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Trends in Distributions of Hearing Threshold Levels by Ages: A Comparison of the ISO 7029 and Newly Available Country-Specific Data

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Hearing thresholds provide essential information and references about the human auditory system. This study aimed to identify changing trends in distributions of hearing threshold levels across ages by comparing the International Organization for Standardization (ISO) 7029 and newly available data after publishing ISO 7029. To compare ISO 7029 and newly available hearing threshold data after publishing ISO 7029, four country-specific datasets that presented average hearing threshold levels under conditions similar to ISO 7029 were utilized. For frequencies between 125 Hz and 8,000 Hz, the deviations of hearing threshold values by ages from the hearing threshold of the youngest age group for each data point were utilized. For frequencies from 9,000 Hz to 12,500 Hz, the median threshold information was utilized. Hearing threshold data reported after publishing ISO 7029 from the four countries were mostly similar to the ISO 7029 data but tended to deviate in some age groups and sexes. As national hearing threshold trends change, the following ISO 7029 revision suggests the need to integrate hearing threshold data from different countries. **J Audiol Otol 2024;28(1):1-9**

Keywords: Auditory threshold; Aging; Hearing; Hearing tests; Standardization.

Introduction

Estimation of hearing thresholds extends our understanding of human hearing sensitivity and characteristics. It also provides essential information about the human auditory system and fundamental references [1,2]. Hearing thresholds reflect the hearing threshold characteristics of the contemporary population, and the prevalence of hearing loss has increased in the old population [3,4]. Over several decades, the International Organization for Standardization (ISO) [5-7] has investigated normal hearing thresholds across different age and sex groups. ISO 7029 was first published in 1984 and provides descriptive statistics on hearing thresholds across various ages [5]. The second and third editions were published in 2000 [6] and 2017 [7], respectively.

ISO 7029 [7] entitled "Acoustics—Statistical distribution of hearing thresholds related to age and gender" provides descriptive statistics of the hearing threshold deviation for otologically normal persons across different age groups for both male and female subjects with the frequency ranges from 125 Hz to 8,000 Hz. Currently, the amendment "Correction of parameter values for estimating the hearing threshold distribution" is in progress to increase data accuracy. This standard provides a baseline for human hearing thresholds across age groups, reflects the hearing thresholds of the contemporary population, and includes threshold statistics from different countries.

A recent study [8] combined four additional datasets from Korea [9,10], Spain [11], and the United Sates (U.S.) [12] with ISO 7029 [7] and discussed several implications. The key implications of the study are as follows: To understand the current population statistics worldwide, emerging data from different countries will be vital to validate the ISO standard. Applying precise and correct calculation formulas will always be considered to increase data precision. In addition, the hearing threshold decline at high frequencies in recent reports may indicate the need for high-frequency information across ages according to international standards. In this context, ISO 7029 [7] provides extended high-frequency hearing thresholds ranging from 9,000 Hz to 12,000 Hz for individuals aged 18 to 80 years.

This study aimed to provide the most recent hearing threshold data across different age groups. We also tried to identify changing trends in the distributions of hearing threshold levels across ages by comparing data between ISO 7029 [7] and the newly available country-specific data [13-16]. This study can be used as a reference for amending the standards in the near future.

Materials and Methods

To compare the ISO data with the newly available country-specific hearing threshold data since the publication of ISO 7029, four country-specific datasets that presented average hearing threshold levels under conditions similar to ISO 7029 [7] were used. ISO 7029 offers information on the deviations of hearing threshold values at various ages, relative to the hearing threshold of normal-hearing 18-year-old population, for frequencies ranging from 125 Hz to 8,000 Hz. ISO 7029 also provides the expected median threshold information at audiometric frequencies for frequencies ranging from 9,000 Hz to 12,500 Hz. ISO 7029 and the other four country-specific hearing threshold datasets have inconsistencies in reference age, but despite this shortcoming, this review compared median hearing threshold deviations for frequencies from 125 Hz to 8,000 Hz and median hearing thresholds from 9,000 Hz to 12,500 Hz across age- and sex-specific studies to examine trends in hearing thresholds in the newly available data.

ISO 7029 data

The current ISO 7029 standard is the third edition [7]. It adopted new audiometric data published after its first edition in 1984 [5]. The scope of this standard represents two main information as following: "the expected median value of hearing thresholds given relative to the median hearing threshold at the age of 18 years" and "the expected statistical distribution above and below the median value." The data of this standard can be used to estimate the amount of hearing loss in a specific population and to assess an individual's hearing in relation to the distribution of hearing thresholds of the person's age population with normal hearing. In addition, it provides the expected median values at audiometric frequencies from 9,000 Hz to 12,500 Hz within the age range of 22–80 years for information only.

Data from ten published references emerged in ISO 7029 [7]. Data were collected from 1980 to 2011 in seven countries: the United Kingdom, Japan, Norway, Germany, the U.S., France, and Australia. Although each reference had different testing frequency ranges and subject ages, the overall frequency range was 125–8,000 Hz, and the age range was 15–96 years. Approximately 6,548 males and 17,891 females were included in the 10 studies. The data included hearing threshold values measured at 125, 250, 500, 750, 1,000, 1,500, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz. The hearing threshold deviations were expressed by applying a new calculation procedure based on polynomial surfaces [8].

For data from both females and males, the median hearing threshold deviations and expected median thresholds from Annexes D (125–8,000 Hz) and E (9,000–12,500 Hz) were utilized. The statistical distribution of hearing threshold deviations is based on the calculation of the hearing threshold of an individual minus the median hearing threshold of a population of 18-year-old otologically normal persons of the same sex. An otologically normal person refers to a person in normal health with no signs or symptoms of ear disease, no earwax blocking the ear canal, no excessive exposure to noise, no exposure to potentially ototoxic substances, or a history of familial hearing loss [6].

American data

These data were collected between 2011 and 2012, 2015 and 2016, and 2017 and 2020. Data from females included 814 ears in their 20s (20–29 years old), 773 ears in their 30s (30–39 years old), 815 ears in their 40s (40–49 years old), 801 ears in their 50s (50–59 years old), 750 ears in their 60s (60–69 years old), 350 ears in their 70s (70–79 years old), and 200 ears in the 80s (80–85 years old). Data from males included 838 ears in their 20s (20–29 years old), 800 ears in their 30s (30–39 years old), 700 ears in their 40s (40–49 years old), 726 ears in their 50s (50–59 years old), 712 ears in their 60s (60–69 years old), 346 ears in their 70s (70–79 years old), and 170 ears in their 80s (80–85 years old). The data included hearing threshold values measured at 500, 1,000, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz. The median values of all hearing thresholds were calculated based on the hearing threshold value of the better ear in both ears. These data were based on participants with no ear-related medical conditions when hearing threshold was measured. For the hearing threshold deviation data, the median hearing threshold for the group in their 20s was used to derive the median hearing threshold deviations for the other age groups [13].

Czech data

The data were collected from 2020 to 2021. Data obtained from females included 76 ears in their 20s (18–24 years old), 124 ears in their 30s (25–34 years old), 78 ears in their 40s (35–44 years old), 76 ears in their 50s (45–54 years old), and 76 ears in their 60s (55–64 years old). Data acquired from males included 32 ears in their 20s (18–24 years old), 62 ears in their 30s (25–34 years old), 30 ears in their 40s (35–44 years old), 38 ears in their 50s (45–54 years old), and 40 ears in their 60s (55–64 years old). The data included hearing threshold values measured at 125, 250, 500, 750, 1,000, 1,500, 2,000, 3,000, 4,000, 6,000, 8,000, 9,000, 10,000, 11,200, and 12,500 Hz. The median values of all hearing thresholds were calculated based on a randomized hearing threshold value for one ear because the difference in hearing thresholds between the two ears was not significant. These data were based on participants with no ear-related medical conditions when hearing threshold was measured. For the hearing threshold deviation data, the median hearing threshold for the group in their 20s was used to derive the median hearing threshold deviations for the other age groups [14].

German data

Data were collected between 2008 and 2012. Data from females included 114 ears in their 20s (18–24 years old), 159 ears in their 30s (25–34 years old), 208 ears in their 40s (35–44 years old), 365 ears in their 50s (45–54 years old), 335 ears in their 60s (55–64 years old), 262 ears in their 70s (65–74 years old), and 198 ears in the 80s (75–84 years old). Data from males included 75 ears in their 20s (18–24 years old), 119 ears in their 30s (25–34 years old), 213 ears in their 40s (35–44 years old), 229 ears in their 50s (45–54 years old), 305 ears in their 60s (55–64 years old), 244 ears in their 70s (65–74 years old), and 220 ears in their 80s (75–84 years old). The data included hearing threshold values measured at 250, 500, 1,000, 2,000, 3,000, 4,000, 6,000, and 8,000 Hz. The median values of all hearing thresholds were calculated based on the average hearing thresholds of both ears. These data were based on participants with no ear-related medical conditions when hearing threshold was measured. For the hearing threshold deviation data, the median hearing threshold for the group in their 20s was used to derive the median hearing threshold deviations for the other age groups [15].

Korean data

These data were provided by the National Standard Reference Data Center (NSRDC) of the Republic of Korea for 2022. Data from females included 690 ears in their 20s (20–29 years old), 484 ears in their 30s (30–39 years old), 394 ears in their 40s (40–49 years old), 212 ears in their 50s (50–59 years old), and 100 ears in their 60s (60–69 years old). Data from males included 276 ears in their 20s, 200 in their 30s, 104 in their 40s, 50 in their 50s, and 22 in their 60s. The data included hearing threshold values measured at 250, 500, 1,000, 2,000, 3,000, 4,000, and 8,000 Hz. The median values of all hearing thresholds were calculated based on the average value without dividing by the direction of the ear. These data were based on participants with no ear-related medical conditions when hearing threshold was measured. For the hearing threshold deviation data, the median hearing threshold for the group in their 20s was used to derive the median hearing threshold deviations for the other age groups [16].

Results

Trends in newly available country-specific hearing threshold data compared to ISO 7029 for female adults

The hearing threshold deviation data for female adults in the 125–8,000 Hz range for ISO 7029 and the four countries showed similar trends, except for a few frequency regions (Fig. 1). In the 30s age group, the difference between the ISO 7029 data and the hearing threshold deviation data of the four countries was within 2 dB. For those in their 40s, the differences between the ISO 7029 data and the hearing threshold

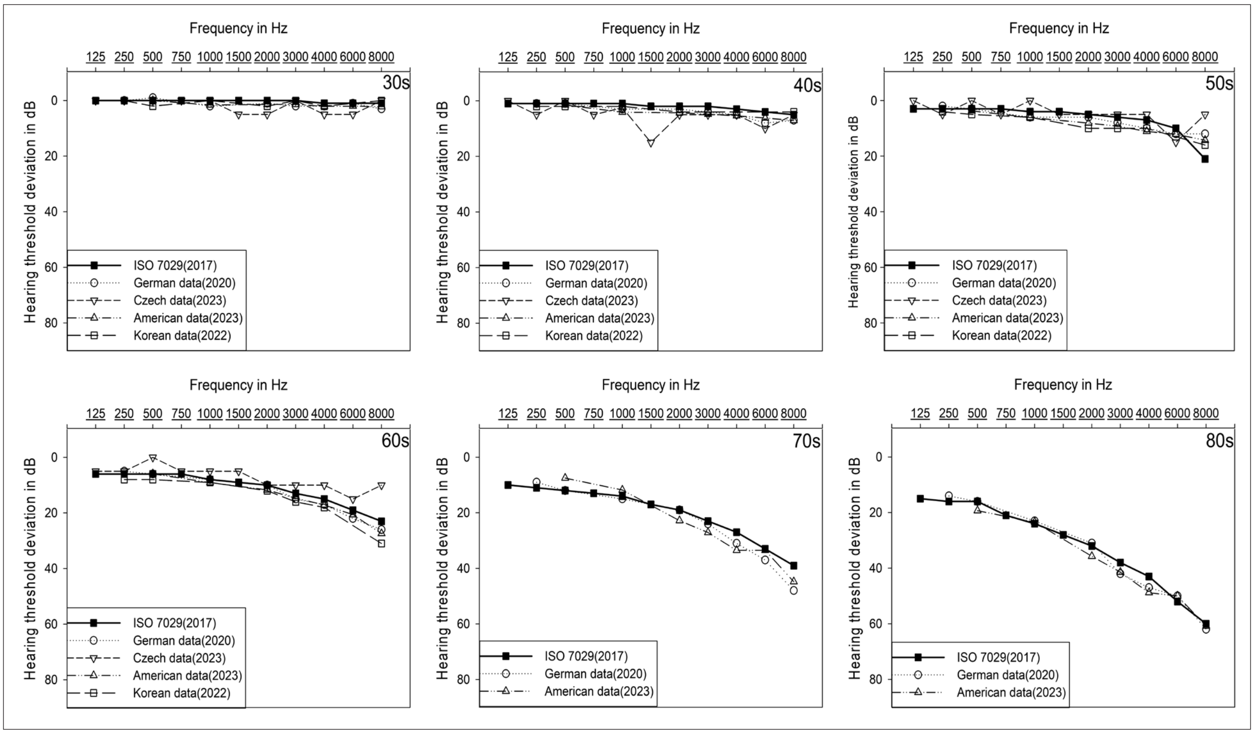

Fig. 1. Hearing threshold deviation data for female adults from ISO 7029 and four countries, covering the range of 125 Hz to 8,000 Hz.

deviation data for the four countries were all within 3 dB, except for 1,500 Hz (a difference of 13 dB) and 6,000 Hz (a difference of 6 dB) in the Czech data. In the 50s age group, the difference between the ISO 7029 data and hearing threshold deviation data from the four countries was within 5 dB, except at 8,000 Hz. For 8,000 Hz, the deviation value of ISO 7029 was 21 dB, whereas the four-country data showed a smaller variation of 5 dB (Czech) to 16 dB (Korea).

For the 60s group, the difference between the ISO 7029 data and hearing threshold deviation data from the four countries was within 5 dB, except at 8,000 Hz. At 8,000 Hz, the deviation value of ISO 7029 was 23 dB, whereas the four-country data varied from 10 dB (Czech) to 31 dB (Korea). For the 70s group, the difference between the ISO 7029 data and the hearing threshold deviation data from the four countries was within 5 dB, except at 8,000 Hz. At 8,000 Hz, the deviation value of ISO 7029 was 39 dB, whereas the four-country data showed a larger variation of 44.8 dB for German data and a smaller variation of 31 dB for American data. For the 80s group, the difference between the ISO 7029 data and the hearing threshold deviation data of the four countries was within 5 dB, except at 4,000 Hz. In the 4,000 Hz region, ISO 7029 had a deviation value of 43 dB, whereas the American data had a deviation of 48.8 dB.

The expected median high-frequency hearing thresholds of ISO 7029 were similar to the median Czech hearing thresholds for the 20s to 40s age groups but differed somewhat in the 50s and 60s groups (Fig 2). For example, in the 50s, the Czech data were lower than the ISO 7029 data by 4 dB (10,000 Hz) to 14 dB (11,200 Hz). In the 60s, the Czech data were also lower than the ISO 7029 data by 10 dB (10,000 and 11,200 Hz) and 13 dB (9,000 Hz).

Trends in newly available country-specific hearing threshold data compared to ISO 7029 for male adults

The hearing threshold deviation data for male adults in the 125–8,000 Hz range for the four countries showed a trend of similar or slightly higher deviations compared to the ISO 7029 data (Fig. 3). In the 30s age group, the difference between the ISO 7029 data and the hearing threshold deviation data of the four countries was within 3 dB except for 4,000 Hz (difference of 6.5 dB) in the Czech data. For the 40s group, the differences between the ISO 7029 data and the hearing threshold deviation data for the four countries were all within 5 dB, except for the Czech data from 2,000 Hz (difference of 7 dB) to 8,000 Hz (difference of 13 dB), American data (difference of 6 dB) at 4,000 Hz, and Korean data (difference of 7 dB) at 4,000 Hz. For the 50s group, the deviation data for the hearing thresholds of the four countries showed higher deviations in several frequency regions than the ISO 7029 data. At 4,000 Hz, for example, the deviation according to ISO 7029 was 11 dB, whereas the German data showed 15 dB; Czech data, 17.5 dB;

Korean data, 19 dB; and American data, 20.4 dB.

For the 60s and 70s age groups, the hearing threshold deviation data from the four countries showed similar trends to the ISO 7029 data below 2,000 Hz, but the higher-frequency regions above 3,000 Hz showed greater deviations. For example, for 8,000 Hz in the 60s, the ISO 7029 data was 30 dB, while the Korean, German, and American data were 35, 41, and 45.3 dB, respectively. For the 80s, the hearing threshold deviation

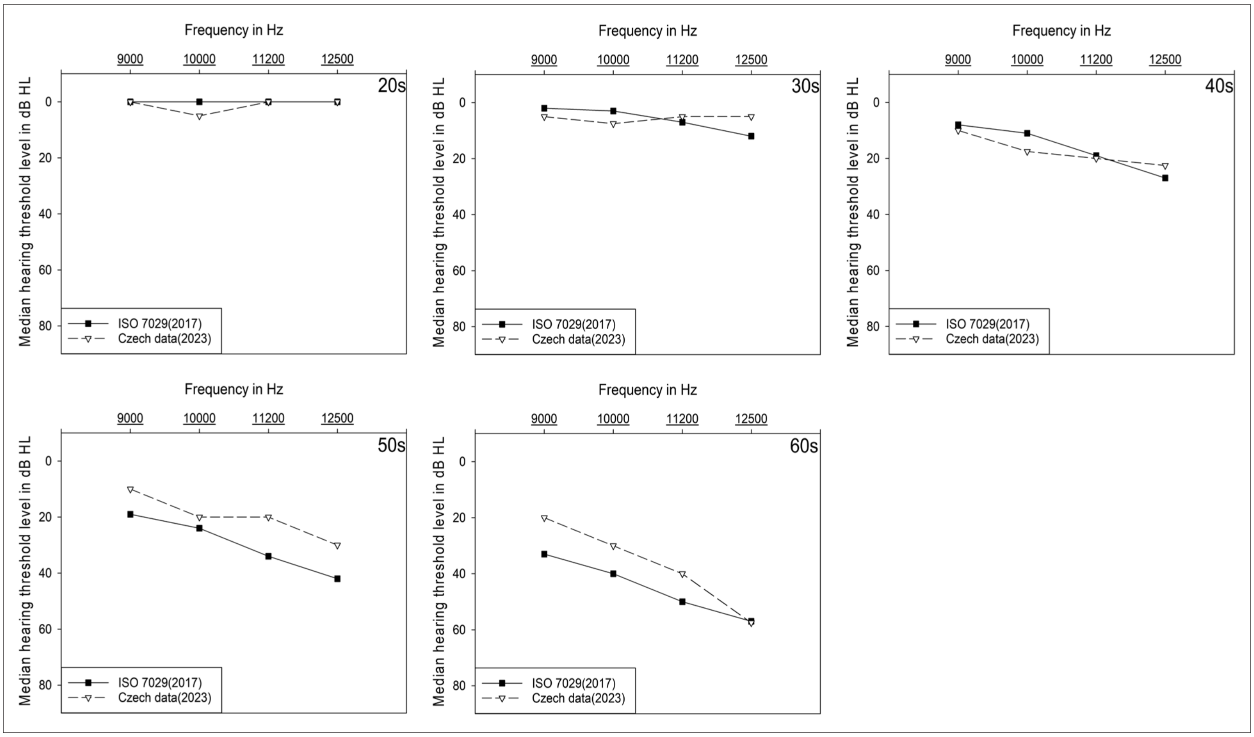

Fig. 2. Median hearing threshold data for female adults from ISO 7029 and Czech, encompassing the range of 9,000 Hz to 12,500 Hz.

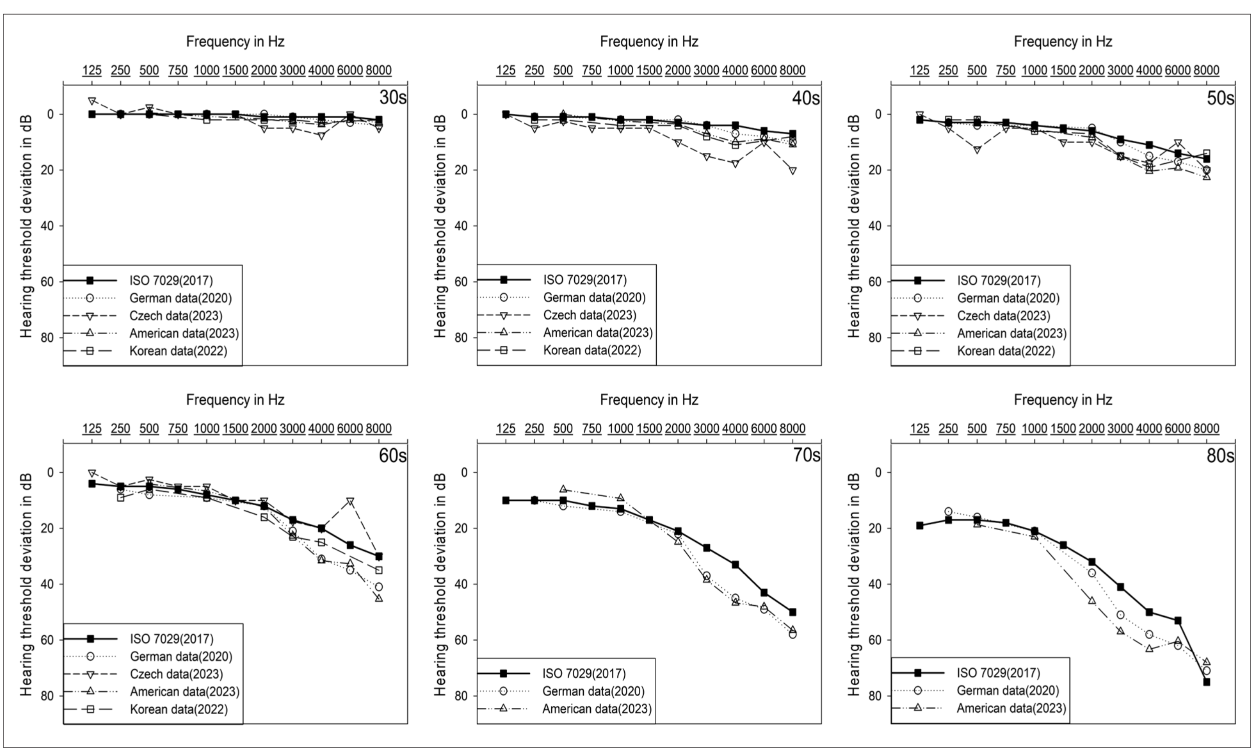

Fig. 3. Hearing threshold deviation data for male adults from ISO 7029 and four countries, covering the range of 125 Hz to 8,000 Hz.

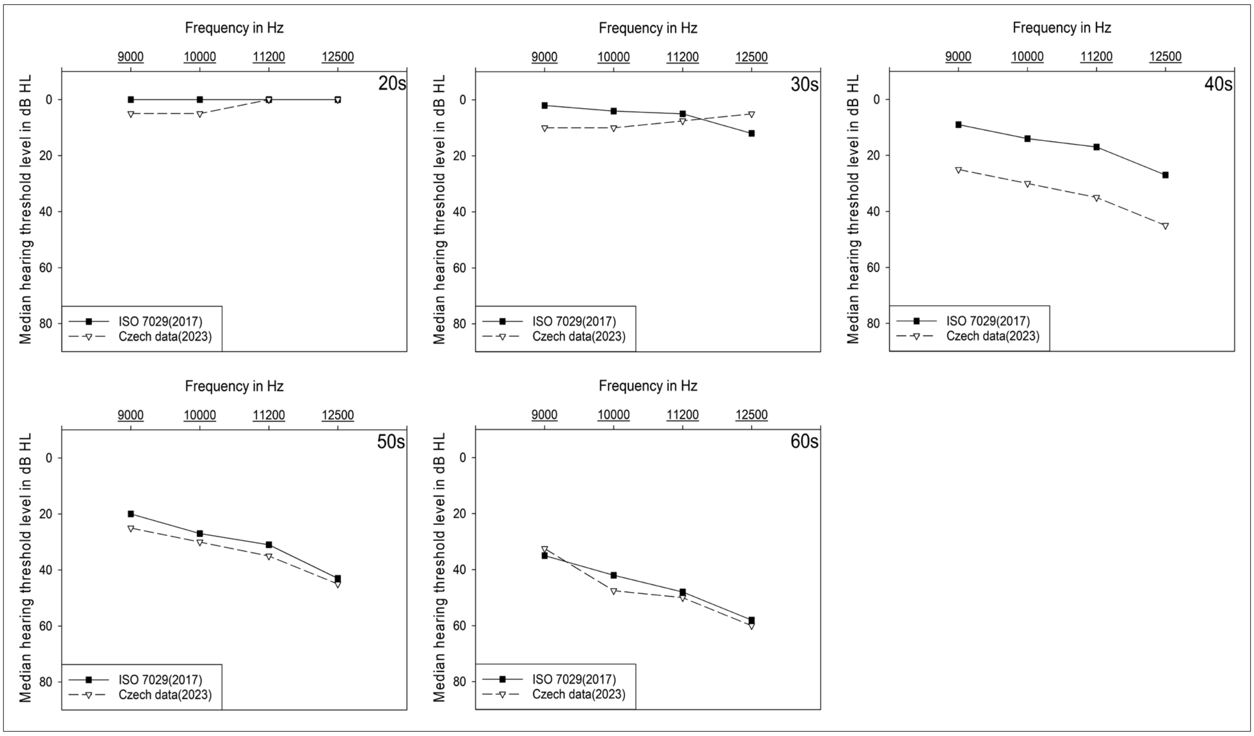

Fig. 4. Median hearing threshold data for male adults from ISO 7029 and Czech, encompassing the range of 9,000 Hz to 12,500 Hz.

data from the four countries showed similar trends to the ISO 7029 data below 1,000 Hz; however, higher-frequency regions above 1,500 Hz showed greater deviations. For example, at 3,000 Hz, the ISO 7029 data were 41 dB, whereas the German and American data were 51 and 57 dB, respectively.

The expected median high-frequency hearing thresholds of ISO 7029 were similar to the median Czech hearing thresholds in the 20s, 30s, 50s, and 60s but differed somewhat in the 40s (Fig. 4). For example, in the 40s, the Czech data were larger than the ISO 7029 data by 16 dB (9,000 and 10,000 Hz) and 18 dB (11,200 and 12,500 Hz).

Discussion

Owing to differences in how hearing threshold data are generated across countries, there were some limitations in comparing ISO 7029 data under uniform conditions. The hearing threshold data from the four countries had different age ranges. For example, for the hearing threshold data for 20s, the Czech [14] and German [15] data were generated for ages 18 to 24, while American [13] and Korean [16] data were generated for ages 20 to 29 years. There were also some differences in the formulas used to calculate the hearing threshold data among the four countries. For example, for the German data, the average of the hearing thresholds of both ears was considered as one data point [15], whereas the Czech data randomly used the thresholds of one of the two ears [14], and the American data were generated based on the thresholds of the better hearing of the two ears [13]. Therefore, rather than a direct comparison of the hearing threshold data from the four countries with ISO 7029 data, the analysis in this review focuses on trends in hearing threshold changes by frequency and age group.

This study examined recent hearing threshold datasets from four countries [13-16] and the ISO 7029 standard [7]. As a result, hearing threshold data from the four countries reported since the publication of ISO 7029 were mostly similar to ISO 7029 data with regards to overall aging effects but tended to deviate from ISO 7029 in some age groups and sexes. More specifically, the difference between the ISO 7029 data and the hearing threshold data for the four countries tended to be more pronounced for male adults than for female adults and for higher frequencies than for lower frequencies.

The results of this study indicate the potential for hearing threshold deviations in males and high-frequency ranges compared with ISO 7029. Integrating additional data from different countries is vital for improving the validity of international standards. In addition, establishing standard references for extended high frequencies across age is important for noise induced hearing loss [17]. In this context, Kurakata [8] recalculated hearing threshold values by merging the results of four additional data points into the latest version of ISO 7029. Several recent studies, including those referred to in this review,

Table 1. Weighted four-frequency average (W4FA) values by sex and age for Koreans calculated based on 50th percentile hearing threshold values

Parameter	20s		30s		40s		50s		60s	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
W4FA (male)	3.2	3.0	4.7	5.0	7.8	7.0	10.3	11.3	16.0	16.7
W4FA (female)	3.0	2.0	4.7	3.3	6.7	5.3	10.7	9.5	15.0	13.7

have reported normative hearing thresholds at extended high frequencies up to 14,000 Hz [18,19], as well as frequencies up to 8,000 Hz [20,21], across age and sex groups. Cumulative data on normative hearing thresholds from different countries will be very important for the next version of the standard publication, and regional attention is urged to collect diverse datasets.

In each revision, ISO 7029 has incorporated the latest hearing threshold data from different countries [5-7]. However, four country-specific hearing threshold data [13-16] reported since the publication of the third edition of ISO 7029 [7] differ in age range, method of calculating threshold values, and so forth. The next revision of ISO 7029 will need to be based on data from various countries with uniform ages, frequency ranges, and threshold calculation methods to generate more accurate hearing threshold data. To achieve this, the ISO 7029 committee will need to include experts from a wider range of countries and replicate discussions and collaborations to collect national hearing threshold data under uniform conditions.

Normative hearing threshold values are represented by age groups of 20–80 years in the current ISO 7029 standard [7]. Owing to the changing environment and increased life expectancy, hearing is becoming an important health issue [22] across the entire age population. For example, hearing loss is estimated to be a global disability burden for people aged >70 years [23]. For this reason, we may consider extending the upper and lower ranges of age populations to include children under 18 years of age and the elderly over 80 years. In addition, normative hearing threshold data for children is lacking [21,24-27]. Haapaniemi [26] reported that the hearing threshold levels of school-aged children improved with age from 7 to 10 years, and Beahan, et al. [27] showed a significant age effect in extended high-frequency thresholds. Recent studies have reported hearing thresholds in the elderly aged over 80 years [20,21,28,29] and up to 99 years [21]. Declining hearing thresholds in those over 80 years in previous studies may indicate the need for additional normative hearing thresholds in the extended age group of the elderly.

Measuring normative bone conduction thresholds across age groups is another consideration for standardization. ISO 389-3 [30] and IEC 60318-6 [31] only provide calibration-related information on bone vibrators. Although several studies have reported normative bone conduction thresholds in some population [32-36], normative bone conduction thresholds across age groups have not been published as international standards. Applying a specific measurement method to obtain normative bone conduction thresholds is challenging [37]. Appropriate methods for measuring normative bone conduction thresholds across age groups should be considered for ISO publications.

Normative hearing thresholds for Koreans have been reported in previous studies [9,10]. Currently, the NSRDC measures the age- and sex-specific normative hearing thresholds of Koreans and continuously accumulates data by expanding the age and frequency ranges. We hope that the updated Korean hearing threshold data will be useful for revising ISO 7029.

Weighted four-frequency average (W4FA) values by sex and age for Koreans, calculated based on 50th percentile hearing threshold values are shown in Table 1 [16]. The W4FA formula is currently used as the standard for determining disability in the Republic of Korea (Ministry of Health and Welfare Notice 2023-42). W4FA is calculated as (500 Hz+1,000 Hz+1,000 Hz+2,000 Hz+2,000 Hz+4000 Hz)/6. For men, W4FA showed that as age increased from the 20s to the 60s, the right ear hearing level (HL) increased from 3.2 dB to 16 dB and the left ear HL increased from 3.0 dB to 16.7 dB. For women, W4FA showed that as age increased from the 20s to the 60s, the right ear HL increased from 3.0 dB to 15 dB and the left ear HL increased from 2.0 dB to 13.7 dB. These results show that, in general, hearing thresholds increased with age, with women tending to have lower thresholds than men. Furthermore, for W4FA values based on ear orientation, men and women showed similar results, within 1.3 dB of each other. The results can be used as a baseline for the average hearing data of Koreans, without ear-related medical conditions, during the counseling process.

ISO 7029 is a useful standard document that provides information on normal-hearing thresholds considering sex and age. If hearing threshold data from various countries collected under uniform conditions are utilized in the next revision, it will become a standard document with higher prediction accuracy and can be used for a wider range of studies and analyses.

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None

Conflicts of Interest
The authors have no financial conflicts of interest.

Author Contributions
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REFERENCES

1) Dadson RS, King JH. A determination of the normal threshold of hearing and its relation to the standardization of audiometers. J Laryngol Otol 1952;66:366-78.
2) Robinson DW, Dadson RS. A re-determination of the equal-loudness relations for pure tones. Br J Appl Phys 1956;7:166.
3) Wiley TL, Chappell R, Carmichael L, Nondahl DM, Cruickshanks KJ. Changes in hearing thresholds over 10 years in older adults. J Am Acad Audiol 2008;19:281-92.
4) Asghari A, Farhadi M, Daneshi A, Khabazkhoob M, Mohazzab-Torabi S, Jalessi M, et al. The prevalence of hearing impairment by age and gender in a population-based study. Iran J Public Health 2017; 46:1237-46.
5) International Organization for Standardization. ISO 7029:1984. Acoustics—Threshold of hearing by air conduction as a function of age and sex for otologically normal persons. Geneva: International Organization for Standardization;1984. p.1-8.
6) International Organization for Standardization. ISO 7029:2000. Acoustics—Statistical distribution of hearing thresholds as a function of age. Geneva: International Organization for Standardization;2000. p.1-9.
7) International Organization for Standardization. ISO 7029:2017. Acoustics—Statistical distribution of hearing thresholds related to age and gender. Geneva: International Organization for Standardization; 2017. p.1-22.
8) Kurakata K. Re-estimated normal hearing threshold levels for pure tones using the calculation procedure of ISO 7029:2017. Int J Audiol 2023;62:720-8.
9) Lee JH, Kim JS, Oh SY, Kim KS, Cho SJ. Effects of age on hearing thresholds for normal adults. J Audiol Otol 2003;7:15-23.
10) Bahng J, Lee J. Hearing thresholds for a geriatric population composed of Korean males and females. J Audiol Otol 2015;19:91-6.
11) Rodríguez Valiente A, Roldán Fidalgo A, García Berrocal JR, Ramírez Camacho R. Hearing threshold levels for an otologically screened population in Spain. Int J Audiol 2015;54:499-506.
12) Jilek M, Šuta D, Syka J. Reference hearing thresholds in an extended frequency range as a function of age. J Acoust Soc Am 2014;136:1821-30.
13) Humes LE. Hearing thresholds for unscreened U.S. adults: data from the national health and nutrition examination survey, 2011-2012, 2015-2016, and 2017-2020. Trends Hear 2023;27:23312165231162727.
14) Škerková M, Kovalová M, Rychlý T, Tomášková H, Šlachtová H, Čada Z, et al. Extended high-frequency audiometry: hearing thresholds in adults. Eur Arch Otorhinolaryngol 2023;280:565-72.
15) von Gablenz P, Hoffmann E, Holube I. Gender-specific hearing loss in German adults aged 18 to 84 years compared to US-American and current European studies. PLoS One 2020;15:e0231632.
16) Seo YJ, Lee JH, Sagong J. Pure tone threshold of Korean adults with normal hearing by gender and age [Internet]. Daejeon: National Center for Standard Reference Data; 2022 [cited 2023 Oct 23]. Available from: https://doi.org/10.20925/KSRD.66658965.V3.
17) International Organization for Standardization. ISO 1999:2013. Acoustics—Estimation of noise-induced hearing loss. Geneva: International Organization for Standardization;2013. p.1-23.
18) Brännström KJ, Karlsson E, Waechter S, Kastberg T. Extended high-frequency pure tone hearing thresholds and core executive functions. Int J Audiol 2018;57:639-45.
19) Oppitz SJ, Silva LCLD, Garcia MV, Silveira AFD. High-frequency auditory thresholds in normal hearing adults. CoDAS 2018;30: e20170165.
20) Homans NC, Metselaar RM, Dingemanse JG, van der Schroeff MP, Brocaar MP, Wieringa MH, et al. Prevalence of age-related hearing loss, including sex differences, in older adults in a large cohort study. Laryngoscope 2017;127:725-30.
21) Wasano K, Kaga K, Ogawa K. Patterns of hearing changes in women and men from denarians to nonagenarians. Lancet Reg Health West Pac 2021;9:100131.
22) Lopez AD, Murray CC. The global burden of disease, 1990-2020. Nat Med 1998;4:1241-3.
23) GBD 2019 Hearing Loss Collaborators. Hearing loss prevalence and years lived with disability, 1990-2019: findings from the Global Burden of Disease Study 2019. Lancet 2021;397:996-1009.
24) Roberts J, Ahuja EM. Hearing levels of youths 12–17 years, United States. 11th ed. Washington, DC: U.S. Government Publishing Office; 1975.
25) Richardson K, Peckham CS, Goldstein H. Hearing levels of children tested at 7 and 11 years: a national study. Br J Audiol 1976;10:117-21.
26) Haapaniemi JJ. The hearing threshold levels of children at school age. Ear Hear 1996;17:469-77.
27) Beahan N, Kei J, Driscoll C, Forde R, Le Dilly M, Charles B. High frequency pure tone audiometry (8-16 kHz) in children: a normative study. Aust N Z J Audiol 2009;31:33-43.
28) Wattamwar K, Qian ZJ, Otter J, Leskowitz MJ, Caruana FF, Siedlecki B, et al. Increases in the rate of age-related hearing loss in the older old. JAMA Otolaryngol Head Neck Surg 2017;143:41-5.
29) Wasano K, Nakagawa T, Ogawa K. Prevalence of hearing impairment by age: 2nd to 10th decades of life. Biomedicines 2022;10:1431.
30) International Organization for Standardization. ISO 389-3:2016. Acoustics—Reference zero for the calibration of audiometric equipment. Part 3: reference equivalent threshold vibratory force levels for pure tones and bone vibrators. Geneva: International Organization for Standardization;2016. p.1-13.
31) International Electrotechnical Commission. IEC 60318-6:2007. Electroacoustics—Simulators of human head and ear - Part 6: mechanical coupler for the measurement on bone vibrators. Geneva: International Electrotechnical Commision;2007. p.1-15.
32) Nixon JC, Glorig A, High WS. Changes in air and bone conduction

thresholds as a function of age. J Laryngol Otol 1962;76:288-98.
33) Dirks DD, Malmquist CW, Bower DR. Toward the specification of normal bone-conduction threshold. J Acoust Soc Am 1968;43:1237-42.
34) Hallmo P, Sundby A, Mair IW. Extended high-frequency audiometry. Air- and bone-conduction thresholds, age and gender variations. Scand Audiol 1994;23:165-70.
35) Bouzid A, Smeti I, Chakroun A, Loukil S, Gibriel AA, Grati M, et al. CDH23 methylation status and presbycusis risk in elderly women. Front Aging Neurosci 2018;10:241.
36) Hulecki LR, Small SA. Behavioral bone-conduction thresholds for infants with normal hearing. J Am Acad Audiol 2011;22:81-92.
37) Carhart R. Clinical application of bone conduction audiometry. Arch Otolaryngol (1925) 1950;51:798-808.