MEASUREMENT AND APPLICATION OF 3D EAR IMAGES FOR EARPHONE DESIGN

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Detail anthropometric dimensions and a 3D shape of the outer-ear are applicable to design ear-related products such as an earphone. However, 3D scanning of the ear part is quite difficult due to a complex shape of the ear, also detailed ear dimensions which are needed to be measured for earphone design were not identified in previous studies. This study collected 3D scan images of the whole outer-ear from 100 Korean participants (50 females and 50 males) aged 20 to 59, then measured their detailed ear dimensions for earphone design. The pinna part was directly 3D scanned; and complex shape of the concha and acoustic canal parts were cast by applying an ear casting tool, then the cast was scanned in 3D. 13 ear dimensions were measured by applying an ear measurement system coded using Matlab. Both 3D ear scans and ear measurements were applied to design some earphone parts (earphone-head, ear-band, ear-tip) in this study.

INTRODUCTION

A 3D scan image of the outer-ear can be usefully applied to design earphones. The structure of the outer-ear can be divided into three main parts: the pinna, concha and external auditory canal. Detail and complex shape of the outer-ear can be quite useful to design parts (e.g., earphone-head, ear-tip, ear-band, hook) of various types of earphone (e.g., open type, canal type, hybrid type; Figure 1). To use 3D ear images in earphone design, the whole outer-ear part needs to be accurately scanned. However, due to a complexity of the ear shape, a 3D body scanner can scan roughly only partial areas of the pinna and concha shapes. Not only those complex shapes in the pinna and concha, but also the auditory canal located inside the concha need to be 3D scanned to use them in earphone design (Jung et al. 2014; Lee et al. 2015).

Figure 1. Types of earphone (illustrated)

Previous studies measured mainly overall ear dimensions which are not enough to be used in earphone design. Most of studies measured dimensions of the pinna part (e.g., ear length, ear width). A few studies (Ahmed and Omer 2015; Algazi et al. 2001; Bozkir et al. 2006; Kalcioglu et al. 2003) measured some dimensions of the concha part. Most of those previous studies focused on an anthropometric survey of the ear, while Jung and Jung (2003) and Liu (2008) measured the ear dimensions for an application to earphone design. But Jung and Jung (2003) and Liu (2008) did not include specific dimensions of the concha and acoustic canal parts in their measurement surveys. Detailed ear dimensions which are necessary in design of various types of earphone require to be measured for better application in earphone design.

This study acquired the 3D ears of 100 Korean civilians and applied them in earphone design. Outside and inside of the ear were captured in 3D. 13 ear-related dimensions were identified in this study, then measured based on the 3D ear scans. The measurements and the scanned 3D ears were applied to design earphones.

MEASUREMENT METHOD

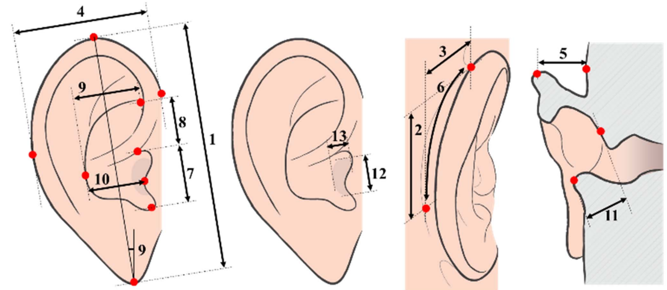
Participants

The right ears of 100 Koreans (50 females and 50 males) aged 20 to 59 were 3D scanned and measured in this study.

Ear Dimensions

13 ear dimensions were selected through a review of literatures and the decision by experts. 22 ear dimensions (length: 8; width: 7; depth: 1; angle: 2; ratio: 3; thickness: 1) were identified from 22 papers (Ahmed and Omer 2015; Alexander and Laubach 1968; Algazi et al. 2001; Barut and Aktunc 2006; Bozkir et al. 2006; Buckley et al. 2005; Dellepiane et al. 2008; Hammond et al. 2004; Herskovits 1930; Jung 2000; Jung and Jung 2003; Jung et al. 2014; Kalcioglu et al. 2003; Kaushal and Kaushal 2011; Liu 2008; Meijerman, van der Lugt, and Maat 2007; Mohamed et al. 2013; Nathan et al. 2008; Paulsen 2004; Porter and Olson 2001; Sickel et al. 2011; Taura, Adamu, and Modibbo 2013; Yoon and Jung 2002). 6 dimensions (length: 3; width: 2; depth: 1) were selected in the present study (Figure 2). And additional 7 dimensions (length: 5; width: 1; arc: 1) were newly proposed

by a panel of five ergonomists as its applicability to the design of earphones shown in Figure 1. For measurement of the selected ear dimensions, 12 landmarks were defined as shown in Figure 3 by referring to aforementioned literatures.



Category		No	Ear dimensions
Ear dimensions	Length	1	ear length
		2	otobasion superius to otobasion posterius horizontal length†
		3	otobasion superius to otobasion posterius vertical length†
	Width	4	ear breadth
		5	ear protrusion
	Arc	6	upper otobasion arc†
Concha dimensions	Length	7	cavum concha length
		8	superior cavum concha to anterior cymba concha length†
		9	posterior concha to anterior cymba concha lengt†
	Width	10	cavum concha width
	Depth	11	cavum concha depth
Ear canal dimensions	Length	12	ear canal length†
	Width	13	ear canal width†

Figure 2. Anthropometric dimensions of the ear
(†: landmarks identified in this study)

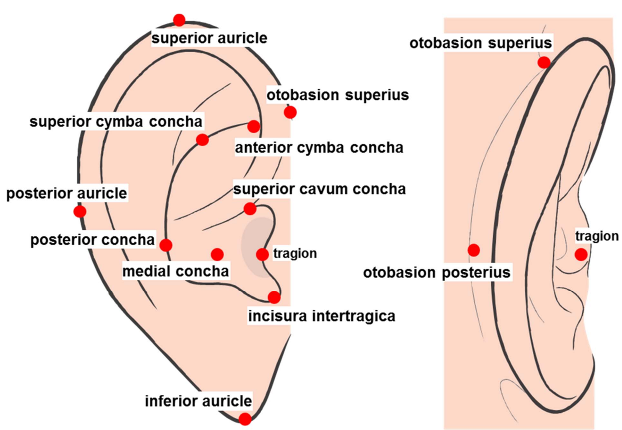


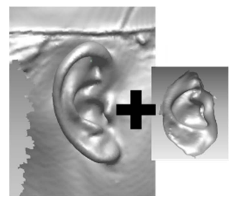
Figure 3. Anthropometric landmarks of the ear

3D Scanning of the Ear

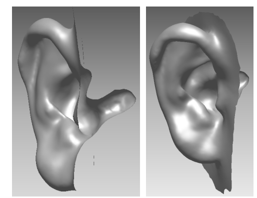
The pinna part, and the concha and acoustic canal parts were separately obtained by different 3D scanning methods, then merged and edited for the ear measurement. The right pinna was captured using Artec Eva (Artec Group, Inc., Luxembourg) 3D scanner and the Artec Studio 9 (Artec Group, Inc., Luxembourg) image processing software (Figure 4.a). The right concha with the ear canal was cast by referring to a method of crafting custom hearing aid using Otoform (Dreve Otoplastik GmbH, Germany), an ear canal casting material (Jung et al. 2014; Mohamed et al. 2013; Paulsen 2004) (Figure 4.b). Then, the scanned pinna and concha were merged in one 3D ear and edited by applying hole-filling, smoothing, and abnormal surface cleaning functions provided by Artec Studio and RapidForm 2006 (INUS Technology, Inc., Korea), the image processing software (Figure 4.c & 4.d). The ear landmarks were manually identified on the merged ear using RapidForm 2006.

(a) scanning of the pinna part

(b) casting and scanning of the concha and acoustic canal parts



(c) merging the pinna and concha/canal parts



(d) the whole outer-ear in 3D

Figure 4. 3D scanning of the ear

Ear Measurement

Then, the ear dimensions were measured using a program developed with Matlab (MathWorks, Inc., Natick, MA, USA) in this study. All 13 ear dimensions were measured by calculating Euclidian distances between corresponding landmarks.

MEASUREMENT RESULTS

The descriptive statistics (mean, SD, minimum, maximum and percentiles) of some ear measurements of Koreans (mixed gender; N = 100) are illustrated in Tables 1.

Table 1. Descriptive statistics of Korean (mixed gender; N = 100) ear anthropometric data (illustrated; unit: mm)

no.	dimension	mean	SD	min	max	percentile 25%	percentile 75%
1	ear length	63.5	4.2	53.2	76.4	60.6	66.4
4	ear breadth	31.3	2.9	22.8	39.2	29.5	33.5
5	ear protrusion	17.1	3.0	11.1	26.8	14.9	19.1
7	cavum concha length	17.2	1.3	12.9	21.2	16.4	18.1
10	cavum concha width	16.9	1.8	11.6	21.5	15.6	17.9

EARPHONE DESIGN

The 3D scanned ears and those measurements were applied to design earphones. Of various design elements of earphones, three parts are illustrated in this paper.

Earphone-Head Design

An earphone-head which fits in the concha part was designed by referring to the concha measurements. The earphone-head is a main part of open-type earphone and houses the speaker. The width and height lengths of the earphone-head were identified based on related concha dimensions such as cavum concha length, cavum concha width, ear canal length, and ear canal width (Figure 6). This study 3D printed earphone dummies having different sizes (diameter: 15 ~ 19 mm; interval: 0.5 mm) for the earphone-head (Figure 7) and surveyed a preferred size of the earphone-head with the participants (N = 200). The preferred earphone-head size was significantly correlated to their concha width (r = 0.223 and p = 0.026 in 100 male participants, r = 0.338 and $p < 0.001$ in 100 female participants), while no significant interrelations between the size of earphone-head and the other concha dimensions (concha length, ear canal length, and ear canal width) were found (α = 0.05).

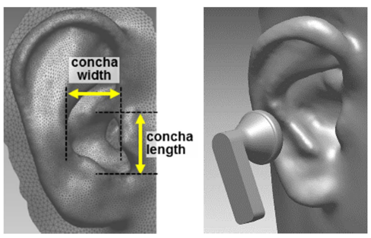


Figure 6. Design of the earphone-head based on anthropometric sizes of the concha part (illustrated)

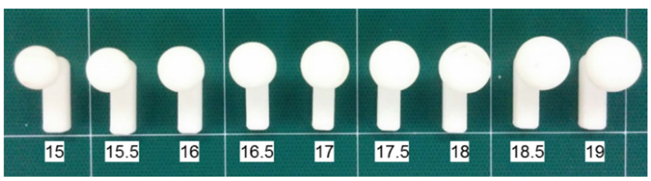
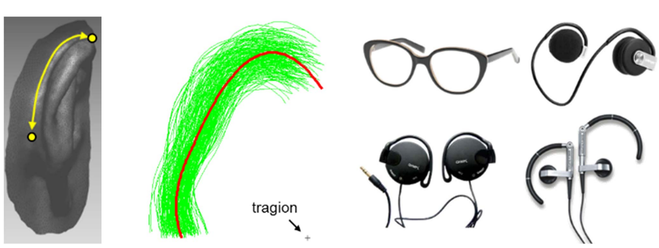


Figure 7. Prototypes of earphone having different head sizes

Ear-Band Design

An ear-band which fits on the root of the ear (ear-root) was designed based on curvatures of the ear-root (Figure 8). The ear-band is to hold earphone (or ear-related product) on the ear position stably. Curvatures of all participants' ear-root were extracted using a program coded with Matlab based on otobasion superius and otobasion posterius landmarks as illustrated in Figure 8.a. All the curvatures (green lines in Figure 8.b) were aligned based on tragion landmark and an average shape of the ear-root were found. The average shape (red line in Figure 8.b) of the ear-root can be utilized to design ear-band shapes for various ear-band-type earphones, headphones, or glasses as illustrated in Figure 8.c.

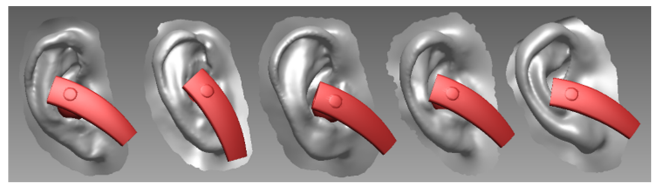


(a) (b) (c)

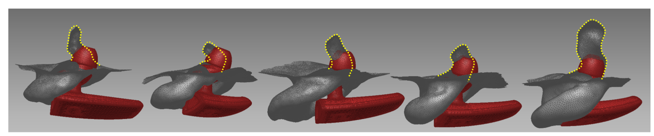
Figure 8. Design of the ear-band based on curvatures extracted from the 3D scan images (illustrated)

Ear-Tip Design

The ear-tip can be designed based on a virtual fit analysis of an earphone with the 3D ears. One of commercial canal type earphone was worn in the ear of 10 participants, and their ears with wearing an earphone (ear+earphone) were 3D scanned by Artec scanner. The 3D scanned ear of each participant was registered to the 3D ear+earphone through Artec Studio, the image processing program. The 3D scanned earphone was also registered to the 3D ears+earphone images. Thus, the 3D earphone image was virtually fit in 3D ears by referring to the 3D ear+earphone images, respectively (Figure 9.a). The fit characteristics of earphone toward the ear canal can be analyzed for ear-tip design (Figure 9.b).



(a) virtual fit of earphone into the ear



(b) analysis of fit based on virtual fitting

Figure 9. Virtual fit analysis of the ear-tip part (illustrated)

DISCUSSION

The whole complex outer-ear shape including the pinna, concha, and acoustic canal parts was 3D scanned in this study. To scan the complex ear shape in 3D, this study applied the casting material which was usually used to design a custom hearing aids. By applying the casting technique, this study could capture the internal shape in the acoustic canal, which can be usefully applied to design the ear-tip part. Also, the 3D scan image data collected in this study can be applied to various kind of ear-related products such as earphones, headphones, hands-free earsets, glasses, or future smart wearable devices.

This study identified detailed ear anthropometric dimensions including new ear dimensions for the application in earphone design. This study found that the existing ear dimensions measured in previous studies were not enough to be used in earphone design. Seven additional ear dimensions were newly defined based on the existing landmarks for its better applicability in ear-related product designs.

The 3D body scan images were applied to design parts of a product in different ways (design based on anthropometric measurement, design based on curvatures, and design through virtual fit analysis). For example of earphone design in this study, design dimensions of some earphone parts such as earphone-head were identified based on the concha measurements by following the traditional anthropometry-based product design approach. Second, design dimensions of some earphone parts such as ear-band shape were designed based on curvatures of the ear-root (Lee et al. 2015). Lastly, design dimensions of some earphone parts such as ear-tip shape can be found based on 3D images through virtual fitting (Lee 2013; Lee et al. 2013; Lee et al. 2015). While curvatures can support a limited information about shape (e.g., line between two landmarks, 2D line of a cross-section) of the body part, the virtual fitting can present advanced information in shape (e.g., shape difference, interference, fit).

Based on the 3D ear images with all their landmarks, new ear dimensions can be additionally defined for design of various parts of ear-related products. Some virtual landmarks (e.g., center of concha, center of ear canal) can be defined based on the other existing landmarks. Then, more dimensions (e.g., center of concha to otobasion superius length, center of concha to anterior cymba concha length, center of concha to incisura intertragica length, ear canal depth, ear canal azimuth/elevation angles) which are closely related to design detailed parts of earphones (e.g., earphone-head, earphone-body, ear-tip, hook) can be measured.

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