TECHNICAL REPORT

Air conduction hearing thresholds of young and older Japanese adults for pure tones from 125 Hz to 16 kHzKenji Kurakata^{1,*}, Tazu Mizunami¹, Kazuma Matsushita² and Kimio Shiraishi³¹*National Institute of Advanced Industrial Science and Technology (AIST),
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Abstract: This Technical Report presents air conduction hearing thresholds measured for pure tones at conventional audiometric frequencies (CAFs) from 125 Hz to 8 kHz and extended high frequencies (EHFs) from 8 kHz to 16 kHz, using apparatus and procedures in accordance with relevant ISO and IEC standards. The subjects were 490 otologically normal Japanese adults aged 18–83 years. Descriptive statistics of their threshold levels are presented in graphical and tabular forms to show the age-related decline of hearing sensitivity and its individual differences. The change in hearing sensitivity of older adults at CAFs was smaller, in general, than the standard values according to ISO 7029:2000, in which the amount of hearing sensitivity decline is estimated as a function of age. The threshold data presented in this report may serve as a basis for revising the international standard. In addition, measurement results at EHF frequencies revealed that the responses of older subjects could be unreliable at the highest frequencies because of an unwanted sound in a lower frequency region generated with test tone presentation. Threshold values at extended high frequencies should be treated with caution.

Keywords: Extended high-frequency audiometry, Pure-tone audiometry, Air conduction, Hearing threshold, Aging effect, ISO 7029

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1. INTRODUCTION

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

The ISO standard has been under revision since 2005. This revision aims at (1) adopting recent hearing threshold data at conventional audiometric frequencies (CAFs) from 125 Hz to 8 kHz, (2) extending the age limit of threshold estimation to over 70 years, and (3) inclusion of threshold estimation at extended high frequencies (EHFs) of 8 kHz and higher.

The authors [2] have reported pure-tone audiometric thresholds of young and older Japanese adults in the revision work. They measured hearing thresholds at CAFs for 291 otologically normal persons aged 15 years to 80

years and older using supra-aural earphones. They then started another project to measure thresholds at EHF frequencies because such data had been scarce in Japan.

In the standardized EHF audiometry, circumaural earphones are used. Because supra-aural earphones and circumaural earphones yield slightly different threshold values [3,4], the authors measured hearing threshold levels at CAFs, in addition to those at EHF frequencies, using circumaural earphones for the same subjects.

This Technical Report presents hearing threshold level data at CAFs and EHF frequencies that were measured using standardized apparatus and procedures. The subjects were otologically normal Japanese adults aged 18 years and older. These data and analysis results are expected to be used effectively for revising ISO 7029.

2. MEASUREMENT METHOD

2.1. Apparatus

The air conduction thresholds for pure tones were measured using a commercially available, manual audio-

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meter (UNITY 2; Siemens Audiologische Technik GmbH) or a computer-controlled audiometer that the authors previously developed. The latter was introduced to improve measurement efficiency and reduce measurement biases that human testers might have. Both audiometers conformed to the specifications for test signals described in IEC 60645-1 [5] and 60645-4 [6].

Test tones were presented to subjects via circumaural earphones (HDA 200; Sennheiser Electronic GmbH & Co. KG). The output level of test tones was calibrated in accordance with ISO 389-5 [7] and 389-8 [8] 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 [9].

2.2. Procedure

When the UNITY 2 audiometer was used, measurements were conducted by a human tester. When the computer-controlled audiometer was used, the threshold was measured automatically by a computer program. The procedure described below was common to both audiometers.

The pure-tone threshold measurement was first conducted for CAFs (0.125, 0.25, 0.5, 0.75, 1, 1.5, 2, 3, 4, 6, and 8 kHz) and then for EHF (9, 10, 11.2, 12.5, 14, and 16 kHz) using the shortened version of the ascending method [9]. Both ears were measured separately for every subject. The order of measurement, starting with the left or right ear, was changed randomly among subjects. An interrupted tone was used as a test tone, the level of which was changed 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 examinations were made of each subject; obstructing wax in the ear canal was removed. In addition, tympanometry and inquiries about hearing difficulties [10] were conducted to screen the subjects for hearing abnormalities.

Measurements were conducted during 2006–2008.

2.3. Subjects

Subjects who participated in the measurements were 554 adults (250 male and 304 female) aged 18–83 years. The numbers of subjects stratified in 10-year age bands are shown in Table 1.

They lived in Tsukuba, Fukuoka, or their neighboring cities in Japan. Subjects in their teens and twenties were students of Tsukuba University or Kyushu University.

Table 1 Numbers of subjects before screening (in parentheses) and after screening.

Age band (yr)	Males		Females	
18–19	12	(15)	7	(9)
20–29	81	(87)	70	(73)
30–39	26	(26)	74	(74)
40–49	24	(24)	65	(65)
50–59	15	(15)	25	(25)
60–69	37	(56)	29	(44)
70–79	14	(26)	10	(14)
80–89	1	(1)	0	0
Total	210	(250)	280	(304)

Other subjects were staff of the authors' affiliations or those who were recruited through public advertisements or introduced by employment agencies. Many of the subjects had previous experience with CAFs' hearing tests, but no experience with EHF tests.

3. RESULTS AND DISCUSSION

3.1. Screening of Subjects

Subjects were screened for 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 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 frequencies between 0.125–8 kHz, the criterion being a threshold level difference of 30 dB or more. Consequently, data obtained for 490 subjects (210 male and 280 female) were adopted for the analyses described below. For the number of subjects in each age band after the screening, see Table 1.

3.2. Effect of Audiometers Used

Two audiometers were used for this study: a manual one and a computer-controlled one. As described in Sect. 2.1, the test signals of both audiometers were calibrated in accordance with relevant standards. However, the difference in threshold recording, namely, whether the thresholds were recorded manually by a human tester looking at the subject's responses, or automatically by a computer program, might have affected the measurement results.

To examine the above effect, a four-way (audiometer $\times$ measurement frequency $\times$ gender $\times$ age band) analysis of variance (ANOVA) was performed using a statistical software package (SPSS Statistics 17.0J for Windows; SPSS Japan Inc.). Data for an 83-year-old male subject were not used because no female counterpart of that age was included in the study. The results of ANOVA

Fig. 1 Median hearing threshold levels of (a) male and (b) female subjects stratified in age bands. Data for an 83-year-old male subject are also shown in panel (a).

confirmed that the main effect of the audiometer was not statistically significant [$F(1,461) = 0.372$, $p > 0.05$]. Therefore, thresholds measured using those audiometers yielded comparable results. The two data sets were combined and subsequently treated as a single set.

3.3. Overview of Hearing Threshold Decline Because of Aging

Figure 1 portrays medians of both-ear average hearing threshold levels of each age group, separately for male and female subjects. The age-related change in hearing sensitivity is observable; the sensitivity decreased as the subject's age increased. The change was greater at high frequencies than at low frequencies. These changes are typically observed in those with presbycusis.

Curves of some older age groups in Fig. 1 show a strange reversal at the highest frequencies, but it was suspected to be an artifact: an unwanted sound in a lower frequency region from the audiometer through the earphones was audible to the subjects when the test tone was presented at a very high level [11]. Subjects retaining good hearing sensitivity at lower frequencies might have detected the sound and responded falsely to it. Therefore, their responses at those frequencies are not reliable. The curves are drawn with dotted lines where more than half

the subjects showed such a strange threshold improvement and the median threshold was contaminated by those unreliable values.

A peak can be seen at 6 kHz for many of the threshold curves in Fig. 1. Han and Poulsen [12] have pointed out that a large variation can be found among threshold data sets at that frequency, which “could be caused by critical geometrical interactions between the individual subjects' ears and the HDA 200 earphone.” The reference equivalent threshold sound pressure level at that frequency specified in ISO 389-8 [8] might be too high for Japanese people in general.

3.4. Individual Differences in Hearing Threshold Levels

Table 2 presents other data of the threshold distribution of individuals in numerical form for males and females, respectively, which are useful for estimating individual differences. Some data at the highest frequencies are questionable on the same grounds as those in Fig. 1 and are written in *italics*. For example, when more than one-fourth of the subjects showed a strange reversal of the threshold curve, the 75th percentile at the frequency was regarded as unreliable.

The variability of the output level among several earphones used was corrected after the threshold measurements. The values in Table 2 are expressed with a precision of 0.1 dB, which is smaller than the measurement step size of 5 dB.

3.5. Comparison with ISO 7029 Thresholds

In an earlier study in which audiometric thresholds in literature were compared with ISO 7029 values [13], the authors pointed out that Japanese people in recent years have better hearing sensitivity than the international standard estimates for the CAF range. The amount of improvement was large, particularly for male subjects, at test frequencies of 4 kHz and 8 kHz.

To examine whether the hearing-ability difference is also observable in the threshold data of the present study, they were compared with the ISO values, as was done in the earlier study. That is, $\Delta H_{md,Y}$, the deviation of median hearing threshold level at the age of Y years from that of the reference age of 18 years, was calculated for the present study data as

$$\Delta H_{md,Y} = \Delta H_{ISO,md,25} + (H_{md,Y} - H_{md,25}),$$

where $\Delta H_{ISO,md,25}$ is the increase in the median hearing threshold level at the age of 25 years from that of the reference age, as calculated according to ISO 7029. In that equation, $H_{md,Y}$ and $H_{md,25}$ respectively represent the median hearing threshold levels of the age band with the center value of Y years and 25 years. The age of 25 years,

Table 2 Data of hearing threshold level distribution of both-ear averages for (a) male and (b) female subjects. P_x , x th percentile; SD, standard deviation.

Values that might be contaminated by false responses of subjects are shown in italics (see text for details). Some statistics were not calculable because thresholds of some subjects “scaled out”; they are denoted as “—.”

(a) Males

Age band (yr)	Frequency (Hz)																											
	125								250								500											
	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	
18–19	–3.6	–2.5	–1.6	–1.3	5.6	8.6	11.0	1.7	5.5	–3.9	–3.2	–2.2	2.3	6.0	9.0	12.0	2.8	5.7	–2.5	–2.5	–0.5	1.9	6.6	10.9	12.4	3.4	5.2	
20–29	–3.8	–2.5	–1.3	1.3	3.8	10.0	11.3	2.0	5.0	–3.8	–3.3	–0.8	1.7	5.5	10.5	13.0	2.7	5.4	–3.5	–2.5	0.0	2.5	7.5	12.5	13.8	3.9	5.9	
30–39	–6.5	–4.0	–1.8	0.0	2.3	4.4	5.3	–0.5	5.4	–5.4	–0.9	0.6	3.7	5.0	5.6	7.2	2.5	4.3	–4.5	–2.6	0.0	2.2	7.4	9.9	10.0	2.9	4.9	
40–49	–5.7	–4.9	0.0	2.1	5.0	5.4	9.6	1.7	5.1	–2.2	–0.2	0.0	3.7	7.5	10.0	11.0	4.3	5.0	–1.5	0.7	5.0	6.8	10.3	13.3	14.8	7.2	4.7	
50–59	0.0	0.7	2.1	5.0	7.5	9.2	10.5	5.3	3.5	–2.5	–0.5	5.6	7.5	10.6	12.5	13.2	7.3	5.0	0.0	1.0	7.5	12.5	16.8	19.0	21.1	11.5	6.9	
60–69	–1.5	–0.5	2.5	6.3	12.5	21.7	26.3	8.5	8.6	–2.4	–1.6	2.5	8.0	15.0	22.2	23.8	9.3	8.9	0.1	2.9	6.5	12.5	18.8	21.8	25.2	12.9	8.3	
70–79	1.2	2.5	4.1	6.9	15.6	20.1	21.8	9.5	7.4	3.0	3.3	4.4	9.0	15.0	21.0	22.1	10.5	6.7	3.9	5.8	9.3	12.5	17.7	23.9	25.4	13.5	6.9	

Age band (yr)	Frequency (Hz)																											
	750								1,000								1,500											
	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	
18–19	–3.9	–2.0	0.8	4.3	9.2	11.1	12.2	4.6	5.8	–3.9	–2.8	–0.4	2.1	8.1	10.6	12.5	3.4	5.6	–3.8	–2.8	–1.8	4.7	10.0	11.0	16.0	5.0	7.7	
20–29	–3.5	–2.2	1.1	4.8	10.0	13.6	16.1	5.6	6.4	–1.7	–1.2	0.8	3.3	8.3	12.1	15.8	5.0	5.6	–4.1	–2.8	0.2	4.7	9.7	13.5	16.0	5.0	5.9	
30–39	–1.1	1.6	5.0	6.9	10.1	11.9	12.5	6.9	4.3	–0.6	0.0	2.0	7.1	10.0	11.6	14.0	6.3	5.0	–0.8	1.5	4.9	6.8	8.7	11.2	12.5	6.6	4.2	
40–49	0.9	1.4	7.3	12.5	13.9	16.8	17.5	10.4	5.3	0.3	2.2	7.5	10.0	13.2	14.8	15.0	9.9	4.8	5.0	5.3	8.7	9.9	12.5	15.8	17.2	10.2	4.4	
50–59	4.3	6.0	10.2	18.9	21.3	24.0	30.7	17.0	9.8	4.2	5.0	8.6	12.5	20.0	22.5	28.7	15.2	9.8	0.8	3.5	7.5	12.5	22.5	25.0	28.7	14.4	10.2	
60–69	3.7	5.3	8.6	15.0	24.8	30.6	35.3	17.0	10.6	0.2	3.1	8.6	13.3	20.8	30.6	42.6	16.3	12.0	2.6	5.1	9.5	13.7	20.0	35.7	51.2	18.2	13.6	
70–79	12.0	12.4	13.9	16.7	21.1	28.2	32.0	18.7	6.9	7.5	8.1	12.1	15.2	21.4	26.5	35.3	18.0	10.2	9.1	12.3	14.7	16.0	23.1	37.4	43.5	19.9	11.2	

Age band (yr)	Frequency (Hz)																											
	2,000								3,000								4,000											
	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	
18–19	–1.9	–0.7	1.3	2.7	7.9	12.6	14.6	4.8	5.7	–2.3	–1.9	0.3	5.4	9.2	9.2	10.3	4.4	4.6	–1.2	–0.6	0.0	2.5	4.7	6.7	6.9	2.5	2.8	
20–29	–3.1	–0.8	1.7	4.7	9.2	14.2	16.7	5.8	5.9	–2.5	–0.9	1.7	4.2	9.2	12.3	14.2	5.1	5.1	–3.2	–2.5	–0.6	1.9	6.9	8.9	9.4	2.7	4.6	
30–39	0.0	0.6	3.3	7.1	10.7	12.4	13.3	6.7	5.4	0.0	0.8	3.0	9.0	14.0	18.7	20.2	8.8	7.1	0.0	0.4	5.0	7.5	10.0	14.4	16.9	7.4	6.2	
40–49	3.3	5.0	7.5	11.0	13.1	17.3	18.3	10.9	4.7	2.8	4.6	7.5	12.8	15.8	21.3	26.6	13.0	7.0	0.8	5.0	7.2	10.0	13.2	16.8	28.2	10.9	7.5	
50–59	4.4	5.0	7.6	13.5	22.5	30.0	30.3	15.7	9.2	7.8	8.0	12.8	15.6	20.0	26.2	33.9	17.5	8.9	8.4	9.0	10.0	12.5	21.9	30.5	40.0	17.9	12.9	
60–69	3.8	5.6	10.5	20.5	24.2	41.0	56.7	21.5	14.8	6.6	7.9	16.7	25.4	32.9	47.2	55.8	26.7	15.1	7.5	16.1	19.4	29.4	42.6	50.7	58.5	30.4	15.8	
70–79	8.9	10.0	11.9	19.2	29.5	44.0	49.3	23.0	13.4	10.7	14.2	15.1	24.8	29.8	42.9	47.5	25.6	13.5	12.0	17.7	20.0	32.8	42.8	50.2	54.4	32.6	15.3	

Age band (yr)	Frequency (Hz)																											
	6,000								8,000								9,000											
	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	
18–19	–8.1	–6.5	–4.6	–2.5	–1.1	2.1	2.3	–2.8	3.5	–4.5	–4.4	–1.4	0.9	4.6	12.3	13.6	2.3	5.9	–3.5	–2.3	–0.2	4.7	7.8	7.8	10.1	4.0	5.0	
20–29	–7.7	–7.5	–5.0	–1.5	1.1	3.6	6.1	–1.3	5.1	–7.0	–4.5	–0.7	1.8	6.8	10.5	10.5	3.0	6.6	–6.0	–4.7	0.0	4.1	6.6	10.3	11.6	3.4	6.1	
30–39	–2.5	–2.4	0.2	4.5	10.1	12.6	14.4	5.4	6.8	0.0	1.6	5.0	7.4	13.2	16.0	20.6	8.3	7.4	–8.0	–6.5	2.2	7.1	10.0	11.7	13.1	5.0	6.6	
40–49	–3.1	–0.1	1.4	7.4	12.5	16.0	32.2	9.4	12.1	6.0	6.7	9.4	10.0	16.9	30.3	36.8	15.3	11.7	–1.7	–1.3	6.5	15.0	18.1	32.8	37.8	14.3	11.8	
50–59	4.5	5.9	10.7	15.0	25.0	36.5	43.3	18.8	12.0	10.4	11.5	14.7	25.0	40.0	42.5	45.0	27.2	13.1	2.7	5.0	14.5	27.5	41.3	56.0	61.3	29.3	19.1	
60–69	11.8	15.1	19.8	24.8	35.0	51.8	57.8	29.5	14.0	15.0	17.8	22.2	35.5	50.0	64.7	65.8	37.7	16.8	14.1	18.2	24.1	44.1	60.3	72.2	76.2	—	—	
70–79	18.1	22.1	28.7	40.4	46.1	53.8	58.4	38.6	12.9	20.1	23.8	35.7	50.5	53.0	62.8	67.0	46.0	15.4	28.4	34.6	48.8	57.8	66.2	68.8	69.7	54.8	14.2	

Age band (yr)	Frequency (Hz)																											
	10,000								11,200								12,500											
	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	
18–19	–6.2	–4.3	–1.2	0.5	2.3	5.3	6.6	0.4	4.2	–9.0	–8.2	–6.2	–0.8	0.8	5.1	5.5	–2.1	4.9	–6.2	–5.5	–4.5	0.9	6.0	6.9	8.6	1.0	5.7	
20–29	–7.1	–5.8	–2.1	1.7	5.5	10.5	15.5	2.3	7.3	–7.0	–5.0	0.5	1.8	5.0	9.3	11.8	2.7	7.0	–6.9	–4.4	–1.9	2.5	6.9	10.7	24.4	4.2	9.9	
30–39	–3.0	–1.5	0.9	6.0	9.8	12.9	13.8	5.8	6.0	–8.8	–4.7	–0.6	4.6	11.9	19.1	31.0	6.6	12.4	–4.0	–2.8	3.1	11.5	20.6	31.3	36.3	13.1	13.4	
40–49	3.2	5.0	6.7	12.3	23.2	35.0	47.0	17.1	13.8	–9.3	–5.0	6.2	12.5	35.1	45.0	52.0	18.0	18.8	5.4	7.8	16.5	27.5	41.9	53.6	59.2	30.1	17.4	
50–59	13.2	15.4	22.7	40.0	48.8	58.0	60.1	37.1	16.2	10.2	19.6	26.3	51.6	61.3	67.2	67.5	44.3	21.5	27.8	39.5	55.1	67.5	70.0	72.5	74.0	59.2	17.4	
60–69	20.9	22.5	31.7	50.5	62.5	77.4	80.5	—	—	28.6	35.1	48.0	63.0	70.8	80.5	81.1	—	—	55.5	57.6	65.9	73.4	75.9	77.1	—	—	—	
70–79	30.0	41.1	61.9	65.5	69.5	70.5	71.6	60.6	14.4	54.1	66.5	69.5	71.1	74.4	76.7	78.5	69.4	10.9	63.0	66.2	71.6	72.5	74.5	75.7	76.3	71.8	4.4	

Age band (yr)	Frequency (Hz)																											
	14,000								16,000																			
	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD	P ₅	P ₁₀	P ₂₅	Median	P ₇₅	P ₉₀	P ₉₅	Mean	SD										
18–19	–8.9	–8.2	–7.1	–1.4	1.4	7.7	8.5	–1.3	6.0	–17.3	–14.4	–7.4	–3.4	5.7	18.1	19.0	–0.6	12.2										
20–29	–9.6	–8.3	–3.3	2.5	10.5	20.5	29.2	5.7	13.7	–10.3	–7.8	–1.2	12.6	23.5	34.7	39.4	12.1	16.0										
30–39	–9.4	–2.5	6.1	24.6	35.0	41.4	44.1	21.1	18.0	–3.7	5.0	16.2	30.7	34.7	41.3	42.4	25.1	13.7										
40–49	15.1	30.0	34.6	41.9	54.7	57.3	57.5	42.6	13.8	32.0	32.3	35.4	40.4	42.5	46.2	49.5	39.6	6.4										
50–59	38.2	49.6	57.5	62.1	65.0	—	—	—	—	35.8	38.0	43.0	46.7	—	—	—	—	—										
60–69	55.9	57.6	61.5	65.4	67.5	—	—	—	—	42.6	44.3	47.5	49.4	—	—	—	—	—										
70–79	55.1	58.0	63.7	65.7	67.5	—	—	—	—	43.0	44.6	50.2	51.1	—	—	—	—	—										

(b) Females

Age band (yr)	Frequency (Hz)																											
	125									250									500									
	<i>P</i> ₅	<i>P</i> ₁₀	<i>P</i> ₂₅	Median	<i>P</i> ₇₅	<i>P</i> ₉₀	<i>P</i> ₉₅	Mean	SD	<i>P</i> ₅	<i>P</i> ₁₀	<i>P</i> ₂₅	Median	<i>P</i> ₇₅	<i>P</i> ₉₀	<i>P</i> ₉₅	Mean	SD	<i>P</i> ₅	<i>P</i> ₁₀	<i>P</i> ₂₅	Median	<i>P</i> ₇₅	<i>P</i> ₉₀	<i>P</i> ₉₅	Mean	SD	
18–19	−5.1	−4.0	−1.3	0.0	6.3	7.5	7.5	1.6	4.9	−4.8	−3.8	−2.5	−0.8	2.3	6.2	7.7	0.3	4.6	−2.1	−1.8	−0.6	0.0	2.0	6.8	9.0	1.6	4.3	
20–29	−9.6	−5.3	−2.5	0.0	5.0	10.1	12.8	1.3	6.7	−6.8	−4.8	−2.1	1.7	5.5	10.0	15.2	2.3	6.2	−3.9	−3.3	−0.9	3.8	8.8	13.8	14.4	4.5	6.5	
30–39	−5.9	−5.0	−0.9	1.7	5.3	7.2	7.9	1.7	5.0	−5.0	−1.8	0.0	3.7	5.0	8.3	10.4	3.2	4.8	−4.6	−2.9	0.0	3.3	9.9	13.3	13.7	4.7	6.3	
40–49	−6.1	−4.6	−0.9	1.7	5.0	5.4	7.3	1.4	4.3	−4.1	−2.8	0.0	3.7	5.0	7.5	10.0	3.4	4.1	−2.5	−1.5	0.0	5.0	7.7	13.2	14.9	4.9	5.7	
50–59	−3.7	0.0	1.7	2.9	6.7	7.7	10.9	3.5	4.2	−3.5	−1.5	2.5	5.0	6.2	10.0	10.0	4.1	4.0	−2.0	1.0	4.7	9.9	11.2	12.4	12.5	7.3	5.0	
60–69	−5.5	0.5	2.5	7.5	13.8	19.3	22.0	8.4	8.1	0.1	0.2	4.2	9.2	18.0	20.7	24.0	10.8	8.2	5.5	6.3	10.0	13.8	16.9	22.5	27.0	14.2	8.0	
70–79	2.9	4.6	5.9	11.9	15.0	20.0	20.0	11.4	6.2	4.8	5.3	6.9	12.1	17.3	19.3	22.2	12.6	6.6	7.9	9.6	13.1	15.6	18.1	22.6	26.3	16.2	6.2	

Age band (yr)	Frequency (Hz)																											
	750									1,000									1,500									
	<i>P</i> ₅	<i>P</i> ₁₀	<i>P</i> ₂₅	Median	<i>P</i> ₇₅	<i>P</i> ₉₀	<i>P</i> ₉₅	Mean	SD	<i>P</i> ₅	<i>P</i> ₁₀	<i>P</i> ₂₅	Median	<i>P</i> ₇₅	<i>P</i> ₉₀	<i>P</i> ₉₅	Mean	SD	<i>P</i> ₅	<i>P</i> ₁₀	<i>P</i> ₂₅	Median	<i>P</i> ₇₅	<i>P</i> ₉₀	<i>P</i> ₉₅	Mean	SD	
18–19	−1.0	−0.6	0.5	2.3	6.2	10.8	13.4	4.3	5.5	−2.5	−2.5	−2.5	2.6	9.6	11.8	12.6	3.9	6.3	−2.7	−2.6	−1.4	2.2	3.0	6.0	7.8	1.8	4.0	
20–29	−2.5	−2.0	2.9	6.1	12.0	15.4	16.9	7.2	6.4	−2.5	−0.6	2.2	7.3	12.1	14.6	18.3	7.2	6.2	−0.7	−0.3	2.6	8.5	12.0	13.5	17.9	7.6	5.8	
30–39	0.0	1.4	4.4	6.9	12.5	16.0	17.6	7.9	5.7	−2.2	0.0	2.5	6.8	9.9	14.1	15.7	6.6	5.5	1.8	2.5	6.2	7.5	9.9	12.5	14.1	8.0	4.1	
40–49	−0.3	1.5	5.0	8.6	12.5	16.4	18.6	8.9	5.7	0.5	2.5	5.0	7.5	10.0	14.0	17.5	7.9	5.3	2.5	2.6	5.0	8.7	10.0	15.0	17.5	8.9	4.7	
50–59	2.5	3.5	8.1	11.4	15.1	18.3	19.8	11.5	5.5	3.0	5.2	9.2	10.0	13.2	14.5	14.9	10.2	4.0	2.5	2.5	5.0	9.9	13.7	15.7	17.2	10.0	6.4	
60–69	6.9	8.8	13.6	15.0	21.1	26.9	28.1	16.9	9.0	5.7	9.1	12.1	17.1	20.0	27.7	28.5	17.0	9.6	8.7	11.0	12.2	19.7	26.0	32.5	36.8	20.8	10.8	
70–79	7.5	7.5	12.5	24.2	27.0	29.8	29.9	20.7	8.5	7.5	7.5	15.5	25.0	26.7	32.9	36.9	22.6	10.0	12.3	14.5	18.5	21.7	26.0	31.2	32.3	21.9	6.8	

Age band (yr)	Frequency (Hz)																											
	2,000									3,000									4,000									
	P_5	P_{10}	P_{25}	Median	P_{75}	P_{90}	P_{95}	Mean	SD	P_5	P_{10}	P_{25}	Median	P_{75}	P_{90}	P_{95}	Mean	SD	P_5	P_{10}	P_{25}	Median	P_{75}	P_{90}	P_{95}	Mean	SD	
18–19	−2.3	−1.3	0.0	1.7	3.3	7.4	10.2	2.6	4.7	−4.3	−3.5	−1.1	1.7	2.9	7.4	10.8	2.1	5.6	−4.4	−3.9	−3.2	−1.9	1.6	5.6	7.5	−0.1	4.6	
20–29	−1.0	0.0	3.0	8.2	12.1	16.1	17.6	8.1	6.2	−0.4	0.4	2.6	6.7	10.4	15.4	15.6	7.0	5.8	−3.8	−1.9	0.4	4.4	6.8	8.2	11.0	3.5	5.3	
30–39	0.0	1.4	5.0	8.5	12.3	14.6	17.3	8.5	5.2	0.0	2.7	6.8	11.8	14.3	15.6	16.0	10.2	5.2	−2.5	−0.2	2.5	6.9	10.0	12.6	15.5	6.5	5.8	
40–49	0.0	4.2	7.3	9.8	13.5	17.5	21.7	10.4	6.2	2.5	5.0	6.8	10.0	15.0	18.1	19.6	10.6	6.1	0.0	0.0	5.0	7.6	10.1	14.6	19.5	8.1	6.2	
50–59	1.0	6.0	9.8	12.5	17.3	20.5	25.3	13.3	7.0	7.5	8.5	11.8	16.8	17.5	18.8	25.9	15.5	5.6	5.3	6.8	7.6	12.5	17.6	21.5	22.5	13.2	7.2	
60–69	11.2	14.2	16.7	23.0	29.7	34.0	44.7	24.0	10.3	8.4	10.2	15.4	24.2	30.0	32.2	34.2	23.0	9.5	5.6	9.1	10.6	24.4	30.0	35.4	38.4	21.9	10.9	
70–79	19.1	20.2	21.0	22.5	26.4	29.5	31.0	24.0	4.2	14.0	18.9	20.9	24.8	37.0	40.8	44.1	27.9	10.9	17.3	21.6	23.3	25.6	40.9	44.0	50.8	31.5	12.5	

Age band (yr)	Frequency (Hz)																											
	6,000									8,000									9,000									
	P_5	P_{10}	P_{25}	Median	P_{75}	P_{90}	P_{95}	Mean	SD	P_5	P_{10}	P_{25}	Median	P_{75}	P_{90}	P_{95}	Mean	SD	P_5	P_{10}	P_{25}	Median	P_{75}	P_{90}	P_{95}	Mean	SD	
18–19	−12.3	−12.0	−10.2	−7.5	−6.4	0.3	4.4	−6.4	6.5	−6.8	−5.3	−3.3	−2.5	10.3	13.5	13.9	2.5	8.3	−9.6	−8.1	−4.1	2.5	7.7	10.8	11.2	1.4	7.8	
20–29	−6.5	−4.1	−2.7	−0.1	4.6	7.3	13.3	1.3	5.8	−2.0	−0.8	0.6	4.3	9.3	12.3	14.5	5.5	6.9	−6.7	−2.2	1.6	5.3	7.8	11.7	13.5	5.5	8.2	
30–39	−5.0	−3.3	0.0	2.7	9.7	13.9	15.1	4.3	6.5	−0.7	0.0	2.2	6.0	10.7	17.2	19.0	7.2	6.9	−6.7	−4.2	−0.8	4.6	7.5	15.0	22.6	4.9	8.5	
40–49	−2.5	0.0	1.4	5.2	10.0	16.5	17.5	6.6	6.7	−0.2	1.5	5.0	9.7	13.5	22.2	24.5	10.8	8.4	−5.4	−4.2	0.8	7.5	20.0	27.5	36.5	10.7	12.9	
50–59	4.1	5.0	5.2	11.4	17.5	26.5	29.6	12.9	8.7	5.4	7.3	11.0	17.5	27.5	32.8	34.9	19.1	10.6	3.4	7.1	10.0	18.3	28.3	39.5	46.2	20.6	13.8	
60–69	12.1	18.6	21.1	27.3	37.5	42.6	43.6	28.2	10.8	16.3	23.3	30.5	44.2	56.3	57.8	61.0	41.9	15.2	20.3	21.3	34.1	50.3	57.5	64.8	68.8	45.2	17.4	
70–79	21.0	22.1	30.1	33.7	49.5	58.5	63.0	39.4	14.9	38.2	39.7	46.6	55.9	66.4	73.3	76.6	56.7	13.5	43.4	48.0	51.6	62.7	76.3	82.8	83.9	63.4	14.9	

Age band (yr)	Frequency (Hz)																											
	10,000									11,200									12,500									
	P_5	P_{10}	P_{25}	Median	P_{75}	P_{90}	P_{95}	Mean	SD	P_5	P_{10}	P_{25}	Median	P_{75}	P_{90}	P_{95}	Mean	SD	P_5	P_{10}	P_{25}	Median	P_{75}	P_{90}	P_{95}	Mean	SD	
18–19	−12.2	−10.5	−5.8	0.0	5.2	10.0	13.3	0.3	9.3	−2.9	−2.5	−1.0	2.5	6.8	16.0	20.1	5.0	8.9	−4.8	−4.6	−4.4	−1.9	10.3	19.2	19.9	3.7	10.2	
20–29	−5.8	−3.5	−2.1	1.7	5.5	10.5	14.3	3.1	9.2	−8.9	−6.6	−1.7	1.8	5.5	14.3	20.5	3.9	11.3	−6.7	−5.3	−3.1	1.5	5.7	14.4	19.0	3.2	10.7	
30–39	−0.9	−0.6	1.7	5.4	12.3	20.3	28.4	8.4	10.1	−11.1	−8.2	−3.1	5.2	14.8	24.1	29.1	7.6	14.0	−5.1	−4.0	1.3	9.1	22.4	36.0	40.4	13.5	15.8	
40–49	−0.7	1.7	5.0	11.7	21.7	35.2	44.0	15.1	13.2	−7.6	−4.6	7.8	20.0	29.1	45.9	53.7	—	—	−0.2	2.9	14.8	30.0	47.3	57.5	65.0	—	—	
50–59	5.5	9.5	21.7	25.0	41.7	49.2	51.4	29.4	14.9	15.5	17.5	25.0	40.3	51.6	59.9	63.6	39.0	16.1	14.3	25.4	42.5	58.0	65.0	69.2	72.0	51.5	18.0	
60–69	24.5	29.7	43.0	56.7	63.7	69.0	72.2	51.6	16.0	42.3	49.8	57.0	60.5	72.3	76.8	79.6	63.7	11.5	51.9	59.6	65.9	72.2	75.2	76.9	78.8	—	—	
70–79	54.2	54.2	57.0	67.3	72.5	75.5	77.8	65.8	9.1	64.9	66.6	67.7	75.6	77.5	78.3	81.6	73.6	6.3	68.0	70.8	72.3	76.0	79.4	—	—	—	—

Fig. 2 Median hearing threshold level deviations in the present study and those from ISO 7029 [1]: (a) male subjects, (b) female subjects.

the center value of the age band of 20–29 years, was chosen because the number of subjects in that band was large (Table 1). Its threshold value was regarded to be the most reliable as a baseline.

On the other hand, the deviation of the median hearing threshold level at the age of Y years from that of the reference age of 18 years, $\Delta H_{\text{ISO},\text{md},Y}$, was calculated by the method described in the ISO standard.

All variables used in the calculation above are a function of the test tone frequency f , but the f parameter was omitted for simplicity. $\Delta H_{\text{md},Y}$ at 750 Hz was not used for comparison because the international standard did not allow direct calculation of $\Delta H_{\text{ISO},\text{md},Y}$ at that frequency.

Figure 2 presents the values of $\Delta H_{\text{md},Y}$ and $\Delta H_{\text{ISO},\text{md},Y}$ for some selected ages. Although some variation can be found depending on gender, frequency, and age, the results support the findings of the previous study. Therefore, we may conclude that the Japanese people retain better hearing ability than the ISO 7029 estimates and that the standard should be revised on the basis of the latest audiometric data such as those obtained through this study.

4. CONCLUSIONS

Hearing threshold levels of otologically normal sub-

jects aged 18 years and older were measured for CAFs and EHF using standardized apparatus and procedures.

The measurement results at CAFs confirmed that the median hearing threshold levels of Japanese adults, particularly males, were lower than the values described in ISO 7029. Japanese men retain better hearing sensitivity than did people in the past. These measurement results might serve as a basis for revising the international standard.

At frequencies of 12.5–16 kHz, the subjects' responses were apparently adversely affected by an unwanted sound from the audiometers used. The threshold data at those frequencies are not reliable and should therefore be regarded with caution in the revision work.

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