The Effects of Age on Hearing and Middle Ear Function

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Audiometric test results from 933 community dwelling males and females were presented to obtain the norm for each generation after middle age. Three aspects were adopted in this analysis ; the cross-sectional aging transition of pure tone thresholds, the comparison in the self-perceived hearing difficulty among generations and the evaluation of middle ear function using multifrequency tympanometry. Subjects were divided into four age groups ; 40s, 50s, 60s and 70s. There were statistically significant differences in pure tone thresholds between almost any two age groups at each frequency in both genders, especially at higher frequencies. The pure tone thresholds were also discussed in regard to gender difference and laterality. A contradiction between self-perceived hearing difficulty and auditory accuracy was observed in the elderly generation. Analysis of tympanometric measurements was performed on static admittance at 226 Hz, tympanometric peak pressure at 226 Hz and resonance frequency of the middle ear. These variables did not show any systematic aging change. However, it was considered they represented the reference values of each generation. *J Epidemiol*, 2000 ; 10 : S26-S32.

aging, hearing , multifrequency tympanometry, self-perception

INTRODUCTION

Pathophysiological aging changes can appear in any part of the auditory system from the external ear through the cerebral cortex. It is known that age-related degeneration changes are caused by several complex mechanisms in many anatomical regions in varying proportions ¹⁾ and this results in large individual differences. It is essential to know the norms for each age generation using diagnostic measurements of auditory function before discussing the process and risk factors of aging to find a prophylaxis as a goal.

On the other hand, in the aspects of the management and rehabilitative intervention in age-related hearing loss, it is also necessary to know to what extent the individuals assess their own disability. Generally, hearing disabilities in the elderly may reflect two components; peripheral and central processing impairments. The impairment of the central component could worsen communication problems ^{2,3)}. It is, however, reported that the self-perceived hearing disability in elderly listeners is

less than that in younger listeners ^{4, 5, 6)}. It is said that elderly listeners may misunderstand the spoken message but respond with confidence that they are correct and fewer demands on communication, or a gradual progression of hearing loss may make them unaware.

The National Institute for Longevity Sciences, Longitudinal Study of Aging (NILS-LSA) was designed to represent the least biased sample in Japan. The present study provided information regarding the normative data of the auditory system, including pure tone thresholds, tympanometric variables and self-perceived hearing difficulty.

MATERIALS AND METHODS

Subjects

The subjects were randomly selected from resident registrations of Ohbu-city and Higashiura-town, located in the central area of Japan. In the period from November, 1997 to March, 1999, 1130 people participated in the ongoing NILS-LSA. All

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participants gave informed consent and will be examined every two years longitudinally. The age at the baseline is to be 40 to 79 years old and the number of subjects in each decade (40s, 50s, 60s, 70s) is to be the same.

All participants were reviewed by a series of questionnaires, including demographic characteristics, personal history, family history and various medical problems. One hundred ninety-four subjects who self-reported a history of ear disease in the questionnaire were eliminated in this analysis, leaving 936 participants who were examined to show the reference values of audiometric tests. The gender and age distribution of the subjects is shown in Table 1. Self-reported hearing problems were able to be checked in 1066 participants.

Instrumentation and procedures

Pure tone audiometric tests were performed with a diagnostic audiometer (AA-73A, RION, Tokyo), calibrated according to JIS (Japanese Industrial Standards T 1201). Air conduction thresholds at octave intervals from 500 to 8000Hz and bone conduction thresholds at octave intervals from 500 to 4000Hz were obtained. The thresholds over the maximum output level of this audiometer were treated as shown in Table 2.

In the analysis of self-perceived hearing difficulty, the following question among 15 otological questions was focused ; "Do you think you have hearing impairment?", with the alternatives being ; "Yes" "Occasionally" "No". The answers, "Yes" and "Occasionally" were put together in the awareness of hearing difficulty in the present analysis.

Middle ear function was assessed with a middle ear analyzer (Grason Stadler model 33, version 2 , Lucas Grason-Stadler,

Inc. Milford, NH) . The first measurement of the test battery was tympanometry performed at a probe tone frequency of 226Hz. Admittance was calculated and shown by an equivalent volume of air in ml. Static admittance and tympanometric peak pressure were taken as variables.

The second measurement of tympanometry was a series of multiple frequency tests. The probe tone automatically swept in frequencies from 250 Hz to 2000 Hz in 50 Hz steps at the start-pressure (+ 200 daPa). Susceptance and phase measurements were stored in memory. The next tympanogram was run at 226Hz and peak data were identified. A second probe tone sweep occurred at peak pressure. The change in susceptance values and phase values between the first sweep and the second sweep of frequencies were calculated and plotted on graphic displays as a function of frequency. The resonance frequency of the test ear was identified as a frequency at which the peak to tail difference values for acoustic susceptance was 0 acoustic mmhos.

Statistical analysis

Data were processed and analyzed using Statistical Analysis System (SAS) version 6.12 software ⁷. Gender differences and laterality in pure tone thresholds were tested with a t-test (T TEST procedure). Age differences in pure tone thresholds were tested using Tukey's multiple comparison method, and trends in pure tone thresholds by age were also examined (GLM procedure). Self-perceived hearing difficulty was compared between two age groups (under 60 years vs. 60 years and over) with a t-test. Spearman's correlation coefficients between age and pure tone thresholds were calculated in octave intervals from 500Hz to 8000Hz (CORR procedure).

RESULTS

Pure tone thresholds

The upper two panels of Figure 1 show the mean air conduction pure tone thresholds in dBHL (dB Hearing Level) and standard errors of the right ear for males and females by four age groups and the lower two panels show those of the left ear. As mentioned earlier, the subjects who self-reported a history of ear disease in the questionnaire were eliminated.

Table 1. Number of subjects by gender and age group without history of ear diseases.

Age Group	Male	Female	Total
40-49	128 (145)	117 (155)	245 (300)
50-59	116 (135)	117 (149)	233 (284)
60-69	109 (139)	117 (134)	226 (273)
70-79	119 (135)	113 (138)	232 (273)
Total	472 (554)	464 (576)	936 (1130)

Numbers in parentheses are the total number of participants.

Table 2. If no response occurred at the maximum output level of the audiometer, the threshold was treated as follows:

	Air conduction		Bone conduction	
	Maximum output level	Input level	Maximum output level	Input level
500Hz	100	105	65	70
1000Hz	100	105	70	75
2000Hz	100	105	70	75
4000Hz	100	105	60	65
8000Hz	95	100		

Figure 1. Air conduction pure tone thresholds by gender and ear. Error bar shows the standard error of the mean.

Age-related changes, gender differences and right/left ear differences in hearing thresholds were examined. There were statistically significant differences between almost any two age groups at each frequency in both genders, especially in higher frequencies. The trends of pure tone threshold by age group at

each frequency for each gender were highly significant ($p < 0.0001$). A gender difference was clear at 4000Hz in any age group ($p < 0.0001$). The differences were smaller but significant at 2000Hz and 8000Hz. There were no significant gender differences at 500Hz and 1000Hz in any age group. As for lat-

erality, almost no significant differences were observed at any frequencies in any age group in either males or females. Table 3 shows the 5, 50 and 95 percentiles of air conduction pure tone thresholds at 500 to 8000Hz by gender and age group.

The results of Spearman's correlation analysis between age and air conduction thresholds are listed in Table 4. All of the correlation coefficients were highly significant ($p < 0.0001$). The higher frequencies were, the greater positive correlation coefficients were in both males and females.

Self-perceived hearing difficulty

Results from inquiry into hearing difficulties are shown in Figure 2 and Table 5. The percentages of subjects who were aware of hearing difficulty were 40.9% for males and 41.7% for females. There was no significant difference in the percentage of hearing difficulty between males and females ($\chi^2 = 0.05$, $df = 1$, NS). The number and percentage of subjects who were aware of hearing difficulty are shown in Table 5. The answers from 872 subjects with no apparent history of ear disease were analyzed. About 41% of these were aware of hearing difficulty in their daily life. Even in subjects aged in their 40s, about one quarter were aware of hearing difficulty. There was a significant age difference in awareness the hearing difficulty ($\chi^2 = 37.1$, $df = 3$, $p < 0.001$).

Mean pure tone thresholds for each age group are shown in the two panels according to the awareness of hearing difficulty (Figure 2). There were significant trends by age group at any frequency ($p < 0.0001$). The pure tone thresholds in subjects with hearing difficulty aged under 60 were compared with the

thresholds in subjects without hearing difficulty aged 60 and over. The thresholds in the younger group with hearing difficulty were better than those in older subjects without hearing difficulty at any frequency ($p < 0.01$).

Tympanometric measurements

Results from tympanometric measurements are shown in Table 6. No directional tendency related to aging was revealed on static admittance, on tympanometric peak pressure or on resonance frequency of the middle ear.

DISCUSSION

Pure tone thresholds

Roughly comparing the results of the present study with the Framingham Cohort Study, a representative international study, the average thresholds of 4000Hz in males in their 60s and 70s and the average threshold of 8000Hz in males in their 60s were better in this study than in the Framingham Cohort Study⁸. For females, the thresholds at any frequency were similar to those in the Framingham Cohort Study. In comparison with the Baltimore Longitudinal Study of Aging (BLSA)⁹, the results in the present study were worse to various extent than those in the BLSA at any frequency or in any generation, except at 8000 Hz in males in their 40s and 50s. Compared with previous domestic estimates, the findings shown through all age groups in this study resembled the longitudinal study reported by Ono¹⁰.

In reference to gender difference, it was indicated in many studies that the hearing acuity in men was poorer than in

Table 3. Percentiles of the air-conducted pure tone threshold by gender and age group.

Age		500Hz			1000Hz			2000Hz			4000Hz			8000Hz		
		5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%	5%	50%	95%
Male	40-49yr	0.0	10.0	20.0	0.0	7.5	20.0	2.5	10.0	25.0	2.5	15.0	37.5	5.0	17.5	45.0
	50-59yr	2.5	12.5	30.0	2.5	10.0	37.5	5.0	15.0	40.0	7.5	22.5	55.0	10.0	30.0	60.0
	60-69yr	5.0	15.0	35.0	2.5	15.0	32.5	7.5	22.5	52.5	10.0	37.5	65.0	17.5	47.5	77.5
	70-79yr	7.5	20.0	50.0	5.0	22.5	57.5	12.5	32.5	67.5	17.5	52.5	80.0	32.5	67.5	90.0
Female	40-49yr	2.5	10.0	22.5	0.0	5.0	17.5	2.5	10.0	25.0	0.0	7.5	22.5	2.5	17.5	45.0
	50-59yr	2.5	12.5	30.0	0.0	10.0	22.5	5.0	12.5	27.5	2.5	12.5	40.0	10.0	25.0	62.5
	60-69yr	7.5	15.0	37.5	2.5	12.5	35.0	5.0	17.5	40.0	5.0	22.5	52.5	15.0	38.8	72.5
	70-79yr	7.5	22.5	45.0	5.0	22.5	45.0	7.5	25.0	60.0	10.0	32.5	70.0	25.0	57.5	92.5

Subjects with a history of ear diseases were excluded.

Table 4. Spearman's correlation coefficients between age and air conduction thresholds.

	500Hz		1000Hz		2000Hz		4000Hz		8000Hz	
	Right	Left	Right	Left	Right	Left	Right	Left	Right	Left
Male	0.46	0.39	0.48	0.47	0.57	0.57	0.60	0.62	0.67	0.69
Female	0.41	0.41	0.51	0.48	0.50	0.51	0.57	0.61	0.67	0.66

All correlation coefficients were significant ($p < 0.0001$).

Figure 2. Air conduction pure tone thresholds according to awareness of hearing difficulty. Error bar shows the standard error of the mean. (Subjects with a history of ear diseases were excluded.)

Table 5. Number and percentage of subjects without history of ear disease who were aware of hearing difficulty by age group.

Age	Aware of hearing difficulty		No hearing difficulty	
40-49yr	61	(26.8%)	166	(73.1%)
50-59yr	85	(39.2%)	132	(60.8%)
60-69yr	95	(45.2%)	115	(54.8%)
70-79yr	119	(54.6%)	99	(45.4%)
Total	360	(41.3%)	512	(58.7%)

Table 6. Percentiles of tympanometric measurements by gender and age group.

	Age	Tympanometric peak pressure (daPa)			Static admittance (ml)			Middle ear resonance frequency (Hz)		
		5th	50th	95th	5th	50th	95th	5th	50th	95th
Male	40-49yr	-20.0	2.5	12.5	0.25	0.50	2.20	525	850	1100
	50-59yr	-47.5	2.5	15.0	0.25	0.55	2.75	475	850	1150
	60-69yr	-87.5	2.5	12.5	0.20	0.40	1.85	550	888	1175
	70-79yr	-77.5	5.0	12.5	0.20	0.45	2.15	450	900	1200
	Total	-65.0	2.5	12.5	0.25	0.60	2.15	475	800	1100
Female	40-49yr	-50.0	2.5	12.5	0.30	0.60	1.65	550	775	1125
	50-59yr	-57.5	2.5	15.0	0.25	0.60	1.55	475	800	1025
	60-69yr	-92.5	2.5	10.0	0.25	0.65	1.50	500	800	1100
	70-79yr	-95.0	2.5	15.0	0.20	0.65	1.25	425	875	1100
	Total	-57.5	2.5	12.5	0.20	0.50	1.50	500	875	1175

women, especially at higher frequencies ^{8, 9, 11, 12}. One of the probable reasons for the progress in male presbycusis was considered to be more risk of noise exposure for men than for women, such as military service, noisy jobs, daily use power tools (yard-keeping, home carpentry), or recreational noise (hunting, loud engines, loud music). Though these studies screened out their subjects from noise-induced hearing loss and otological diseases in various ways, it is impossible to rule out noise exposure and otological disease history from self-reports completely. The difference among hearing thresholds in each study may result partly from the degree of rigorous screening for causes of hearing loss besides aging. Recent domestic investigations found that the gender difference has been getting smaller than reported before ^{13, 14}. Less difference in life-style between genders than before, due to the current reduced chance of military service, little daily power tool usage or hunting in Japan, could have contributed to this finding. In our study, a gender difference was still detected.

A right/left ear difference in hearing thresholds was not revealed in the present study, while laterality was observed in some other studies in which the hearing loss in the left ear was greater than that in the right ^{8, 15}.

Self-perceived hearing difficulty

There are several confounding factors which contribute to self-perception of hearing disability in the elderly. Though hearing threshold levels and word recognition influence self-perception, they are not as strong as determinants. The factors of central auditory processing disorder (CAPD), cognitive deficit or sociological status also affect the self-perception of a hearing handicap ^{2, 3, 6}. While speech understanding deteriorates with worsening pure-tone sensitivity and CAPD, the demand for understanding speech decreases with aging, especially for noisy and degraded speech with which the difference in speech-understanding performance between elderly and young listeners with matched hearing sensitivity becomes obvious.

The inquiry used in the present analysis was not for certain listening situations imagined in detail, but for general situations. Therefore one subject might assume the optimal condition and another the worst. The explanation for the gap between hearing sensitivity and self-perceived difficulty in subjects aged 60 and over can be provided by considering their lower necessity to communicate under difficult listening situations.

Tympanometric measurements

Several investigations have shown the possibility of age-related anatomical changes in the middle ear. Etholm and Belal found that all 34 temporal bones from individuals aged over 70 years showed moderate to severe arthritis in both the incudo-malleal and incudostapedial joints ¹⁶. Moreover, they reported only one of 32 cases, using audiometric studies, showed conductive hearing loss out of the 34 temporal bones. That means

the arthritis in the ossicular joints can exist even though conductive hearing loss is not detected yet. Ruah et al. examined the tympanic membranes of 54 temporal bones from patients aged 33 weeks' gestation to 91 years microscopically ¹⁷. They demonstrated that the tympanic membrane became less vascular, less cellular, more rigid, and less elastic with aging. They also discussed a finding that some older eardrums with no apparent history of otologic disease appeared thicker and less transparent, probably due to deposition of calcium molecules, which are known to have a particular predilection for age-degraded elastic fibers.

Tympanometric measurements are considered to reflect several aspects of middle ear mechanisms ¹⁸. Tympanometric peak pressure at 226 Hz correlates highly with middle ear pressure. When tympanometry is performed with low frequency probe tones such as 226Hz, the middle ear system is mainly controlled by stiffness, because mass reactance is negligible. Therefore, static admittance is expected to change with changes in stiffness. Resonance occurs when the contributions of the mass and the stiffness components of the middle ear are equal. High resonance frequency is associated with middle ear conditions that produce abnormal stiffness in the middle ear, such as ossicular fixation or otosclerosis. Low resonance frequency is associated with eardrum abnormalities, ossicular discontinuity or mass lesions ^{19, 20}. Regarding the anatomical changes with aging, the arthritis in ossicular joints or the higher rigidity of the tympanic membrane causes an increase in stiffness, while the greater thickness of the tympanic membrane with deposition of calcium molecules causes an increase in mass. These degeneration changes affect individuals to varying degrees. One probable reason why the present study did not show any systematic aging change in tympanometric measurements is that these inverse effects might cancel each other out.

There are only a few studies which have investigated the aging transition via tympanometry in the elderly population ^{21, 22}. Thompson et al. reported no significant changes in static admittance or its components, susceptance, or conductance at 220 or 660 Hz in 20 to 79 year old subjects. Holte demonstrated no significant aging effect on the resonance frequency of the middle ear, static admittance at 226Hz and tympanometric width at 226Hz in 136 subjects in their 20s to 90s. The present study also indicated no systematic aging change. However, the present findings provided useful information on the reference values for each generation.

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