Basic Study on the Mechanism of Earphone Hearing loss: About Correlation between Ear Age and Real Age

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ABSTRACT [1]

Young people around the world are at risk of the earphone hearing loss. To prevent the risk, authors have been studying on the mechanism of the earphone hearing loss in the laboratory since 2010. In the present paper, earphone hearing tests to 46 subjects are carried out to obtain the ear age compared with the real age. The ear deterioration index is proposed to evaluate the effect of earphones quantitatively. For reference, both their accumulated earphone usage time and their favorite genre of the sound source are collected from the subjects to calculate the approximately accumulated sound energy received in their life. The results are as follows. The younger the real age is, the older the ear age is. The ear ages of subjects under the age of 45 exceeds the real ages. The ear degradation index tends to be worse with the accumulated earphone usage time. Ear ages of junior high school boys aged between 13 and 14 are remarkably old. The earphone hearing loss can be explained by the concept of the fatigue fracture.

Keywords: Earphone Hearing Loss, Ear Age, High Frequency, Fatigue Fracture, Audiogram and Sound Source.

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1. INTRODUCTION

WHO warns that about 1.1 billion adolescents, about 12-35 years old, will have the hearing loss by earphones worldwide [1,2]. However, previous studies have not found specific data on the earphone hearing loss nor on solutions.

By the authors' study on the earphone hearing loss since 2010, following qualitative suggestions have been obtained. Earphone users tend to turn up the volume. Earphone users tend to use it for a long time. The earphone emphasizes high frequency sounds [3,4]. When the accumulated usage time of an earphone exceeds about 10,000 hours, probability of the hearing loss for user can increase. The authors are trying to elucidate the mechanism of the earphone hearing loss in order to prevent the hearing loss in young people by improving the usage of earphones.

In the present paper, the hypothesis of the mechanism of the earphone hearing loss, as a kind of fatigue destruction phenomenon, is explained [5,6]. For estimation of the ear damage, parameters are proposed: the ear age, and the ear deterioration index. To discuss whether the hearing loss is triggered by the usage of an earphone, the survey on the earphone hearing loss has been conducted on the subjects who have consented to the present research.

2. CONCEPTS FOR MECHANISM OF HEARING LOSS

Hearing Sense

The sound wave collected by an auricle reaches an eardrum through an external ear canal. The vibration of the eardrum is amplified in a middle ear to be transmitted to the cochlea in an inner ear. The basilar membrane vibrates as a resonance plate. The cross-sectional shape of the basilar membrane changes from the middle ear side to the inner ear side for resonance: the higher tone on the middle ear side, and the lower tone on the inner ear side. Information of pitch is converted into information of the position. The hair cell at the corresponding position senses resonance and transmits the signal to the brain. The brain comprehensively judges the time history of the resonance positions to recognize it as the timbre history: language, or music.

Type of Hearing Loss

In general, deafness is roughly classified into two types: conductive deafness, and sensorineural deafness. Conductive deafness is caused by the abnormality in the path of the sound transmission to the cochlea. Sensorineural deafness is caused by the abnormality from the cochlea to the central nervous system. The hearing loss caused by the cochlea is called the inner ear hearing loss. The hearing loss caused by the auditory nerve is called the post-maze hearing loss, which is sometimes called the nervous hearing loss. The hearing loss caused by the center nervous system is called the central hearing loss. There are few patients with the nervous hearing loss. The hearing loss caused by the abnormality in the brain is considered as sensory impairment, which is out of otolaryngology. The sensorineural hearing loss is roughly classified into two types: the congenital type, and the acquired type. The hereditary hearing loss is a kind of the congenital hearing loss. Either embryonic developmental abnormality or mother's having rubella during pregnancy sometimes causes the congenital hearing loss. The acquired hearing loss includes the traumatic hearing loss, the age-related hearing loss, the noise-induced hearing loss, the hearing loss by Meniere's disease, meningitis, the tumors, and the side effects of drugs.

Both the acoustic trauma, and the age-related hearing loss can be physically considered as fatigue phenomena. The noise-induced hearing loss is physically controlled by the same phenomenon as the age-related hearing loss: the former is due to the acceleration of artificial destruction by the lifestyle, and the latter is the natural phenomenon. The earphone hearing loss is synonymous with the noise-induced hearing loss.

Sound Energy

The energy flux ϕ [J/m^2・s] of the sound wave which is transmitted in the space of density ρ[kg/m^3] at the speed c [m/s] [7] can be calculated by Eq. (1).

$$\phi = 2\,\pi^2\,\rho\,c\,A^2 f^2 \tag{1}$$

In Eq. (1), A [m] is the amplitude and f [Hz] is the frequency. This energy flux is multiplied by the cross-sectional area of the external ear canal, and is integrated over time to calculate the total amount of the acoustic energy that enters the ear. The energy decays during the transmission through the external ear canal and the eardrum to the basilar membrane. Even if the sound with the same energy flux enters at the same time, the sound energy received by the basilar membrane has variation, because of individual variation in physical properties (shapes and materials) from the external ear canal to the cochlea.

Applying the Concept of Fatigue Fracture to Earphone Hearing Loss

In the present study, the earphone hearing loss is modeled as a fatigue fracture phenomenon of hair cells [5,6]. In the fatigue phenomena, the work done by the external force initiates and propagates the crack in the material. Hair cells are finely arranged from the high frequency side to the low frequency side. The sound energy of the corresponding pitch is given to hair cells through resonance. When the accumulated acoustic energy supplied to the hair cells exceeds its critical fatigue energy, they will be fractured. The critical fatigue energy depends on the individual cell strength. The fatigue limit depends on the decay of the acoustic energy. Since both the critical fatigue energy and the decay cannot be directly measured, the change of the ear age, which is described in the next section, has been estimated.

3. MEASUREMENTS OF EAR DETERIORATION

Ear Age

According to Eq. (1), treble sounds have significantly more energy than bass sounds. Hair cells, on the other hand, may not have significant difference on the critical fatigue energy regardless of the corresponding frequency. Therefore, a person becomes inaudible at higher pitch in order. The pitch, that a person can hear, corresponds to his ear age. Needless to say, it is desirable that the ear age does not exceed the real age. When the ear age is older than the real age, the ear must have been damaged excessively.

Audiogram

Audiograms [8-11] show the audible intensity of sounds at each frequency for each age. Some of them are illustrated separately for male and female. Although women are less likely to have the hearing loss due to the action of female hormones, the present paper does not consider gender differences.

In the present survey, the audiogram shown in Fig. 1 has been used with -40 dB of the hearing threshold border for the hearing loss. The authors have made the audiogram by averaging several audiograms mainly for Japanese. Because of little data for above 8 kHz, authors pay attention to the large error in the range of the frequency above 8 kHz in Fig. 1.

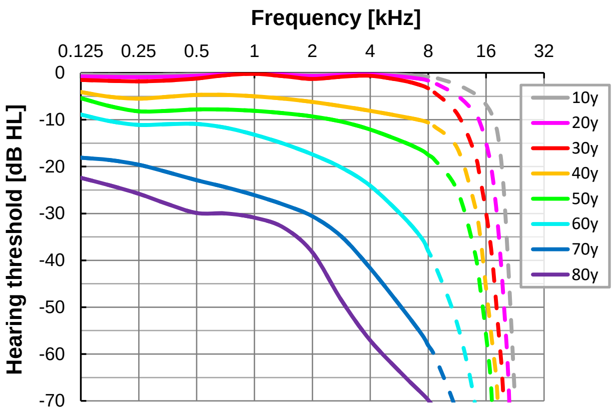

Fig. 1: Employed audiogram in the test.

Measurement and Estimation

In the present test, each sound from 1 kHz to 21 kHz in 1 kHz increment has been prepared, and audibility has been measured at each subject. The ear age A_E corresponding to the audible frequency is read from the audiogram shown in Fig. 1 (see hearing test in Table 2). Various errors inherent in this method should be discussed in the future.

The subjects in the present survey are 46 people. They are interested in the earphone hearing loss. They are citizens in Kamakura area in Japan. Some of the subjects complained of hearing problems ("anxiety about ears" in Table 2).

4. PREDICTION OF SOUND ENERGY

Accumulated Time Using an Earphone

The term of usage of earphones by each subject is generally unknown without their own record. Some applications, which record the accumulated usage time to listen to the music by the smartphone, are being provided recently. These applications, however, may not measure the volume or the frequency of the music. The auditory information can be compensated by the questionnaire to the subjects: "What kind of sounds have you ever heard? How many hours (t) a week? How many years (y)?".

The accumulated earphone usage time t_{total} for each subject is approximately calculated based on his answer to the above mentioned question in the present test.

Spectrum of Sound Source

Types of sounds cannot be obtained for the listening history of each subject, because nobody records the details. The sound energy received by the ear, on the other hand, depends on types of sounds.

Because of the difference on spectrum [12] (the sound volume and frequency), the sound energy is different between the western classical music and the rock music. Even in the western classical music, the spectrum has variation: Bach's organ fugue, Beethoven's symphony No. 9, or "The rite of spring" composed by Stravinsky. The spectrum also depend on composers and music instruments.

In our laboratory, the database of spectrum have been made on each parameters: composers, the genre of music, and music instruments. In the present survey, the sound sources of the earphone are simply classified into 15 genres (Table 1). Both the approximated overall volume and spectrum of each case are referred to the database. The frequency is classified into three ranges: the mainly low frequency (up to 200 Hz), the mainly middle frequency (up to 2 kHz), or the full frequency (up to 20 kHz).

Estimation

Each subject selects favorite genre from 15 genres of sound sources ("Favorite sound source genre" in Table 2). The accumulated earphone usage time is distributed to each time related to these favorite sound sources. Each value of the sound volume is set to the relative ratio, when western classical music is set to 1. The ratio of the border of the frequency for the range among the low, the middle, and the full is 1:10:100. Accumulated sound energy was relatively calculated with the value of the volume A and the frequency f using above mentioned values ("Accumulated energy from an earphone" in Table 2).

Environmental Sound

For reference, each subject answers about his history exposed to noise: trains, traffic, planes, TV and PC, factories, and human voices. In the present paper, the sound energy ratio is estimated not from data on the environmental sound, but from previous data in the laboratory. The energy ratio is assumed as 1: 0.5: 2: 1: 10: 0.1: 10: 0.5: 0.2 for Train: Traffic: Airplane: TV and PC: Factory: Loud voice: Concert: Amusement: Cooking.

5. RESULTS AND DISCUSSIONS

Ear Age and Real Age

In Fig. 2, solid and open marks show data of female and male, respectively. The square and triangle marks show the data of the history of subjects: who have used the earphone for a long time, and who have worked in noisy workplaces, respectively.

The solid line shows the regression line between the ear age and the real age in Fig. 2. The ear age A_E tends to increase with the real age A_R. Subjects younger than 45 years old tend to have ear damage. Subjects older than 45, on the other hand, tend to have better ear than age regardless of gender.

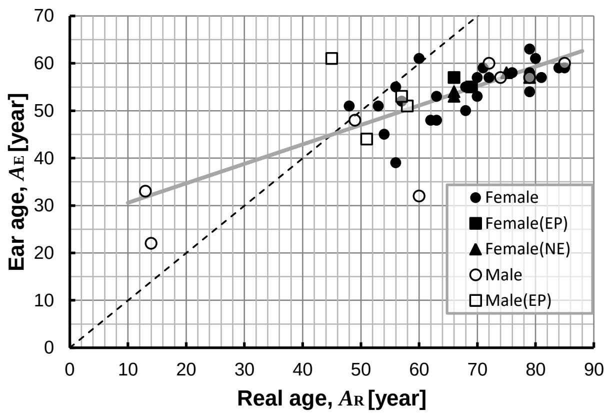

Fig. 2: Relationship between ear age and real age.

The male subject, whose real age of 60 years old (No. 30 subject in Table 2), has exceptionally good ear: the ear age of 32 years old. He may have sensed the noise of the audio equipment itself as a mistake. The method of the hearing test should be improved for the next step. No clear effect of noise on the ear damage is observed related to the following factors: working in the noisy workplaces, or using an earphone for a long time.

According to previous researches by the authors, many people stop using an earphone when they feel strange sense at their ears. The elder subjects in the present survey who are using an earphone may have strong ears. Both the high school boy of 13 years old (No. 44 subject in Table 2) and male of 45 years old (No. 28 subject in Table 2) have remarkably older ear ages A_E. They have used earphones mainly for pops for 1252 hours and for 31307 hours, respectively. Pops have high frequency sounds and serve rather large sound energy to their ear.

Ear Degradation Index

The authors defined the ear degradation index F by Eq. (2). It means how worse the ear age (A_E) against the real age (A_R).

$$F \equiv (A_E - A_R) / A_R \tag{2}$$

The ear degradation indexes of 13 and 14 years old junior high school boys (No. 44 and 41 subjects in Table 2) are significantly worse than those of the others, which suggests that their hearing loss may be severely progressing. Both of them have listened to sound sources including high frequencies through earphones.

The ear degradation index tends to increase with the earphone accumulated usage time for the subjects. The following subjects are exception: those who never use an earphone, and the above mentioned boys (No. 44 and 41 subjects in Table 2). There is no gender dependence.

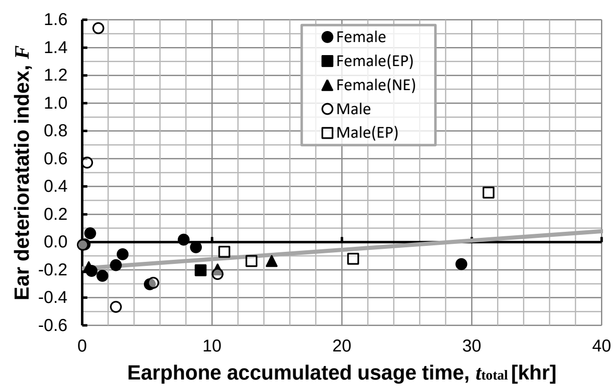

Fig. 3: Relation between accumulated earphone usage time and ear degradation index.

Table 1: Classification of sound source through an earphone and their energetic characteristics.

Sound source		Overall Loudness	Approximate range of music		
No.	Genre		Low freq	Middle-freq	High-freq
1	Pops	2.25	1	1	1
2	Roukyoku：Japanese naniwabushi recitation	0.25	1		
3	Rakugo：Japanese traditional comic storytelling	0.25	1		
4	Gagaku：Japanese clasic music	0.50	1	1	
5	Enka：Japanese traditional ballads	1.00	1	1	
6	Japanese popular music	1.50	1	1	
7	Western clasic music	1.00	1	1	
8	Jazz music	1.00	1	1	
9	Church music	1.00	1	1	
10	Rock music	4.00	1	1	1
11	Koudan：Japanese tradittional narration	0.25	1		
12	Ambient / Healing music	0.50	1	1	
13	Easy listening music	1.00	1	1	
14	Animation music	2.00	1	1	1
15	Chanson	1.00	1	1	

Table 2: All the results of the earphone test.

Subject No.	Subjects Age		Accumulated time listening sounds								Hearing test (A : audible, I : inaudible, ? : unclear)																						
	Male	Female	Train	Trafic	Airplane	TV & PC	Factory	Laud voice	Other	Earphone	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	Ear Age	***F***
1	85									5479	A	A	A	A	?	?	?	I	I	I	I	I	I	I	I	I	I	I	I	I	I	60	-0.29
2		85								0	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	59	-0.31
3		56	6261							5218	A	A	A	A	A	A	A	A	A	A	A	A	?	?	?	I	I	I	I	I	I	39	-0.30
4		80								0	A	A	?	A	A	I	I	I	I	I	I	A	I	I	I	I	I	I	I	I	I	61	-0.24
5		68		2505						0	A	A	A	A	A	A	A	A	?	?	I	I	I	I	I	I	I	I	I	I	I	55	-0.19
6	72									0	A	A	A	A	A	?	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	60	-0.17
7		71						522		0	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	59	-0.17
8		83									?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?	?		
9		75					17375			0	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	I	58	-0.23
10		56	27550				1565	1565		209	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	55	-0.02
11	58		20871							20871	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	51	-0.12
12		81				65745				0	A	A	A	A	A	A	?	A	I	I	I	I	I	I	I	I	I	I	I	I	I	57	-0.30
13		62	3131							0	A	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	48	-0.23
14		63	3131							0	A	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	48	-0.24
15	57		10958							10958	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	53	-0.07
16	74		37569							10436	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	57	-0.23
17		76	626							0	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	I	58	-0.24
18		72	20037	20037						731	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	57	-0.21
19		84				32873		20454	9392 (cooking)	0	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	59	-0.30
20		79					104			0	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	I	63	-0.20
21		79						10958		0	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	I	57	-0.28
22		66			7670	15341				14610	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	I	57	-0.14
23		79								0	A	A	A	A	A	A	A	A	A	?	I	I	I	I	I	I	I	I	I	I	I	54	-0.32
24		70								0	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	57	-0.19
25		66	15654	10436	5479	5479	10436			10436	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	53	-0.20
26		69	15654							9131	A	A	A	A	A	A	A	A	?	?	I	I	I	I	I	I	I	I	I	I	I	55	-0.20
27		60	3913	26298		7305				7827	A	A	A	A	A	I	I	I	I	I	A	I	I	I	I	I	I	I	I	I	I	61	0.02
28	45								21915 (amusement)	31307	A	A	A	I	A	?	I	I	I	I	I	A	?	?	?	I	I	I	I	I	I	61	0.36
29		79	7827	262980						0	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	I	57	-0.28
30	60		15654							2609	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	32	-0.47
31		57	7305							3131	A	A	A	A	A	A	A	A	A	A	?	I	I	I	I	I	I	I	I	I	I	52	-0.09
32		54	17741					2087	522 (comcert)	2609	A	A	A	A	A	A	A	A	A	A	A	A	?	I	I	I	I	I	I	I	I	45	-0.17
33		48	2087			3757		1878		626	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	51	0.06
34		66	154282	4018						522	A	A	A	A	A	A	A	A	A	?	I	I	I	I	I	I	I	I	I	I	I	54	-0.18
35		70								1565	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	53	-0.24
36	79		15654							0	A	A	A	A	A	A	A	I	?	I	?	I	I	I	I	I	I	I	I	I	I	57	-0.28
37								1044		0	A	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	48	
38		79								0	A	A	A	A	A	A	?	I	I	I	I	I	I	I	I	I	I	I	I	I	I	58	-0.27
39	51									13045	A	A	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	44	-0.14
40		53	2505	5114						8766	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	51	-0.04
41	14		391							391	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	A	?	I	I	I	I	22	0.57
42		63					1044			29220	A	A	A	A	A	A	A	A	A	?	?	I	I	I	I	I	I	I	I	I	I	53	-0.16
43	49		6001				1957			52	A	A	A	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	48	-0.02
44	13		130			1252				1252	A	A	A	A	A	A	A	A	A	A	A	A	A	A	?	I	I	I	I	I	I	33	1.54
45		68								0	A	A	A	A	A	A	A	A	A	?	?	?	?	I	I	I	I	I	I	I	I	50	-0.26
46	66		25046							0	A	A	A	A	A	A	A	A	A	I	I	I	I	I	I	I	I	I	I	I	I	55	-0.17

Subject No.	Subjects Occupation	Anxiety about ears			Favorite sound source genre															Accumulated energy from an earphone		
		Bad sound	Conversation deafness	Tinnitus	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	Low-frquency	Middle-frquency	High-frquency
1	-	V	V	V	1					1	1									87	867	4109
2	City officer, Housekeeper	V							1	1										0	0	0
3	Researcher				1						1		1	1						108	1076	8153
4	-	V									1		1							0	0	0
5	City counselor	V			1		1				1		1							0	0	0
6	-	V									1	1								0	0	0
7	-						1				1									0	0	0
8	Housekeeper										1									0	0	0
9	Office worker						1				1	1								0	0	0
10	Office worker	V	V																	0	0	0
11	Office worker				1					1	1									330	3305	15654
12	City officer										1									0	0	0
13	-				1						1									0	0	0
14	Office worker				1					1	1								1	0	0	0
15	City officer	V	V		1		0.5				1			0.5					0.5	184	1800	13306
16	Board of directors	V																		0	0	0
17	Office worker (Telephone operator)										1									0	0	0
18	City officer (Librarian)	V																		0	0	0
19	-										1		1							0	0	0
20	Office worker	V																		0	0	0
21	Childminder			V							1									0	0	0
22	Researcher (Ruins excavation worker)	V			1						1									237	2374	16436
23	-				1		1				1		1							0	0	0
24	-	V									1									0	0	0
25	Office worker						1	1			1		1		1					63	522	0
26	Art designer	V	V		1							1								148	1484	10273
27	Office worker							1			1									59	587	0
28	Administrative scrivener	V			1															704	7044	70441
29	Office worker										1									0	0	0
30				V							1	1								26	261	0
31	System engineer	V		V																0	0	0
32	Art designer									1	1	1					1			29	294	0
33	Teacher of electric music	V										1		1		1				11	115	835
34	-				1		1				1	1	1							6	55	235
35	Office worker				1						1									25	254	1761
36	Office worker	V																		0	0	0
37	Office worker				1						1	1								0	0	0
38	-	V	V		1							1								0	0	0
39	Office worker				1									1						408	4076	40765
40	Office worker	V	V		1					1	1									139	1388	6575
41	Junior high schooler																	1		8	78	783
42	Teacher of junior high school										1									292	2922	0
43	Office worker										1	1								1	5	0
44	Junior high schooler				1															28	282	2818
45	-	V																		0	0	0
46	Office worker				1						1									0	0	0

Error of Estimating the Ear Age

As Figs. 2 and 3 show, the ear age of the elderly subjects is better than their real age in the present survey. Every ear age would be estimated higher, if the threshold border as the criterion of the hearing loss were set at -50 dB. The appropriate value for threshold can be proposed after increasing the number of the data especially from young subjects. The tendency on the ear age obtained from the present survey, on the other hand, would not vary regardless of the threshold level.

Consideration of Sound Source

In the present paper, energy provided by the sound source is considered to find the relationship to the ear age. No clear relationships cannot be found between parameters. Eq. (1) shows the following concepts. The accumulated time until destraction of the hair cells is significantly longer at low frequencies than at high frequencies, under the idea that the sound energy of the corresponding pitch destroys the hair cells. In other words, the high frequency sound can make the ear age of young people worse.

The accumulated sound energy of each frequency should be estimated for each hair cell corresponding to the frequency to predict the ear age more precisely. Sound energy should be calculated more precisely after the database is extended. The sound sources were classified into three types according to the spectrum in the present paper.

9. CONCLUSIONS

In the present study, the earphone hearing loss, which is a type of the noise-induced hearing loss, is regarded as a fatigue fracture phenomenon. It is considered that the accumulated sound energy from the sound source destroys hair cells. The frequency corresponding to broken hair cells cannot be sensed. The proposed method to predict the critical fatigue energy, which depends on individual difference, will be improved in the future.

The authors have carried out the earphone hearing loss test, and obtained the following results. The difference between male and female is not clearly observed. It is necessary to get data from more subjects: especially from young people.

1) To compare with the real age, the ear age is calculated from the pitch which each subject can hear with -40 dB of the threshold border as the criterion of the hearing loss in the audiogram. There is the linear tendency that the younger the real age is the worse the ear age is. Every ear age of the subject under 45 years old exceeds the corresponding real age. Both scrutiny of error and consideration of the appropriate value of the threshold border in the audiogram are planned.

2) The accumulated earphone usage time is collected from each subject. The ear degradation index is defined. Ear ages of junior high school boys aged 13 and 14 are remarkably bad. The ear degradation index tends to be worse, as accumulated earphone usage time increases.

3) The sound sources, to which subjects might listen with earphones, are classified into 15 genres. The sound energy received by each subject has been estimated to compare data relatively. The sound energy received from surroundings has also been estimated. The effect of the environmental sound on the ear is not clearly found out. Detail considerations of the spectrum of the sound source are carried out.

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