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Basic Study on Evaluation of Earphone Hearing Loss
- Audiogram database for ear age estimation -

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ABSTRACT [1]

Audiograms indicate expected ear age when used in studies that address the prevention of deafness resulting from earphone use. So far, the authors have collected data from Japan and other countries, statistically integrated them, and evaluated errors. While a Caucasian population was sampled in a previous study, a Japanese sample was considered in the present study.

The present study refers to the simplest modeling example of an audiogram, which is confirmed to be in good agreement with the actual situation. The gender gap of Japanese people was smaller than that of Caucasians. Furthermore, Japanese and Caucasian females were less likely to have deafness than males, and hearing capabilities of males varied more than that of females. The hearing of young people falls near 3000 Hz as a result of the integration, but it is considered that the graph around the region should be interpolated smoothly.

Improving the modeling accuracy would let us understand various things.

Keywords: FFT analysis, 1/*f* characteristics, Natural sounds environment, Statistic analysis, 3000 Hz.

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1. INTRODUCTION

Our laboratory has conducted research on the prevention of deafness resulting from earphone use [1,4]. The mechanism of deafness needs to be elucidated to establish a method to predict hearing function, an indicator of ear health. If the frequencies of sound that cause hearing loss can be predicted in advance, one will be able to take good care of your hearing, which is a consumable item.

Audiograms indicate one's ear health [1]. Our research group has collected audiograms from Japanese, Spanish, American and Dutch populations; however, each audiogram differs depending on the sound source and listener. Therefore, the authors evaluated the error between the audiograms [2,3].

In this study, 19 audiograms obtained from Japanese participants were analyzed. The simplest modeling of audiogram is proposed and referenced for consideration.

2. MODELING OF AUDIOGRAM

Essential Meaning of Audiogram

An audiogram is a graph which describes the extent to which each sound frequency is audible to participants of different age groups [1-3]; each participant has a unique audiogram. The graphs corresponding to younger ages than the current age indicate how much sound energy a participant has been exposed and how many hair follicles have been destroyed as a result. The graphs for older than the current age provide an estimate of how much sound energy a participant can perceive and predict many hair follicles will be destroyed as a result.

The ultimate goal of the earphone deafness prevention research conducted by our laboratory is to model this audiogram and propose a method for appropriately determining the parameters in it. Detailed modeling is a topic for the future, and here the simplest model is shown as a starting point.

Hypothesis about Sound Environment

The sounds present in the natural environment display $1/f$ characteristics [6], meaning that the soundwave volume decreases as the frequency increases. There is a qualitative view that the pleasing sounds in music also belong to this $1/f$ spectrum [7]. As for why these sounds are pleasing, it stands to reason that as human beings evolved and developed in nature, we are comfortable with natural sounds.

The definition of $1/f$ characteristic waveforms is vague; the frequency f and the amplitude A have characteristics that resemble a constant product relationship. These waveforms are sometimes described graphically with a logarithmic frequency on the X-axis and intensity on the Y-axis as shown in Eq. (1), and sometimes graphed with a logarithmic intensity on the Y-axis as shown in Eq. (2).

$$\log A \propto \frac{1}{\log f} \quad \cdots\cdots \quad (1)$$

$$A \propto \frac{1}{\log f} \quad \cdots\cdots \quad (2)$$

The Fast Fourier Transform (FFT) analyses of the actual sounds in nature suggests that many of them display characteristics close to Eq. (1) and that others close to Eq. (2). In this study, the $1/f$ characteristic is regarded as that which is between these two, or a combination of both Eq. 1 and Eq. 2 characteristics.

Estimating Audiogram

It is thought that the more you listen to a sound, the more the sound energy reaches your ears, which mechanically stresses structures in the ear and can contribute to hearing loss; however, more research is needed to consider various real life factors in detail.

In the event that soundwaves exhibit the $1/f$ characteristic represented by the Eq. (1), the sound energy flux Φ_1 [1] is calculated according to Eq. (3).

$$\Phi_1 \propto A^2 f^2 = (f_{200kHz})^2 \quad \cdots\cdots \quad (3)$$

Here, we assumed that the proportional coefficient in Eq. (1) is equal to f_{200kHz}. Since the sound energy flux Φ_1 is constant, deafness proceeds equally regardless of the frequency. On the other hand, in reality, the higher the frequency of the sound, earlier the sound becomes inaudible. This fact suggests that the sound heard on a daily basis does not have the $1/f$ characteristic as expressed by Eq. (1).

On the other hand, when the sound exhibits the $1/f$ characteristic as represented by Eq. (2), the sound energy flux Φ_2 follows Eq. (4).

$$\Phi_2 \propto A^2 f^2 = (f_{200kHz})^2 \left(\frac{f}{\log f} \right)^2 \quad \cdots\cdots \quad (4)$$

Here, it is assumed that the proportional coefficient a in Eq. (2) is also equal to f_{200kHz}.

Our research group proposes that the sound energy flux Φ that reaches the human ear is the linear sum of Φ_1 and Φ_2. It may be the case in nature, or because of living in human society. The mixing ratio of Φ_1 and Φ_2 can be written as $1:c$. Assuming that $c = 10$, Φ can be calculated as shown in Eq. (5).

$$\Phi = \frac{\Phi_1 + 10\Phi_{10}}{11} \propto (f_{200kHz})^2 \frac{1 + 10\left(\frac{f}{\log f} \right)^2}{11} \quad (5)$$

The hair follicles, which detect each soundwave frequency, are destroyed over time according to the constant Φ from each soundwave. That is, $D(t)$, calculated by Eq. (5'), demonstrates an audiogram-like curve.

$$D = -\Phi = -\frac{(f_{200kHz})^2}{10^8} \frac{1 + 10\left(\frac{f}{\log f} \right)^2}{11} \quad \cdots \quad (5')$$

Here, let 10^{-8} is set as the proportionality coefficient in Eqs. (3) and (4).

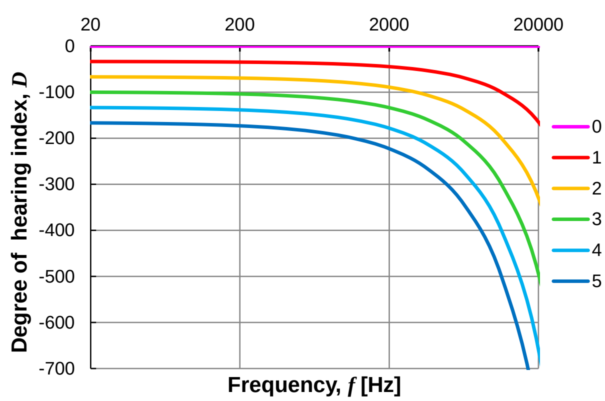


Fig. 1: Audiogram based on a simple deafness model.

Based on Eq. (5'), $D(t)$ when t = 0, 1, 2, 3, 4, and 5 are calculated as shown in Fig. 1. However, it does not account for differences in the ability of an individual's hair follicles to resist destruction based on age and genetic factors. Interestingly, the results produce a curve which matches the audiogram well.

3. ANALYSES OF AUDIOGRAMS FOR A JAPANESE SAMPLE

Analysis Target

Audiograms obtained from 19 Japanese participants were integrated and statistically analyzed by gender. The data contained the 18 audiograms, introduced in the previous report [2], and one [5] of the newly added audiograms, which examined a large number of participants. Mixed-gender audiograms were excluded from analysis, but will be considered when discussing differences in audiograms between ethnic groups in hearing in a later study.

"The audiogram Nos." described in Table 1 refer to a previous study [2]. In addition, three reference audiograms for Spanish, American, and Dutch are given in the previous study [2].

Integration and Analysis Results

Table 1 lists the results of the data analyses according to gender. Since the original data was not published, a method of reading and processing the audiogram data was adopted. The hearing level (HR) varies depending on the standard. Therefore, each audiogram was corrected for the hearing level (HR) and integrated to fit the other audiograms. Although the possibility cannot be ruled out that some data may include results from unhealthy individuals, all data were considered here as data from healthy individuals. The details on the method of integration, statistical processing, and the content structuring of Table 1, were based on a previous report [3].

Figs. 2 a) and b) show the average audiogram results according to gender. The variance is shown in Fig. 1. The scale of the vertical line which demonstrates the variation in Figs. 1 and 2 is marked at positions $\pm 1\sigma$, $\pm 2\sigma$, and $\pm 3\sigma$ from the mean, where σ indicates 'standard deviation.' The probability that the true average value would be within $\pm 1\sigma$, $\pm 2\sigma$, and $\pm 3\sigma$ are 68.3%, 95.5%, and 99.7%, respectively. Here, the human corridor was considered a natural phenomenon and this data was assumed to be normally distributed.

Average and Standard Deviation

Our findings indicate that females can hear soundwaves of higher frequencies than males, especially in older people; however, the gender difference is not significant. In addition, hearing variability is generally larger in males than in females, especially at higher frequencies and ages. The coefficient of variation was calculated for each gender, each frequency, and each age and we obtained averaged values of 0.23 for females and 0.27 for males. The largest values were 0.71 and 1.16 for females and males in their 40s at 250 Hz, respectively.

4. DISCUSSIONS

Accuracy of Audiogram Modeling

Curves similar to those of actual audiograms were obtained based on two assumptions:

1) the natural sound environment can be expressed as a linear sum of two types of $1/f$ characteristics, and

2) all the sound energy provided from outside destroys hair follicles.

There seems to be no need to change the essential idea. In the future, researchers should consider whether it is possible to express a real audiogram by adding realistic elements which were not considered in the present study.

The factors affecting audiogram variability may be categorized into individual differences and those which are not. It is necessary to further distinguish the individual differences into those which can be measured and those which are unmeasurable. The elements which are not correlated with individuality of the participant can be measured in some way. Ethical restraints prevent us from testing the resilience of the hair follicles of each participant against the mechanical stresses of sound wave pressure, as can be done with other materials.

Hearing loss may be influenced by a variety of health conditions, such as diabetes mellites, hypertension, and genetic factors. The accuracy of the modeling is expected to be improved without involving unmeasurable elements as much as possible. It will also be necessary to reverse-estimate unmeasurable factors from the results based on biological and engineering findings.

Mean and Variability

The accuracy of this model should be verified in comparison with an actual audiogram. Audiograms vary with sound source and listener for several reasons, including the selection of reference values, differences in testing methods, and inter- and intra-individual variability. Every audiogram should be produced in standard conditions and with standard equipment. Additionally, individual audiogram results vary depending on the physical condition of the participant on the day of testing.

It is useful to calculate the mean through data adjustment, such that the variability in audiogram baselines is minimized. However, the value of the mean reduces if the variation within the dataset is large.

We collected audiograms from a large number of participants. It should be noted that the error margin of the audiogram is never small. Based on our findings, we assert that ear health is not as an absolute entity and it changes over time.

Impaired hearing of 1000–4000 Hz sound waves in young people

This study found that participants of both sexes in their 20s were better able to hear soundwaves in the 1000-4000 Hz region than teens. No medical evidence has been found so far for better hearing in 20s than in 10s. The sound frequencies from 1000 to 4000 Hz are the easiest to hear, so the results were contrary to the expectations, with participants displaying poor hearing of sounds in the 1000-4000 Hz range.

Previous studies [5] reported that the hearing of adolescents is suppressed for soundwaves around 3000 Hz. However, our study was unable to replicate these findings in audiograms from non-Japanese participants [2].

Table 1: Numerical values read from Japanese audiograms.

(a) Female

Audiogram	No.	5	7	12	13	14	17	19	21	24	28	29	30	31	32	33	34	38	42	Reference three audiograms		
	When drawn	1992-2002	1984-	unclear	unclear	unclear	2006-2008	2006	1990	unclear	2011-2016	2011-2016	2011-2016	2011-2016	2011-2016	2011-2016	unclear	1998-2005	2000-2020			
Subjects	Number	831	949	77	234	595	239	210	20	5584	547	622	569	340	367	336	266	100	3990	15876		
	Nationality	Japan																		Spanish, American and Dutch		
Age	Frequency, f[Hz]	(Mean of) Hearing level. HR[dB]																		Mean	Variance	S.D., σ
10's	125						3.6	8.0		9.1								7.2	12.5	10.9	4.84	2.2
	250						2.3	7.4		9.6								6.9	10.8	9.9	2.68	1.6
	500	2.3					2.6	7.8		6.6								4.7	8.6	6.8	5.92	2.4
	1000	2.3					5.9	8.0		3.1								0.1	6.5	4.9	5.12	2.3
	2000	2.3					4.6	8.9		4.1								0.6	6.4	5.1	4.60	2.1
	3000						4.1	10.6												9.5	6.22	2.5
	4000	2.3					1.9	7.3		1.1								-2.0	4.5	3.3	4.49	2.1
	8000	2.3					4.5	7.9		5.1								3.4	6	5.1	2.52	1.6
	Number	89					7	32		83								31	256			
20's	125						3.3			4.6								6.8	12	8.7	13.70	3.7
	250		8.1				4.3		7.5	8.3								7.3	10.8	8.9	3.78	1.9
	500	3.5	7.1				6.5		3.0	6.6								5.0	9	6.5	5.46	2.3
	1000	2.1	4.7				9.2		-1.1	4.1								1.9	7.3	4.6	10.30	3.2
	2000	2.6	2.7				10.1		2.1	5.3								1.6	7.6	5.5	6.88	2.6
	3000						9.0													9.0		
	4000	2.6	3.5				5.5		0.2	1.6								0.6	5.6	3.3	4.88	2.2
	8000	3.5	6.1				7.5		2.4	3.6								2.3	7.5	5.2	4.88	2.2
	Number	113	25				70		156	213								56	388			
30's	125						3.7			7.1							13.1		12	10.6	7.86	2.8
	250		8.9		3.6		5.2		9.4	10.1							9.8		10.8	9.8	2.28	1.5
	500	4.8	7.3		3.6		6.7		5.2	7.6	7.9		6.7	5.7	10.7	8.7	9.8		9.1	7.4	3.09	1.8
	1000	3.6	5.3		-1.4		8.6		0.1	6.6	1.7		13.0	9.4	7.4	5.3	4.2		8.3	5.6	10.85	3.3
	2000	4.1	3.2		-0.8		10.5		3.3	9.0	1.1		1.7	3.2	9.0	5.5	5.4		8.2	6.3	6.92	2.6
	3000						12.2													12.2		
	4000	5.1	4.6		-0.8		8.5		1.9	5.6	-2.7		-0.8	6.9	9.0	2.0	7.0		6.7	5.3	4.46	2.1
	8000	7.6	11.2		4.9		9.2		7.8	4.6									9.4	8.7	2.57	1.6
	Number	111	134		8		74		264	97	4		2	2	3	3	20		547			
40's	125						3.4			6.6							13.7		12.6	11.2	9.35	3.1
	250		10.9		5.4		5.4		10.4	10.1							11.3		10.8	10.4	1.51	1.2
	500	4.6	8.7		2.9		6.9		7.0	9.1	7.6	5.1	6.5	6.1	8.7	7.2	9.7		9.4	7.8	2.51	1.6
	1000	5.0	7.4		2.2		9.9		4.0	8.1	5.0	4.1	5.3	6.7	5.9	5.6	5.2		9.1	6.6	5.00	2.2
	2000	7.1	5.4		4.7		12.4		7.4	10.1	7.5	4.7	6.9	6.4	6.6	8.0	6.2		9.9	8.1	3.43	1.9
	3000						12.6													12.6		
	4000	7.5	8.2		4.3		10.1		7.7	6.0	4.4	1.8	4.1	2.3	3.4	4.3	8.7		9.7	7.9	3.69	1.9
	8000	11.9	15.9		10.7		12.8		15.0	7.4									13.4	13.7	3.78	1.9
	Number	149	203		14		65		480	86	26	27	39	25	35	29	20		549			
50's	125						5.5			8.6							19.9		13.70	13.5	3.23	1.8
	250		12.7		3.6		6.1		13.3	11.4							12.7		12.10	12.3	1.03	1.0
	500	6.0	11.0		1.1		9.3		10.1	13.9	10.9	10.0	10.1	11.4	11.0	11.6	12.2		10.15	10.1	1.53	1.2
	1000	6.7	10.6		1.1		12.2		6.8	10.8	8.1	6.8	9.0	10.9	10.2	9.8	9.6		9.00	8.7	1.86	1.4
	2000	8.6	9.8		1.1		15.3		10.5	12.6	9.6	10.4	12.1	11.4	12.6	12.7	12.2		11.01	10.8	1.09	1.0
	3000						17.5													17.5		
	4000	9.8	12.7		-6.4		15.2		11.2	13.3	8.3	9.7	7.4	9.2	9.5	11.0	16.2		8.86	10.0	3.27	1.8
	8000	15.0	23.6		6.1		21.1		22.9	14.6									16.77	18.7	10.10	3.2
	Number	104	183		2		25		308	37	44	41	41	36	30	35	20		557			
60's	125					9.3	10.4			18.4							23.0	20.1	16.35	15.5	8.40	2.9
	250		15.2		15.1	9.3	12.8		14.8	18.2							16.7	19.2	14.54	14.2	4.58	2.1
	500	12.9	14.2		9.1	8.3	16.2		12.6	17.6	22.3	19.7	20.5	17.8	15.2	17.2	14.2	18.5	12.19	12.5	5.77	2.4
	1000	14.5	15.0		7.1	11.3	19.0		10.6	16.4	22.6	18.7	21.9	18.2	12.6	16.9	8.9	15.3	12.01	12.6	4.22	2.1
	2000	18.4	17.2		13.6	15.3	26.0		9.3	22.3	25.4	19.4	19.7	20.5	14.0	19.0	13.1	18.4	14.89	15.5	7.97	2.8
	3000						25.0													25.0		
	4000	21.9	21.2		18.6	21.3	23.9		18.6	22.2	22.3	19.4	18.5	16.3	16.9	17.0	20.5	22.3	13.69	16.5	13.18	3.6
	8000	36.1	33.2		27.6	36.3	43.9		37.8	39.1								37.0	27.53	30.9	21.92	4.7
	Number	68	84		10	216	29		113	79	8	8	9	13	15	15	20	28	624			
70's	125					15.0	13.4			16.9							28.5	20.5	19.77	18.9	5.08	2.3
	250			16.9	38.2	15.5	14.6		28.5	20.8							22.6	18.7	18.07	17.9	6.10	2.5
	500	26.8		16.3	35.4	16.0	18.2		26.4	18.1							20.9	17.0	17.25	17.5	6.35	2.5
	1000	25.2		15.4	27.9	18.0	24.6		21.3	22.0							16.5	19.5	18.41	18.6	2.94	1.7
	2000	30.4		20.4	31.1	21.5	26.0		27.8	23.1							21.0	24.4	22.43	22.6	3.08	1.8
	3000						29.9													29.9		
	4000	39.5		27.3	34.3	30.6	33.5		37.5	34.6							29.7	32.4	23.11	25.8	18.98	4.4
	8000	58.5		51.2	63.2	48.0	58.7		56.8	55.0								50.2	45.30	47.0	11.80	3.4
	Number	45		55	14	298	10		11	33							20	36	671			
80's	125																	26.2	26.46	26.5	0.00	0.0
	250			24.6	43.6													29.5	25.69	25.9	4.92	2.2
	500	26.1		23.9	39.1													30.6	26.21	26.3	2.81	1.7
	1000	27.7		26.3	30.6													25.7	28.10	28.0	0.27	0.5
	2000	31.5		31.3	36.6													32.2	33.26	33.2	0.39	0.6
	3000																					
	4000	43.0		42.5	44.6													37.1	38.07	38.4	1.77	1.3
	8000	67.7		62.6	73.1													69.0	62.67	62.9	2.20	1.5
	Number	11		30	10													4	358			

Table 1: Numerical values read from Japanese audiograms.

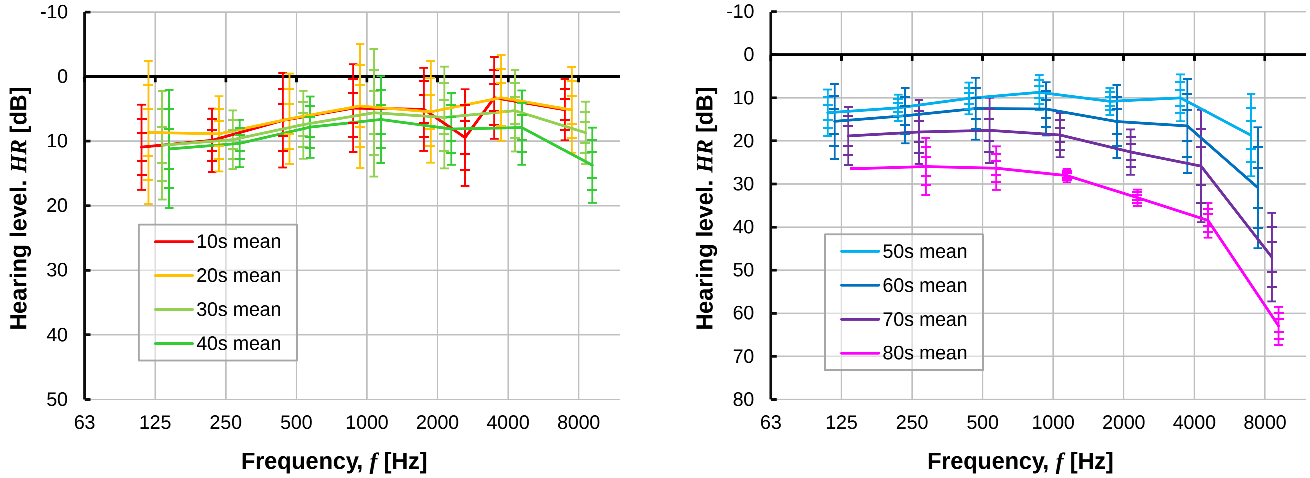
(b)Male

Audiogram	No.	5	7	12	13	14	15	17	19	21	24	28	29	30	31	32	33	34	38	42	Reference three audiograms		
	When drawn	1992-2002	1984-	unclear	unclear	unclear	1985	2006-2008	2006	1990	unclear	2011-2016	2011-2016	2011-2016	2011-2016	2011-2016	2011-2016	unclear	1998-2005	2000-2020			
Subjects	Number	831	949	77	234	595	239	210	20	5584	547	622	569	340	367	336	266	100	191	3990	16067		
	Nationality	Japan																			Spanish, American and Dutch		
Age	Frequency, f[Hz]	(Mean of) Hearing level. HR[dB]																			Mean	Variance	S.D., σ
10's	125							4.2	8.8		7.0								2.7	12.5	10.4	10.00	3.2
	250							5.3	8.0		9.0								2.2	10.8	9.6	4.94	2.2
	500	1.0						5.9	8.1		7.0								0.2	8.6	7.0	7.89	2.8
	1000	1.0						5.9	7.8		3.0								-0.8	6.5	4.9	5.85	2.4
	2000	1.0						7.3	7.6		3.0								-0.7	6.4	4.9	5.69	2.4
	3000							6.9	10.3												9.0	2.63	1.6
	4000	1.0						5.0	7.5		2.0								-2.6	4.5	3.4	4.36	2.1
	8000	1.0						4.8	7.6		2.0								-1.4	6	4.4	5.99	2.4
	Number	47						12	20		85								23	256			
20's	125							4.5			8.0								4.8	12	9.3	8.48	2.9
	250		7.8				-0.2	5.2		6.1	8.7								5.2	10.8	7.5	5.14	2.3
	500	2.3	6.2				-1.2	6.4		1.8	7.2								3.4	9	4.5	9.65	3.1
	1000	1.4	4.6				-2.2	7.5		-0.1	4.5								0.8	7.3	2.8	10.19	3.2
	2000	1.7	4.0				-4.5	8.3		1.3	5.7								0.7	7.6	3.6	8.93	3.0
	3000							7.6													7.6		
	4000	2.7	4.7				-1.1	5.2		0.7	3.2								0.2	5.6	2.5	4.42	2.1
	8000	2.6	7.9				2.7	5.5		1.0	3.4								-0.7	7.5	3.2	7.64	2.8
	Number	144	52				24	81		775	249								83	388			
30's	125							2.0			5.0							10.0		12	11.2	5.97	2.4
	250		8.7		5.9		0.4	5.0		9.0	10.6			8.8	8.3	8.6	9.6	9.1		10.8	9.2	2.03	1.4
	500	3.5	7.7		3.1		0.2	5.4		6.7	6.4	8.6	7.4	5.3	4.5	3.3	5.3	5.7		9.1	7.0	2.86	1.7
	1000	2.7	6.0		1.6		1.3	8.8		4.4	7.0	4.5	5.1	2.3	2.4	0.7	-0.2	2.8		8.3	5.1	4.08	2.0
	2000	2.9	3.5		0.2		0.7	9.2		5.4	6.6	3.4	4.6	1.7	1.1	0.0	-1.5	2.3		8.2	5.2	4.66	2.2
	3000							11.3													11.3		
	4000	4.3	7.2		1.1		8.3	9.9		7.2	6.0	3.9	5.8	3.8	2.2	0.6	1.1	9.1		6.7	6.4	2.58	1.6
	8000	5.2	12.6		6.2		10.5	10.8		10.7	7.1			5.0	1.4	-0.3	0.3			9.4	9.6	6.44	2.5
	Number	142	198		40		27	26		1224	31	128	90	64	37	24	28	20		547			
40's	125							4.2			8.0							12.6		12.6	12.1	3.30	1.8
	250		9.0		5.2		2.4	6.8		10.8	10.0			10.5	10.9	13.5	11.1	10.0		10.8	10.4	2.58	1.6
	500	3.4	8.1		2.3		2.4	9.7		8.2	11.5	7.3	5.3	6.2	6.6	7.3	7.7	10.1		9.4	7.7	3.37	1.8
	1000	5.1	7.0		2.7		3.3	12.4		6.5	11.2	3.8	3.8	1.5	3.7	3.7	5.0	2.4		9.1	6.3	3.49	1.9
	2000	6.2	6.2		4.2		3.9	13.4		8.1	12.0	3.4	4.1	2.1	3.8	4.3	3.7	5.6		9.9	7.3	4.40	2.1
	3000							15.5													15.5		
	4000	9.4	10.7		6.7		12.3	13.4		12.0	9.3	4.1	7.6	5.4	4.4	6.6	6.7	12.7		9.7	10.3	5.40	2.3
	8000	12.4	17.5		14.6		17.9	17.8		17.3	10.1			8.2	6.6	7.7	6.6			13.4	15.2	10.62	3.3
	Number	225	256		102		50	24		1788	26	103	96	55	100	106	76	20		549			
50's	125							7.8			10.0							17.0		14.05	13.9	1.63	1.3
	250		10.9		8.3		10.7	9.8		11.6	14.1			16.8	16.8	16.8	20.4	10.8		12.25	12.1	2.97	1.7
	500	3.7	9.8		4.0		12.2	14.0		9.3	16.2	12.4	10.6	14.0	13.4	12.1	15.6	10.4		10.75	9.9	4.66	2.2
	1000	5.9	10.1		4.1		13.9	17.7		8.6	13.1	10.4	9.6	11.9	13.4	10.7	12.4	7.1		11.05	9.6	3.43	1.9
	2000	7.2	10.4		6.7		17.3	18.2		11.6	14.0	12.8	12.1	13.5	14.3	12.1	12.2	9.8		12.59	11.8	2.94	1.7
	3000							20.0													20.0		
	4000	12.0	19.6		12.1		27.7	20.4		17.3	11.0	22.6	22.1	24.4	24.1	22.3	16.4	18.2		14.12	17.8	12.58	3.5
	8000	15.6	30.7		19.7		36.0	29.7		26.1	24.6			27.0	27.0	29.5	21.4			22.61	25.4	13.74	3.7
	Number	157	232		54		60	15		1365	15	214	192	83	87	51	12	20		557			
60's	125					7.2		11.0			14.5							19.7	15.1	16.41	14.5	12.45	3.5
	250		12.4		12.8	7.2	8.1	11.8		13.3	16.4			20.2	22.0	21.0	20.4	12.5	13.8	14.11	13.7	10.76	3.3
	500	10.5	12.0		12.8	5.2	10.9	15.4		12.3	17.0	15.9	15.8	18.0	17.5	17.5	17.8	11.3	13.3	12.21	12.6	9.20	3.0
	1000	11.2	13.2		16.8	8.2	15.8	18.8		12.6	15.0	15.9	13.8	13.4	14.4	17.6	18.0	11.5	12.5	13.22	13.2	4.70	2.2
	2000	16.9	15.4		16.3	17.2	20.3	24.0		17.3	20.6	21.8	19.4	16.7	18.3	21.6	22.4	14.0	20.3	16.12	17.6	4.52	2.1
	3000							29.2													29.2		
	4000	27.8	30.7		24.3	29.2	36.3	32.9		27.8	30.6	30.7	33.8	33.1	32.5	33.5	36.1	25.1	31.7	20.65	27.2	24.44	4.9
	8000	38.9	42.5		37.3	38.2	48.2	40.2		40.9	42.0			39.2	39.3	38.3	40.9		45.9	34.73	38.7	11.55	3.4
	Number	83	154		10	170	36	37		379	93	72	75	35	41	49	49	20	42	624			
70's	125					15.0		12.0			17.3							24.3	18.5	18.69	17.5	3.96	2.0
	250			15.3	32.5	16.7	16.6	13.0		22.2	19.0							18.4	19.9	16.89	17.2	2.97	1.7
	500	21.5		15.3	34.1	15.0	18.7	16.0		19.9	18.5							17.9	20.7	15.14	16.0	4.65	2.2
	1000	24.5		17.3	27.5	18.5	24.8	20.5		18.4	19.0							17.8	23.9	17.73	18.6	3.67	1.9
	2000	30.1		26.6	33.3	29.5	33.0	25.5		25.9	23.5							24.4	32.1	22.58	25.5	12.67	3.6
	3000							28.1													28.1		
	4000	46.0		41.9	37.5	44.1	47.3	35.1		41.0	44.5							44.6	49.0	31.67	37.6	41.09	6.4
	8000	58.8		58.3	65.0	53.8	55.9	48.5		58.0	55.2								58.9	50.10	52.5	9.35	3.1
	Number	29		37	6	333	42	14		53	48							20		671			
80's	125					20.2													32.5	23.84	23.5	3.19	1.8
	250			19.4	35.0	21.2													28.9	23.14	22.8	3.87	2.0
	500	35.9		19.0	33.3	23.2													22.9	23.63	23.4	4.13	2.0
	1000	35.6		20.2	28.3	25.2													22.0	28.60	27.4	6.93	2.6
	2000	43.9		29.4	30.0	37.2													39.1	34.31	34.4	4.41	2.1
	3000																						
	4000	70.0		46.2	37.5	51.2													57.6	44.71	46.0	12.84	3.6
	8000	77.8		65.6	60.8	61.2													66.8	66.01	65.4	4.18	2.0
	Number	4		38	6	63													8	358			

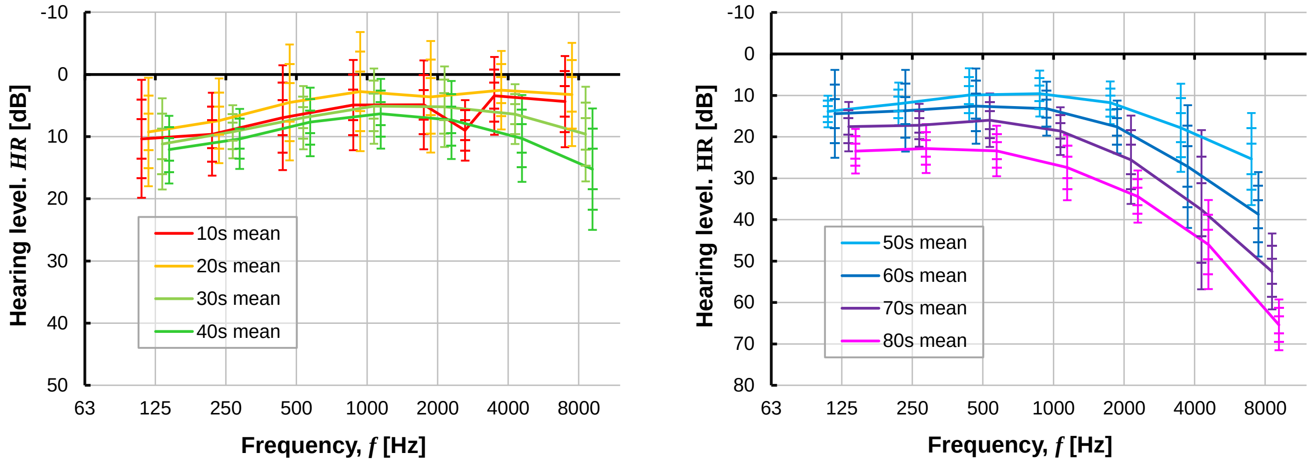
To integrate the audiogram data, our group adjusted the results to minimize the sum of squares of the differences from the reference data during data analysis. As there was no 3000 Hz in the reference data, the data near 3000 Hz range could not be recognized and adjusted. Considering that the above-mentioned modeling is simple and well represents the actual data, it is possible that the suppressed hearing at 3000 Hz in young people does not exist. Therefore, in this region, it should be interpolated so as to smoothly approach the curve in Fig. 2. On the other hand, more data must be collected near 3000 Hz from Japanese participants to identify a more accurate mean.

Audiogram for Japanese Participants

The results were consistent with the general medical experience in that females are less likely to hurt their ears than males. In particular, this tendency was significant in the regions where the ear ages of the elderly varied widely. While all males may be prone to hearing loss due to the effects of hormones, at the same time, more men are susceptible to have deafness than women, or deafness



(a) Female



(b) Male

Fig. 2: Integrated Japanese audiogram.

is known to be more severe in men than in women. Although Caucasian data [3] are inadequate, Caucasian gender differences are evidently greater than Japanese, at least in terms of variability, and are likely to be greater, especially in the elderly.

It is easier to collect Japanese data than overseas data in Japan. However, we expect to observe differences in the audiograms depending on race and environment, based on the differences in the characteristics of overseas and Japanese data.

5. CONCLUSIONS

19 Japanese audiograms were statistically integrated and compared with the simplest modeling results. The findings obtained in the present research are listed below:

1) The simplest model of the audiogram has been tested and we confirmed that it matched well with the actual one. Here, the following two rough hypotheses are under consideration: 1: the sounds in the natural environment have 1/*f* characteristics. However, since the log-log 1/*f* characteristic does not explain the phenomenon in which sounds become inaudible at high frequencies, we assumed that audible sounds had semi-logarithmic characteristics; 2: all the soundwaves entering the ear canal contribute to the degeneration of hair follicles in the ear.
2) It may be possible to improve the accuracy of the model by considering unmeasurable factors, in the future. In addition, it is expected that factors which cannot be measured can be reversely estimated based on biological and engineering knowledge.
3) A mean Japanese audiogram was obtained. The gender differences in the hearing of this Japanese population were smaller than those of Caucasians.

Females were less likely to be deaf than males, and the degree of hearing in males varied more than that of females.

4) The audibility of soundwaves around 3000 Hz was reduced in young people compared to people above 20 years of age. However, there was no medical rationale to explain the result. It is necessary to obtain data on audibility of sounds near 3000 Hz for Japanese people in the future.

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