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Individual differences of sound-localization ability on median plane

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ABSTRACT

This study examines the relationship between individual differences of sound-localization ability and anthropometric parameters of the pinna shape. We analyze the relationship between inter-subject differences of localization ability and pinna shape by the sound localization test on the median plane. We conducted a localization test for ten subjects by using sound sources in the frontal quadrant of median plane on the upper hemisphere. The result shows there are inter-subject differences for the localization ability and two subjects are hardly responded to the sound source. The degree of response error was quantified by calculation of root-mean-square (RMS) between a presented source angle and a perceived one. Ten pinna shape parameters were measured from seventy-two subjects and ten of them were the same subjects as used for the localization test. Principal component analysis was applied for the left pinna shape parameters by using Martin's method. Three components are extracted and the first principal component was considered to be a ear length and a prominent from the head. Three components were compared with the value of response error by the ten subjects. There was a negative significant correlation ($r=-0.69$, $P<0.05$) between the value of response error and the first principal component score. Therefore results of the analysis suggest that individual differences of localization ability were primarily related to the first principal component of the pinna shape.

1. INTRODUCTION

Many researchers propose sound localization technologies for high realistic presence. Morimoto and Ando [1] have shown that accurate horizontal and median plane localization can be attained without any consideration of head movements if head-related transfer functions (HRTFs) are accurately and completely simulated. Morimoto and Aokata [2] indicate that the lateral angle and the rising angle are determined independently of each other. Kirkeby, Nelson and Hamada [3] suggest a virtual sound source system using two close loudspeakers, which is very robust with respect to head movements. But sound field reproduction for the elevation angle is difficult because there are individual differences for HRTFs. It is well known that the individual differences of HRTFs depend on the pinna shape in particular in the elevation angle.

In this paper, we examine the relationship between individual differences of localization ability and anthropometric parameters of the pinna shape. We analize the pinna shape in localization ability by the sound localization test on the median plane. Both ears have the same distance from the sound source on the median plane. As a result, interaural-level-difference (lLD) and interaural-time-difference (ITD) cues are invariant. We conducted a localization test on the median plane to investigate for inter-subject differences of localization ability. The perceived angles by two subjects are hardly responded to the sound source although actual sound sources were used for the localization test. A principal component analysis was applied for the left pinna shape parameters by using Martin's method as the pinna shape features. Localization abilities were compared with extracted components and the pinna shape parameters to examine for individual differences.

2. SOUND-LOCALIZATION TEST

2.1. Subject

Subjects were ten males and ranged from 22 to 26 year in age (23.4±1.4, mean±standard deviation) with normal hearing sensitivity.

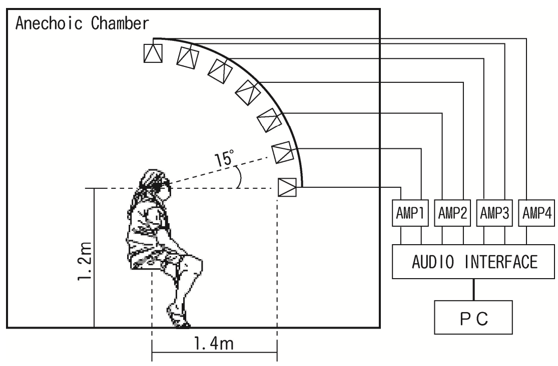

Figure 1. Test system diagram in anechoic chamber

2.2. Apparatus and procedure

The sound-localization test was carried out in an anechoic chamber. Sound sources (Fostex model fe87e) are located from 0 to 90 degrees at a 15 interval degree in the frontal quadrant of median plane on the upper hemisphere as shown in Fig.1. The source was 1.4m distant from the center of the subject's head where presented sound presure level was 65dB (SPL). The duration of the stimuli was 1s and the interval between two stimuli was 14s. The sound stimuli was the band-limited white noise (250～12,500Hz), which were presented ten times for each direction in random order. The task by the subjects was to mark down the angle of a sound image on the recording sheet. Two angular scales for an angle reference were placed on both sides of the sound source. Each subject was separately tested while seated and head-fixed in anechoic chamber and made 70 trials (10 × 7, times × direction) for the band-limited white noise. The same localization test set was conducted four months later after the first test set to confirm the validity of test results. The result for both test sets is similar.

2.3. Test results

The test result shows there are inter-subject differences for the localization ability and two subjects (S2 and S10) are hardly responded to the sound source. The degree of localization error $\underline{D}$ was quantified by calculation of root-mean-square (RMS) method as a total error. Average root-mean-squares for all direction sources on the median plane are computed as follows:

$$\underline{D} = \frac{1}{M}\sum_{j=1}^{M}|E_j| \qquad (1)$$

where j (= 1,...,M) is a source direction number, and E_j is localization error by root-mean-square method for each source directions. This function is given by

$${E_j}^2 = \frac{1}{N_j}\sum_{i=1}^{N_j}(R_{i,j} - S_j)^2 \qquad (2)$$

where $R_{i,j}$ is a subject's responded angle on the scale of source numbers to the ith trial on which stimulus source S_j, presented source direction angle, is presented. The total number is N_j trials. E_j indicates localization error from the presented source angle to the responded one for each source direction. $\underline{D}$ indicates the total error for each subject in the sound-localization test. Table 1 shows the computed values for each subject as the total error. The results of localization test indicate that there are individual differences in localization ability because of two subjects are hardly responded to the sound source.

Table 1. Total error $\underline{D}$ of first localization test

No.	$\underline{D}$	No.	$\underline{D}$
S1	12.92	S6	10.56
S2	28.70	S7	7.77
S3	11.07	S8	14.58
S4	22.44	S9	9.41
S5	8.50	S10	34.27

3. ANALYSIS OF PINNA SHAPE

3.1. Subjects

Pinna shape parameters were measured from seventy-two subjects, fifty-five males and 17 females ranged from 18 to 31 year in age (22.2±1.9, mean±standard deviation). Ten of them were the same subjects as used for the localization test.

3.2. Method

Left ear of the subjects were measured from ten parameters using Martin's method. A caliper was used to measure distances between the points on the external ear shown in Fig.2. The measurements include (1)superaurale to subaurale (physiognomic ear length, A to B), (2)praeaurale to postaurale perpendicular to physiognomic ear length (physiognomic ear breadth, C to D), (3)incisura auris anterior immediately above tragus to tuberculum auriculae (morphological ear breadth, E to F), (4)otobasion superius to otobasion inferius (morphological ear breadth, G to H), (5)superaurale to crus anthelicis inferius along the lines with physiognomic ear length (A to I), (6)subaurale to crus helicis along the lines with physiognomic ear length (B to K), (7)crus antihelix to incisura intertragica (concha length, I to J), and(8)incisura terminalis auris to antihelix perpendicular to physiognomic ear length (concha breadth, L to M). In addition, the other parameters were (9)prominent length (N) and (10)prominent angle (O [degree]) from the head. Table 2 gives summary statistics of these measurements.

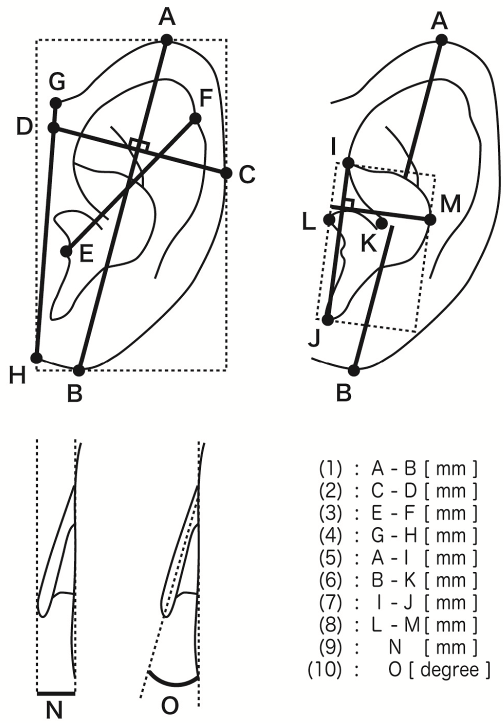

Figure 2. Ten anthropometric parameters of the pinna shape by Martin's method

Table 2. Summary statistics of ten measurements by using Martin' method

		Mean	Std.Division
(1)	A ~ B [mm]	63.22	4.88
(2)	C ~ D [mm]	33.42	2.25
(3)	E ~ F [mm]	31.33	3.61
(4)	G ~ H [mm]	53.35	4.98
(5)	A ~ I [mm]	20.99	2.34
(6)	B ~ K [mm]	33.57	3.26
(7)	I ~ J [mm]	27.48	2.41
(8)	L ~ M[mm]	20.59	2.24
(9)	N [mm]	21.40	3.24
(10)	O [degree]	30.97	6.90

3.3. Principle component analysis

Principal component analysis shows that the first principal component was considered to be "a ear length and prominent from the head" factor, the second principal component was considered to be "no prominent from the head" factor which involve a factor by lower part of the pinna vertical axis and upper part of the horizontal axis, and the third principal component was considered to be "a ear breadth" factor. Table 3 shows the first to the third principal component loading for each parameters and each proportion of variance. Fig.3 shows a plot of all subjects by the first and second principal component scores including ten subjects who participated in the localization test.

Table 3. Results of extracted component loading

proportion of variance	PC1 (40.9%)	PC2 (35.6%)	PC3 (10.9%)
dimension			
(1)	0.81	0.52	
(9)	0.81	-0.34	
(7)	0.74		
(5)	0.63	0.30	0.40
(6)	0.63	0.50	
(10)	0.69	-0.72	
(2)		0.68	0.48
(4)	0.43	0.67	-0.56
(3)	0.47	0.56	0.52
(8)		0.37	0.60

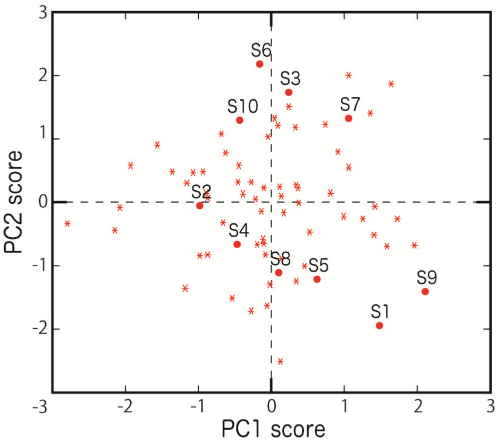

Figure 3. First and second component scores

4. DISCUSSION

We examined the relationship between individual differences of localization ability and anthropometric parameters of the pinna shape. In the results of sound-localization test, two subjects (S2 and S10) of responded angles with the highest value of <u>D</u>, which means disability for sound localization test, are hardly responded to the sound source in the localization test as shown in Fig.4. For comparison, Fig.5 shows the test result of two subjects (S5 and S7) with the lowest value of <u>D</u>. For example, Fig.4 (a) shows the result by subject S2 with the first test 1, each bubble indicates each response by S2, and the size of a bubble corresponds to the frequency of the same response at 5 degree intervals. The horizontal axis denotes the presented source angles and the vertical axis denotes the responded angles. The diagonal line in Fig.4 and Fig.5 indicates the ideal response line on which the responded angle corresponds with the presented source angle. In the pinna shape analysis, three components are extracted

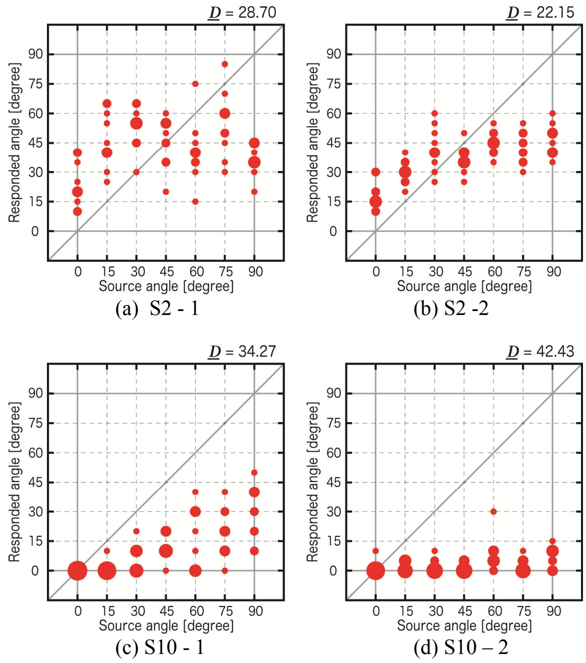

Figure 4. Results of Sound-Localization test by S2, S10.

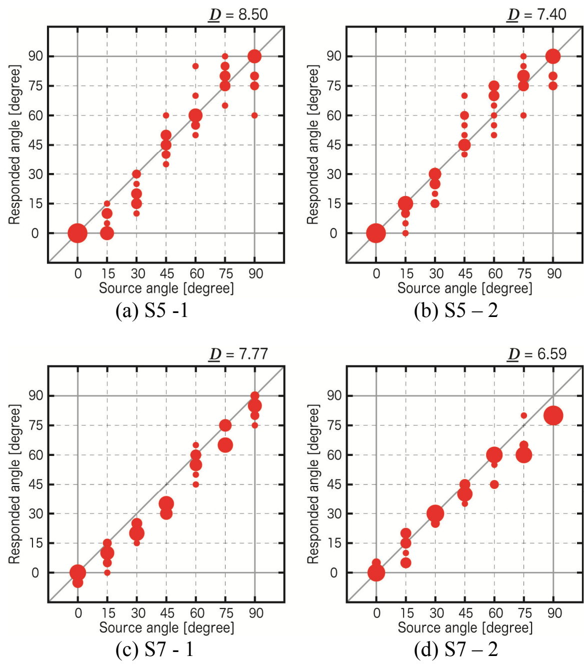

Figure 5. Results of Sound-Localization test by S5, S7.

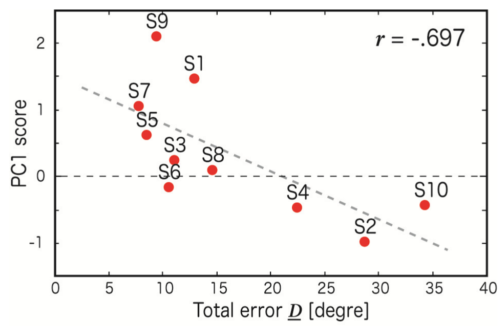

Figure 6. Relationship between PC1 and total error <u>D</u>

with the measurements of ten parameters using Martin's method. Three component scores and ten parameters were compared with total error $\underline{D}$ by ten subjects to examine the relationship between each pinna parameter and the localization ability. As a result, there was a negative significant correlation ($r=-0.69$, $P<0.05$) between the value of $\underline{D}$ and the first principal component score shown in Fig.6. In addition, the relations between the value of $\underline{D}$ and the other component scores were not significant and the correlation value of the first component was higher than ten parameters. Therefore results of the analysis suggest that individual differences of localization ability are primarily related to the first principal component.

5. CONCLUSION

The results of localization test indicate that there are individual differences in localization ability because of two subjects are hardly responded to the sound source and a few subjects are accurately localized. Pinna shape features are extracted by principal component analysis by using mesurements of Martin's method. Individual differences of localization ability are compared with pinna shape features which are three component scores and ten parameters by Martin's method. As a result, there is a relationship between sound-localization ability and pinna shape of the first principal component score. The data suggest that individual differences of localization ability are primarily related to the first principal component which contains ear length and prominent factor although the lack of data for the localization tests.

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