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TECHNICAL REPORT

Pure-tone air conduction thresholds of Japanese high-school students

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Abstract: This Technical Report describes air conduction hearing thresholds measured for pure tones at conventional audiometric frequencies and extended high frequencies using apparatus and procedure in accordance with relevant ISO and IEC standards. The subjects were otologically normal Japanese high-school students aged 15–17 years. Descriptive statistics of their threshold levels are presented in graphical and tabular forms. Analyses of the measured data showed that the median threshold levels did not significantly deviate from the reference level of 0 dB and that they differed depending on the earphones used: supra-aural or circumaural earphones. These measurement results might be used effectively for revision of ISO 7029:2000, which describes the method for calculating the estimated hearing sensitivity decline as a function of age.

Keywords: Pure-tone audiometry, Air conduction, High-frequency audiometry, Hearing threshold, High-school student, ISO 7029

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1. INTRODUCTION

The method for estimating the expected amount of decline in the hearing sensitivity of otologically normal persons as a function of age is described in ISO 7029 [1]. That estimation can be conducted separately for males and females for audiometric frequencies of 0.125–8 kHz.

Although this international standard has been accepted widely as a reference for audiological evaluations such as the estimation of noise-induced hearing impairment [2], people in recent years have a different auditory profile: they have better hearing ability, particularly males, at high frequencies [3]. In response to the inference above, the ISO/TC 43 (Acoustics)/WG 1 (Threshold of hearing) set up a new project in 2005 to explore the possibility of updating ISO 7029.

The amount of hearing loss in that standard is expressed as the deviation from the average hearing threshold of persons aged 18 years. The threshold at that age was chosen as a reference because the rate of hearing loss increase was zero around that age and then became positive as the age increased [4]. Therefore, we first need to measure the average hearing threshold levels of the people around that age in recent years for determining the reference level. Unfortunately, such measurement data are not abundant in Japan, although large-scale data for people aged 20 years or above have been made public [5,6].

The revision of the ISO standard includes adoption of extended high-frequency audiometry: threshold measurement at frequencies higher than 8 kHz. However, such audiometry has not been conducted widely in Japan, except in pursuit of some medical interests. Measurement data obtained from otologically normal young persons have not been accumulated. Therefore, it is necessary to obtain the threshold level data from young people at frequencies higher than 8 kHz to determine the reference level for the age-related threshold deviation.

This Technical Report presents hearing threshold level data at conventional audiometric frequencies and at extended high frequencies that were measured using standardized apparatus and procedure. The subjects were Japanese high-school students younger than 18 years. The measurement data were analyzed further in relation to the reference zero for the calibration of audiometric equipment and to the earphones used. Those data and analysis results might be useful for revising ISO 7029.

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2. MEASUREMENT METHOD

2.1. Apparatus

The air conduction thresholds for pure tones were measured using an audiometer (UNITY 2; Siemens Audiologische Technik GmbH) with circumaural earphones (HDA 200; Sennheiser Electronic GmbH & Co. KG). The audiometer conformed to the specifications presented in IEC 60645-1 [7] and 60645-4 [8]. The output level of test tones was calibrated in accordance with ISO 389-5 [9] and 389-8 [10] using an artificial ear [Type 4153; Brüel and Kjær (B&K)] with adapters (DB 0843 and YJ 0304; B&K), a microphone (Type 4192; B&K), a preamplifier (Type 2669 L; B&K), and a conditioning amplifier (Type 2690-A-0S1; B&K).

Measurements were conducted in a soundproof room. The background noise level in the room was sufficiently low for threshold measurements; it met the criteria specified in ISO 8253-1 [11].

2.2. Procedure

The pure-tone threshold measurements were conducted for conventional audiometric frequencies (0.125, 0.25, 0.5, 0.75, 1, 1.5, 2, 3, 4, 6, and 8 kHz) and for extended high frequencies (9, 10, 11.2, 12.5, 14, and 16 kHz), using the shortened version of ascending method [11] separately for both ears. The order of measurement, starting with the left or right ear, was changed randomly among listeners. An interrupted tone was used as a test tone, its level being changed by a trained tester in 5 dB steps. Subjects were asked to respond by pushing a button at their hand when they detected a test tone.

Prior to the threshold measurement, otoscopic examination was made for every subject; obstructing wax in the ear canal was removed. In addition, tympanometry and inquiry about difficulties in hearing [12] were conducted to screen the subjects for abnormalities of their hearing.

2.3. Subjects

Fifty-two high-school students (20 males and 32 females) in Tsukuba, Japan participated in the measurement. They were 15–17 years old at the time of measurement in 2006.

3. RESULTS AND DISCUSSION

3.1. Screening of Subjects

Subjects were screened for the otological abnormalities that were measured or reported: (1) a middle ear pressure out of the range of ±50 daPa, (2) extensive exposure to loud sounds in daily life, (3) a history of a severe ear disease or injury, (4) familial hearing loss, (5) self-report of unusual hearing on the measurement day, or (6) an unbalanced threshold between left and right ears at any of the measured

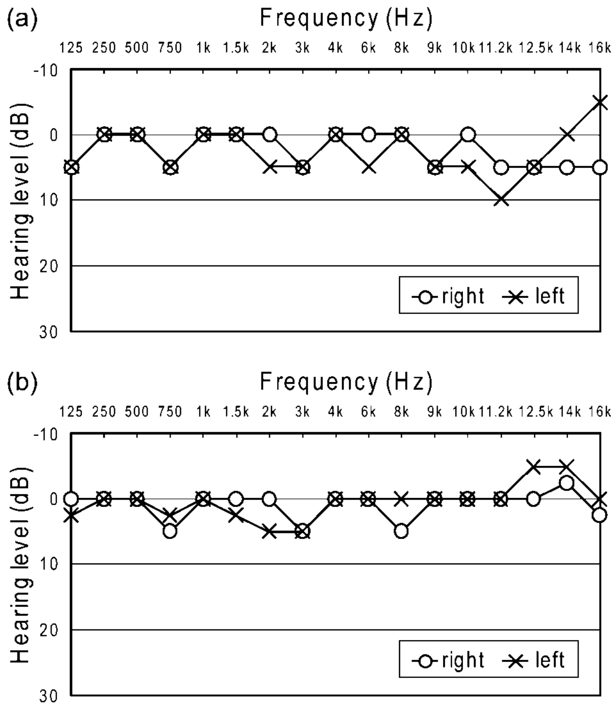

Fig. 1 Median hearing threshold levels of (a) male and (b) female subjects.

frequencies between 0.125–8 kHz, the criterion being a threshold level difference of 25 dB or more.

Nine subjects showed at least one of the hearing abnormalities listed above: two for criterion (1), three for criterion (3), two for criterion (5), and two for criterion (6). Consequently, data taken from 43 subjects (17 males and 26 females) were adopted for the analyses described below.

3.2. Descriptive Statistics of Hearing Threshold Levels

Figure 1 portrays median hearing threshold levels of left and right ears separately for male and female subjects.

Tables 1 and 2 present other data of the threshold distribution of individuals in numerical form for males and females respectively, which are useful for estimating individual differences.

3.3. Deviation from 0 dB

The reference equivalent threshold sound pressure levels for HDA 200 earphones, to which 0 dB of audiometer with earphones of this type is calibrated, are specified in ISO 389-5 [9] and 389-8 [10]. The levels were determined based on hearing thresholds of otologically normal persons aged 18–25 years inclusive. Because the hearing sensitivity decreases with age and because the subjects in this study were younger than 18 years, they are expected to show hearing threshold levels lower than 0 dB, especially at very high frequencies.

A binomial test was performed to examine whether the threshold level at each frequency (Fig. 1) was lower than

Table 1 Statistics of hearing threshold level distribution of male subjects in decibels. Medians are presented graphically in Fig. 1(a).

(a) Left ears

Statistical index	Frequency, Hz										
	125	250	500	750	1,000	1,500	2,000	3,000	4,000	6,000	8,000
P_{10}	0.0	0.0	0.0	0.0	0.0	0.0	−2.0	0.0	−5.0	−5.0	−2.0
P_{25}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−5.0	0.0
P_{75}	5.0	5.0	5.0	5.0	5.0	5.0	5.0	10.0	5.0	5.0	10.0
P_{90}	5.0	5.0	10.0	5.0	5.0	7.0	7.0	10.0	10.0	10.0	12.0
Mean	2.6	2.4	2.4	3.2	1.8	2.6	2.6	4.4	2.4	2.1	3.8
SD	3.0	3.5	4.2	2.9	3.4	4.6	5.5	4.5	4.9	7.1	8.0

	Frequency, Hz					
	9,000	10,000	11,200	12,500	14,000	16,000
P_{10}	−5.0	−2.0	−5.0	−7.0	−5.0	−10.0
P_{25}	0.0	0.0	5.0	0.0	−5.0	−10.0
P_{75}	5.0	10.0	10.0	10.0	5.0	10.0
P_{90}	15.0	14.0	15.0	17.0	18.0	15.0
Mean	5.3	5.0	6.5	5.9	3.8	1.5
SD	7.2	7.7	7.6	12.6	12.5	13.3

(b) Right ears

Statistical index	Frequency, Hz										
	125	250	500	750	1,000	1,500	2,000	3,000	4,000	6,000	8,000
P_{10}	0.0	−5.0	−2.0	0.0	0.0	−5.0	−2.0	0.0	−5.0	−5.0	−5.0
P_{25}	0.0	0.0	0.0	0.0	0.0	−5.0	0.0	0.0	0.0	−5.0	−5.0
P_{75}	5.0	5.0	5.0	5.0	5.0	5.0	0.0	10.0	5.0	5.0	5.0
P_{90}	10.0	7.0	10.0	10.0	5.0	5.0	7.0	10.0	5.0	10.0	7.0
Mean	3.5	2.1	2.4	3.8	2.4	0.9	1.2	4.7	1.2	1.2	0.0
SD	3.7	4.6	4.6	3.6	3.0	4.6	4.0	5.0	4.0	6.3	5.1

	Frequency, Hz					
	9,000	10,000	11,200	12,500	14,000	16,000
P_{10}	−5.0	−5.0	−5.0	−5.0	−7.0	−10.0
P_{25}	0.0	0.0	0.0	0.0	−5.0	−5.0
P_{75}	5.0	10.0	10.0	5.0	15.0	10.0
P_{90}	10.0	10.0	12.0	10.0	24.0	22.0
Mean	3.8	2.9	4.4	3.5	7.4	5.0
SD	6.3	6.9	7.0	7.4	14.4	12.0

P_x: xth percentile, SD: standard deviation.

0 dB. For this test, average thresholds of both ears were calculated for individual subjects. The test results showed that, contrary to expectations, the threshold deviation was not statistically significant ($p > 0.05$) at any frequency for either gender group. Therefore, although some subjects had a threshold lower than 0 dB, the median threshold level of this population of 15–17 years does not differ substantially from the reference zero.

3.4. Effect of Earphones Used

Kurakata *et al.* [13] reported hearing threshold levels of high-school students for conventional audiometric frequencies of 0.125–8 kHz. They used supra-aural earphones (AD-02B; Rion Co., Ltd.), which are widely used in Japan. It has been pointed out that AD-02 (an older model of AD-02B) earphones yield slightly deviated threshold levels even when calibrated according to the standardized method, which is attributable to the sound leakage through the gap between earphone and subject's ear [14].

To examine the effect of earphones used, the threshold level data of this study were compared to those measured in an earlier study [13]. The subjects in those two studies were students of the same high school, but they did not overlap. They were tested with an interval of only three years, using standardized audiometers and the same measurement method. Consequently, both student groups can be regarded as samples from an identical population and they can be mutually compared.

Table 2 Statistics of hearing threshold level distribution of female subjects in decibels. Medians are presented graphically in Fig. 1(b).

(a) Left ears

Statistical index	Frequency, Hz										
	125	250	500	750	1,000	1,500	2,000	3,000	4,000	6,000	8,000
P_{10}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−5.0	−5.0
P_{25}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
P_{75}	5.0	5.0	5.0	5.0	5.0	5.0	5.0	10.0	5.0	5.0	5.0
P_{90}	5.0	7.5	5.0	10.0	5.0	10.0	10.0	12.5	7.5	7.5	10.0
Mean	2.9	1.9	2.5	3.5	1.9	3.1	4.0	5.8	2.3	1.9	2.7
SD	3.2	3.9	4.0	4.6	3.7	4.6	4.8	5.7	4.0	5.7	5.2

	Frequency, Hz					
	9,000	10,000	11,200	12,500	14,000	16,000
P_{10}	−5.0	−5.0	−5.0	−7.5	−10.0	−10.0
P_{25}	0.0	−5.0	0.0	−5.0	−8.8	−5.0
P_{75}	5.0	5.0	5.0	5.0	0.0	8.8
P_{90}	10.0	5.0	10.0	7.5	10.0	20.0
Mean	2.5	0.8	2.5	−1.2	−1.9	4.0
SD	6.1	6.3	5.9	6.5	7.2	12.1

(b) Right ears

Statistical index	Frequency, Hz										
	125	250	500	750	1,000	1,500	2,000	3,000	4,000	6,000	8,000
P_{10}	0.0	0.0	−2.5	0.0	0.0	−5.0	0.0	0.0	−5.0	−5.0	−5.0
P_{25}	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	−3.8	−5.0	0.0
P_{75}	5.0	3.8	5.0	5.0	5.0	5.0	5.0	10.0	5.0	0.0	5.0
P_{90}	5.0	7.5	5.0	7.5	7.5	7.5	10.0	10.0	5.0	5.0	5.0
Mean	2.1	1.9	2.1	3.8	3.1	1.9	2.7	4.4	1.2	−1.2	2.1
SD	4.0	4.2	5.7	4.0	4.8	4.6	4.6	4.9	4.7	4.5	5.0

	Frequency, Hz					
	9,000	10,000	11,200	12,500	14,000	16,000
P_{10}	−5.0	−5.0	−5.0	−7.5	−10.0	−10.0
P_{25}	0.0	−5.0	0.0	−5.0	−5.0	−8.8
P_{75}	8.8	5.0	5.0	3.8	5.0	13.8
P_{90}	10.0	7.5	10.0	5.0	12.5	15.0
Mean	2.9	0.8	1.9	−0.4	0.2	4.2
SD	6.1	5.5	5.7	5.4	9.9	13.5

P_x: xth percentile, SD: standard deviation.

Figure 2 shows the hearing threshold levels of the two studies. Median thresholds of both ear averages are compared separately for male and female subjects. Since the threshold data of the age band from 15 to 19 years were grouped together in the previous study [13], median thresholds for subjects aged 15–17 years were recalculated for comparison.

Assuming the normality of individual-threshold distribution, the two sets of measurement data in the figure were analyzed using a $2 \times 7 \times 2$ (earphone $\times$ test frequency $\times$ gender) analysis of variance (ANOVA) with a statistical software package (SPSS Statistics 17.0 J for Windows; SPSS Japan Inc.). The ANOVA results showed that the main effect of earphones was statistically significant [$F(1,68) = 5.20$, $p < 0.05$]. The effect of test frequencies was significant, but that of gender was not [$F(6,408) = 12.8$, $p < 0.01$; $F(1,68) = 1.42$, $p > 0.05$, respectively]. Furthermore, a significant two-way (earphone $\times$ test frequency) interaction was obtained [$F(6,408) = 10.4$, $p < 0.01$]. Consequently, the earphones of two types (AD-02B and HDA 200) yielded different threshold levels, which were frequency-dependent and free from the gender effect. Hearing threshold data measured using those earphones cannot be combined; they should be analyzed separately.

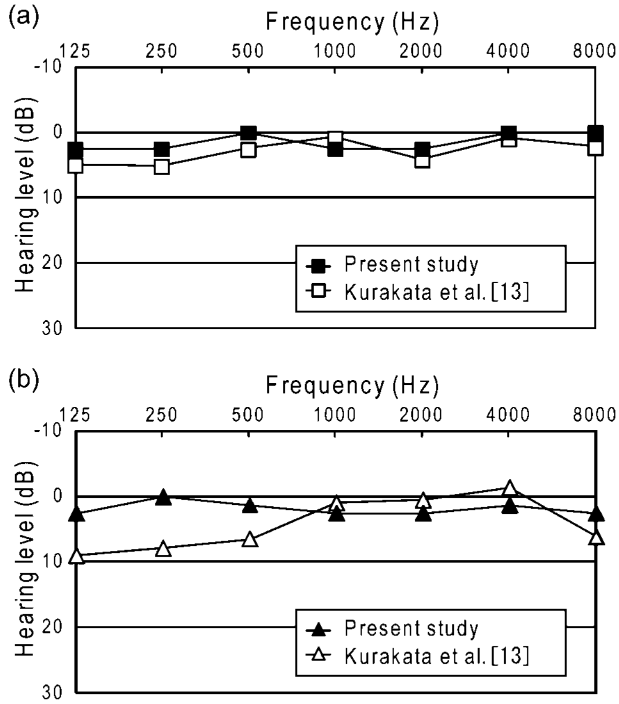

Fig. 2 Comparison of hearing threshold levels measured using circumaural earphones (present study) and supra-aural earphones [13] for (a) male and (b) female subjects.

4. CONCLUSIONS

For revising ISO 7029, hearing threshold levels of otologically normal young subjects of 15–17 years old were measured for conventional audiometric frequencies and extended high frequencies using standardized apparatus and procedure. The results of measurements showed that their threshold levels did not deviate significantly from the reference level of 0 dB. Therefore, the hearing threshold level at the age of 18 years, as adopted in the current edition of ISO 7029, serves as a good reference to illustrate the age-related decline of hearing sensitivity.

Furthermore, the results of this study showed that hearing threshold levels differed depending on the earphones used, i.e. supra-aural or circumaural earphones, even when they had been properly calibrated according to the standard procedure. Therefore, it would be more reliable to calculate a threshold value *relative* to a reference level, not as an *absolute* value, when combining audiometric data that were measured in separate studies.

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REFERENCES

[1] ISO 7029, *Acoustics — Statistical distribution of hearing thresholds as a function of age* (International Organization for Standardization, Geneva, 2000).
[2] ISO 1999, *Acoustics — Determination of occupational noise exposure and estimation of noise-induced hearing impairment* (International Organization for Standardization, Geneva, 1990).
[3] K. Kurakata and T. Mizunami, "Reexamination of the age-related hearing sensitivity decrease in ISO 7029: Do the Japanese have better hearing sensitivity?" *Acoust. Sci. & Tech.*, **26**, 381–383 (2005).
[4] D. W. Robinson and G. J. Sutton, "A comparison analysis of data on the relation of pure-tone audiometric thresholds to age," *NPL Acoust. Rep.*, AC 84 (1978).
[5] M. Okamoto, T. Shitara, Y. Momiyama, M. Hirayama and T. Ishii, "Pure-tone hearing levels according to age," *Audiol. Jpn.*, **32**, 81–86 (1989) (in Japanese).
[6] N. Kiritani, H. Inoue, Y. Asano, H. Seki, Y. Honda, Y. Ikeda and K. Doumitsu, "Evaluation of age classified adult hearing level tested by the new JIS standard audiometer —Mean, standard deviation, mode and median—," *Oto-Rhino-Laryngol.*, **35**, 221–228 (1992) (in Japanese).
[7] IEC 60645-1, *Electroacoustics —Audiological Equipment— Part 1: Pure-tone audiometers* (International Electrotechnical Commission, Geneva, 2001).
[8] IEC 60645-4, *Electroacoustics —Audiological Equipment— Part 4: Equipment for extended high-frequency audiometry* (International Electrotechnical Commission, Geneva, 1994).
[9] ISO 389-5, *Acoustics —Reference zero for the calibration of audiometric equipment— Part 5: Reference equivalent threshold sound pressure levels for pure tones in the frequency range 8 kHz to 16 kHz* (International Organization for Standardization, Geneva, 2006).
[10] ISO 389-8, *Acoustics —Reference zero for the calibration of audiometric equipment— Part 8: Reference equivalent threshold sound pressure levels for pure tones and circumaural earphones* (International Organization for Standardization, Geneva, 2004).
[11] ISO 8253-1, *Acoustics —Audiometric test methods— Part 1: Basic pure tone air and bone conduction threshold audiometry* (International Organization for Standardization, Geneva, 1989).
[12] ISO/CD 389-9, *Acoustics —Reference zero for the calibration of audiometric equipment— Part 9: Preferred test conditions for the determination of reference hearing threshold levels* (International Organization for Standardization, Geneva, 2005).
[13] K. Kurakata, T. Mizunami and K. Matsushita, "Pure-tone audiometric thresholds of young and older adults," *Acoust. Sci. & Tech.*, **27**, 114–116 (2006).
[14] T. Mochizuki, Y. Yokoyama and T. Matsuhira, "Comparison between supra- and circum-aural earphones in pure-tone audiometry —test–retest variability and normal hearing threshold levels—," *Otol. Jpn.*, **17**, 209–214 (2007) (in Japanese).