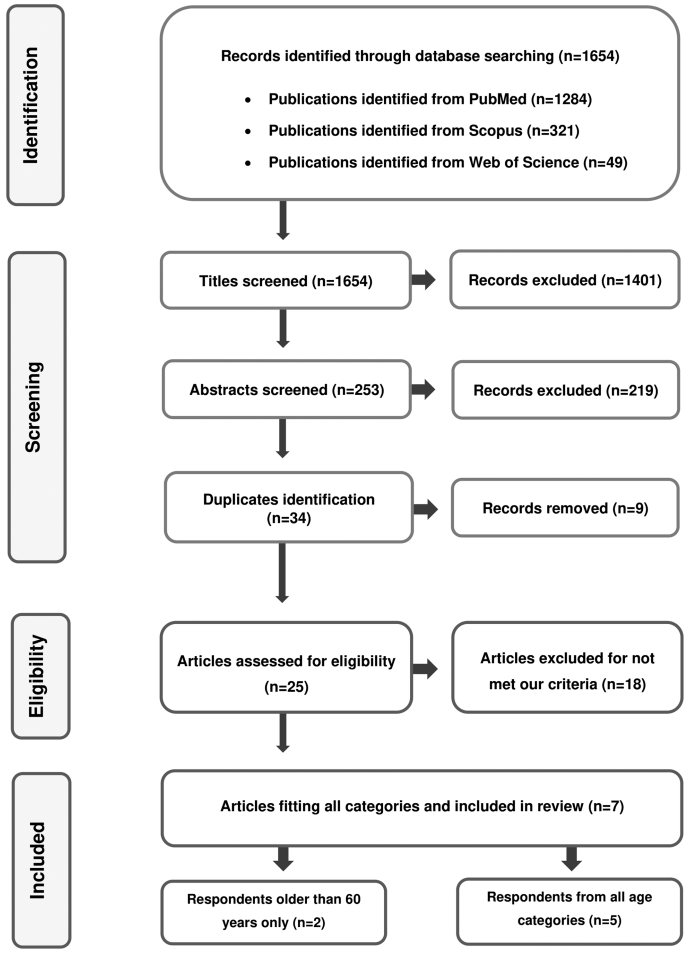

Figure 1. The flow diagram.

Table 1. Overview of the Selected Studies

Author, Year	Number of Respondents	Mean Age (Years) + (Range or SD)	City, Country	Frequencies Measured (kHz)	Type of Audiometer	Groups (n = Number of Participants)	Objective	Findings
Guo et al, 2023	37 (27 women, 10 men)	47.1 years (Range 19-68)	Wuhan, China	CA 0.125-8 kHz; HFA 10 kHz; 12.5 kHz; 16 kHz	Astera audiometer (Otometrics A/S, Taastrup, Denmark)	Probable vestibular migraine (n = 15); and vestibular migraine (VM) (n = 22)	To explore HT at CF and EHFs. To determine if the HFA is a useful tool for the early detection of hearing loss in individuals with VM.	Patients with vestibular migraine tended to have bilateral EHF and high-frequency hearing loss. EHF can be used in the early detection of hearing loss and monitoring of disease progression.
Wang et al, 2021	162 (69 women, 93 men)	(range 21-70 years)	Jinan, China	CA 0.25-8 kHz; HFA 9-20 kHz	Audiometer GSI-Grason-stadler, USA	Group 1: age 21-30 (n = 23); Group 2: age 31-40 (n = 25); Group 3: age 41-50 (n = 44); Group 4: age 51-60 (n = 39); Group 5: age 61-70 (n = 31)	To monitor the age-related HT at 9-20 kHz in a healthy hearing population.	Hearing abilities in HFA deteriorated starting from 31 years of age and were most obvious in the 2 oldest age categories. No responsiveness to 20 kHz was found in Group 4 and even to 18 kHz in Group 5.
Rodrígues et al, 2014	645 (324 women, 321 men)	(range 5-90 years)	Madrid, Spain	CA 0.125-8 kHz; HFA 9-20 kHz	Madsen clinical audiometer (Madsen Orbiter 922, version 2; Madsen Electronics, Taastrup, Denmark)	Group 1: age 5-19 (n = 90); Group 2: age 20-29 (n = 92); Group 3: age 30-39 (n = 94); Group 4: age 40-49 (n = 89); Group 5: age 50-59 (n = 99); Group 6: age 60-69 (n = 88); Group 7: age 70-90 (n = 93)	To investigate hearing thresholds at 0.125-20 kHz and compare the results with existing values at EHF in an attempt to establish new standards.	An increase in the hearing thresholds as a function of frequency and age has been found. For the 20 -69 year-old- group, hearing thresholds were lower in females than in males, especially at 12.5 and 16 kHz.
Jílek et al, 2014	411 (225 women, 186 men)	(range 16-70 years)	Prague, Czech Republic	CA 0.125-8 kHz; HFA 9-16 kHz	Madsen clinical audiometer (Madsen Orbiter OB 922 version 2)	Group 1: age 15-19 (n = 23); Group 2: age 20-24 (n = 25); Group 3: age 25-29 (n = 36); Group 4: age 30-34 (n = 34); Group 5: age 35-39 (n = 27); Group 6: age 40-44 (n = 31); Group 7: age 45-49 (n = 59); Group 8: age 50-54 (n = 48); Group 9: age 55-59 (n = 50); Group 10: age 60-64 (n = 41); Group 11: age 65-70 (n = 37)	To determine reference HT above 8 kHz.	The results make the determination of reference HT depending on age possible over the full frequency hearing range.
Kurakata et al, 2011	490 (280 women, 210 men)	(range 18-89 years)	Tsukuba, Japan	CA 0.125-8 kHz; HFA 9-16 kHz	Manual Audiometer UNITY 2, Siemens Audiologische Technik GmbH; Computer-controlled audiometer that the authors developed	Group 1: age 18-19 (n = 19); Group 2: age 20-29 (n = 151); Group 3: age 30-39 (n = 100); Group 4: age 40-49 (n = 89); Group 5: age 50-59 (n = 40); Group 6: age 60-69 (n = 66); Group 7: age 70-79 (n = 24); Group 8: age 80-89 (n = 1)	To measure hearing thresholds at CF (125 Hz-8 kHz) and EHFs (8 kHz-16 kHz) in otologically normal Japanese.	The results at EHFs revealed that the responses of older subjects could be unreliable at the highest frequencies.

(*Continued*)

Table 1. Overview of the Selected Studies (Continued)

Author, Year	Number of Respondents	Mean Age (Years) + (Range or SD)	City, Country	Frequencies Measured (kHz)	Type of Audiometer	Groups (n = Number of Participants)	Objective	Findings
Lee et al, 2005	188 (91 women, 97 men)	68 years (range 60-81 years)	Charleston, South Carolina USA	CA 0.25-8 kHz; HFA 9-18 kHz	Madsen OB822 Clinical audiometer; Demlar 20P high-frequency audiometer	Men (n = 97); Women (n = 91)	To analyze HT for conventional and EHF in older adults and study longitudinal changes in HT.	On average, HT increased approximately 1 dB per year for the elderly. Subjects with higher initial thresholds at middle and high frequencies tended to have a slower rate of change at 6-8 kHz in the following years.
Stenklev et al, 2004	232 (153 women, 139 men)	range 60-90+ years	Tromsø, Norway	CA 0.125-8 kHz; HFA 9-16 kHz	Madsen audiometer Orbiter 92 v.2	Other participants (n = 172); Otologically normal sample (n = 60)	To analyze the changes in HT with age.	HT deteriorated with age at high frequencies in otologically normal adults. The screening criteria in ISO 7029 may be unreliable in subjects older than 60 years.

CA, conventional audiometry; CF, conventional frequencies; dB, decibel; HFA, high-frequency audiometry; HF, high frequencies; HT, hearing thresholds; kHz, kilohertz; n, number; SD, standard deviation.

Studies Involving Participants Older Than 60 Years Only

In 2004, Stenklev et al[17] published the results of their study investigating the age-related changes in hearing thresholds in 232 randomly selected elderly (over 60 years of age) individuals, of which 60 were otologically normal. The participants completed CA (frequency range of 0.125-8 kHz) and extended HFA (frequency range of 9-16 kHz). The results were compared to the reference values defined by ISO 7029,[13] which provides descriptive statistics of the hearing threshold deviations for populations of otologically normal persons of various ages. The authors found that hearing thresholds at tested high frequencies worsened with increasing age, and the difference between hearing thresholds at EHF in otologically normal men and women was not significant.[17] After comparing the results with ISO 7029,[13] the authors concluded that the criteria for screening otologically normal elderly persons may be questionable.[17]

A year later, the results of a longitudinal study aiming to analyze the hearing thresholds in 188 elderly individuals aged 60-81 years using CA and extended HFA (at frequencies of 9 kHz, 10 kHz, 11 kHz, 12 kHz, 14 kHz, 16 kHz, and 18 kHz) were published by Lee et al, who investigated longitudinal changes in hearing thresholds and the effects of age, sex, initial results, and past noise exposure.[18] The authors found the rate of changes in hearing thresholds to be affected by age, sex, and initial threshold levels. On average, the hearing thresholds increased by approximately 1 dB per year in the elderly.[18] Older women had a faster rate of changes at frequencies of 0.25-3 kHz (CA) and 10-11 kHz (extended HFA) compared to younger women (aged 60-69 years). Older men had a faster rate of changes at 6 kHz compared to younger men aged 60-69 years. Comparing men and women, a faster rate of changes at the higher frequencies of 6-12 kHz in women was found. No significant effect of past noise exposure on the rate of hearing threshold changes was observed by the authors.[18]

Studies Including Participants From All Age Categories

In 2011, Kurakata et al[20] published the results of their examination of hearing thresholds at frequencies ranging from 125 Hz to 16 kHz in Japanese adults. The study included 490 otologically normal participants, with 210 men and 280 women aged 18-89 years. Their results showed that the median hearing thresholds of Japanese participants were lower than the ISO values. They also pointed out that the responses of older participants could be unreliable at the highest frequencies.[20]

A 2014 Czech study aimed to determine reference values of hearing thresholds at EHF above 8 kHz using CA and extended HFA (frequency range of 9-16 kHz) in 411 otologically normal individuals within the age range of 16-70 years.[19] The authors compared the results with ISO 7029[13] and calculated the coefficients of quadratic, linear, polynomial, and power-law approximations for the measured frequencies. These presented results can be used to determine normal hearing thresholds at high frequencies for individual age groups.[19]

In the same year, Rodríguez et al[5] published the results of their prospective study with 645 otologically normal participants aged 5-90 years. The purpose of their study was to investigate and determine reference values of hearing thresholds at frequencies of 0.125-20 kHz, using CA (frequency range of 0.125-8 kHz) and extended HFA (frequency range of 9-20 kHz). Their study also aimed to compare the results with existing values at EHF.[5] They found that the measured

hearing thresholds worsened with increasing frequencies and increasing age.[5]

In 2021, the Chinese study by Wang et al[11] aimed to investigate age-related hearing loss in 162 participants with normal hearing aged 21-70 years using CA (frequency range of 0.25-8 kHz) and extended HFA (frequency range of 9-20 kHz). Changes in hearing thresholds since 31 years of age were observed, with the greatest measured hearing loss at EHF in the 2 oldest age categories (51-60 and 61-70 years). The authors did not observe any response at 20 kHz in participants over 51 years of age and at 18 kHz in those over 61 years of age.[11]

Two years later, the study by Guo et al[12] was published. The aim of this study slightly differed from previous studies.[12] We have, nevertheless, decided to include it in our review because it met our criteria. The authors conducted a study involving 37 participants with an age range of 19-68 years with vestibular migraine (VM) and probable VM to determine their hearing thresholds at conventional and high frequencies, including 3 EHFs (10, 12.5, and 16 kHz) and confirmed the usefulness of extended HFA for early detection of hearing loss. The authors concluded that persons with VM tend to have bilateral hearing loss at EHF.[12] However, the number of participants older than 60 years was low, as well as their reported percentage of responses at EHF,[12] so we could not include their results in the analysis below.

Analysis of Hearing Thresholds in the Selected Studies

The hearing thresholds of the elderly varied across the included studies. This may be caused by the different composition of the study groups, the different numbers of participants, and possibly socio-cultural differences. For the purpose of our review, we have categorized the participants of the included studies by sex and by age into 2 groups, i.e., younger elderly (60-70 years) and older elderly (70+ years). If the authors of the included studies did not analyze the hearing thresholds of individual subcategories, we reported "all participants" (see Table 2 and Figure 2). Almost all studies, with one exception, reported hearing thresholds for the left and right ear combined. In one study, authors reported hearing thresholds in otologically normal (n = 60) and all participants for the left and right ear separately.[17] We have decided to present the results of this one study as hearing thresholds of the better hearing ear (BHE) in otologically normal participants (Table 2 and Figure 2).

Table 2. EHF Hearing Thresholds of the Elderly in the Included Studies; Median (M) or Mean Values (m) Across Studies

Author	Age Group	Frequency (kHz)									
		9	10	11	11.25	12	12.5	14	16	18	20
Wang et al, 2021	61-71 years, all participants (M)	60	70	*NM*	75	*NM*	75	75	*NR*	*NR*	*NR*
Rodríguez et al, 2014	60-69 years, all participants (M)	55	70	*NM*	75	*NM*	75	115	120	120	120
	70-90 years, all participants (M)	80	90	*NM*	95	*NM*	90	120	120	120	120
Jílek et al, 2014	60-70 years, men (m)	50	56	*NM*	63	*NM*	74	*NR*	*NR*	*NR*	*NR*
	60-70 years, women (m)	40	48	*NM*	57	*NM*	68	*NR*	*NR*	*NR*	*NR*
Kurakata et al, 2011	60-69 years, men (M)	44.1	50.5	*NM*	63	*NM*	73.4	65.4	49.4	*NR*	*NR*
	70-79 years, men (M)	57.8	65.5	*NM*	71.1	*NM*	72.5	65.7	51.1	*NR*	*NR*
	80+ years, men (M)	58	63	*NM*	66	*NM*	*NR*	*NR*	*NR*	*NR*	*NR*
	60-69 years, women (M)	50.3	56.7	*NM*	65	*NM*	72.2	67.5	51.1	*NR*	*NR*
	70-79 years, women (M)	62.7	67.3	*NM*	75.6	*NM*	76	67.5	*NR*	*NR*	*NR*
Lee et al, 2005	60-81 years, men (m)	96	98	102	*NM*	109	*NM*	113	115	115	*NM*
	60-81 years, women (m)	80	85	93	*NM*	102	*NM*	111	113	115	*NM*
Stenklev et al, 2004	65-69 years, men, BHE (M)	90	90	*NM*	108	*NM*	*NR*	*NR*	*NR*	*NM*	*NM*
	70-74 years, men, BHE (M)	55	78	*NM*	93	*NM*	103	*NR*	*NR*	*NM*	*NM*
	75-79 years, men, BHE (M)	85	90	*NM*	100	*NM*	100	*NR*	*NR*	*NM*	*NM*
	80-84 years, men, BHE (M)	100	105	*NM*	105	*NM*	*NR*	*NR*	*NR*	*NM*	*NM*
	85-89 years, men, BHE (M)	100	103	*NM*	110	*NM*	*NR*	*NR*	*NR*	*NM*	*NM*
	90+ years, men, BHE (M)	*NR*	*NR*	*NM*	*NR*	*NM*	*NR*	*NR*	*NR*	*NM*	*NM*
	60-64 years, women, BHE (M)	50	70	*NM*	75	*NM*	88	105	110	*NM*	*NM*
	65-69 years, women, BHE (M)	55	70	*NM*	88	*NM*	95	100	110	*NM*	*NM*
	70-74 years, women, BHE (M)	78	83	*NM*	100	*NM*	105	*NR*	*NR*	*NM*	*NM*
	75-79 years, women, BHE (M)	80	85	*NM*	98	*NM*	103	110	*NR*	*NM*	*NM*
	80-84 years, women, BHE (M)	85	95	*NM*	103	*NM*	*NR*	*NR*	*NR*	*NM*	*NM*
	85-89 years, women, BHE (M)	90	93	*NM*	100	*NM*	105	*NR*	*NR*	*NM*	*NM*
	90+ years, women, BHE (M)	85	95	*NM*	95	*NM*	*NR*	*NR*	*NR*	*NM*	*NM*

BHE, better hearing ear; M, median; m, mean values; NM, not measured; NR, no response.

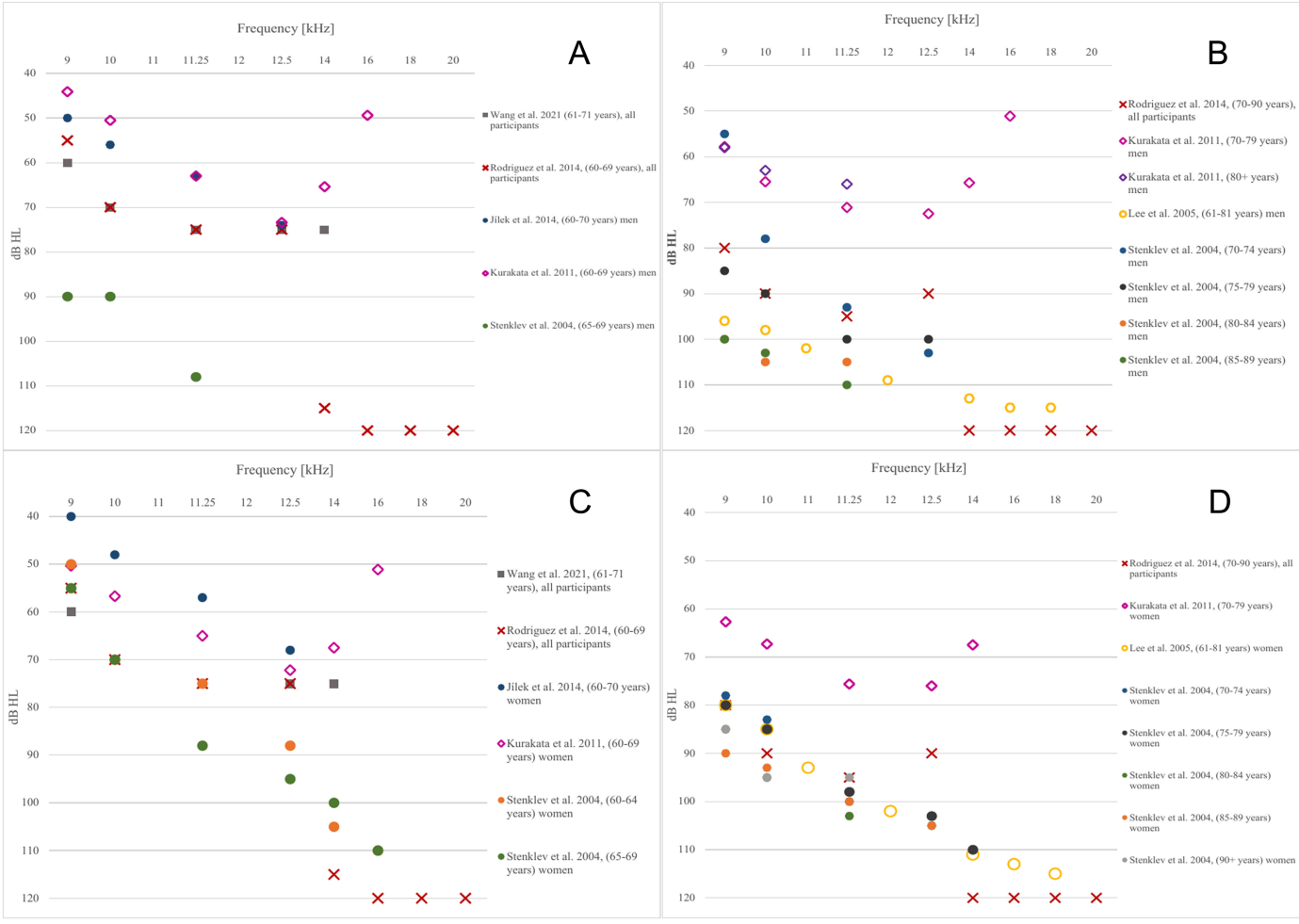

Figure 2. Hearing thresholds audiogram for men and women in age categories of 60-70 years and >70 years, ([1]A=Hearing thresholds at EHF in men aged 60-70 years across the studies; [2]B=Hearing thresholds at EHF in men aged >70 years across the studies; [3]C=Hearing thresholds at EHF in women aged 60-70 years across the studies; [4]D=Hearing thresholds at EHF in women aged >70 years across the studies).

An overview of hearing thresholds across the included studies in relation to age and sex is shown in Table 2.

Figure 2 below illustrates the distribution of hearing thresholds values reported in the literature.

DISCUSSION

Extended HFA can detect hearing loss before it starts to affect low or middle frequencies, where the human voice frequency range spreads out. Some authors considered the frequency range of 4-8 kHz or 6-8 kHz as high frequencies,[6-10] while others designated the frequency range of 9-20 kHz as high frequencies, often defined as "extended high frequencies" (EHF). Only studies using the latter definition were included in our review.

In the elderly, many age-related changes are observed in the organism, with changes in hearing thresholds being one of the prominent ones. So far, there are no internationally determined standard values for most EHF in this age group.[13] Not many authors have measured HFA in the elderly over 60 years of age. Only 7 such studies were identified from the last 22 years and included in our review. The reasons can be easily assumed—at such an old age, there is a very small chance that the respondents would reliably hear high-frequency tones. However, if these measurements are not performed and published, normative values can never be established. For this reason, we appeal for the usefulness of extended HFAs even for those over 60 years of age to inform future meta-analyses and the subsequent establishment of normative hearing thresholds for these individuals. Our review shows that younger elderly (under 70 years of age) are able to hear surprisingly high-pitched tones, and although the results are poorer in the older age group (over 70), good hearing is not impossible even in that age group.

The results vary widely across studies (Figure 2). Admittedly, most of them did not aim to focus primarily on hearing in the elderly; only 2 did so.[17,18] Different sample sizes may account for the differences in results. It is evident that the authors certainly tried to make their study groups as large as possible, but in the elderly, the possibilities to perform an audiometric test are limited, and the conditions more difficult because of, e.g., presbycusis, possible cognitive impairment, and/or poor compliance (as mentioned above).

Extended HFA is a very topical issue, so there should be no hesitation in obtaining data that could enable establishing norms for all frequencies and all age categories without limitation.

Limitations

The fact that only 7 studies were ultimately included in the review can be considered a limitation by some. However, we consider this rather a strength of our review as we can be certain that it only contains relevant studies. Besides, this very well describes the situation in the field, which indeed lacks a greater number of reliable studies focusing on (or at least including) the elderly. This highlights the fact that hearing at audiometric frequencies from 9 to 20 kHz deserves further investigation, especially in older adults because the values measured across the studies differed considerably.

We could also mention that several other studies reporting that they measured hearing thresholds at high frequencies in the elderly have been published and it can, therefore, appear that our list of studies is not complete. However, it should be noted that those studies used the term "high frequencies" to describe a frequency range of 4-8 kHz, which did not meet our criteria and led to their exclusion from this review.

CONCLUSION

Significant age-related hearing loss at frequencies above 8 kHz may be observed in people older than 60 years. Currently, not many studies are available that assess extended HFA in individuals older than 60 years; those considering individuals over 70 years of age are even rarer. Extended HFA and hearing thresholds at EHF deserve further investigation as the current estimated reference values for those frequencies in the elderly are burdened with a great amount of uncertainty.

Peer-review: Externally peer reviewed.

Author Contributions: Concept – N.G., M.S.; Design – N.G., M.S.; Supervision – M.K., E.M.; Resources – N.G.; Materials – M.K.; Data Collection and/or Processing – N.G.; Analysis and/or Interpretation – N.G., M.K., M.S., E.M.; Literature Search – N.G., M.S.; Writing – N.G., M.K., M.S., E.M.; Critical Review – M.K., E.M.

Declaration of Interests: The authors have no conflicts of interest to declare.

Funding: This article has been produced with the financial support of the European Union under the LERCO project number CZ.10.03.01/00/22_003/0000003 via the Operational Programme Just Transition.

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