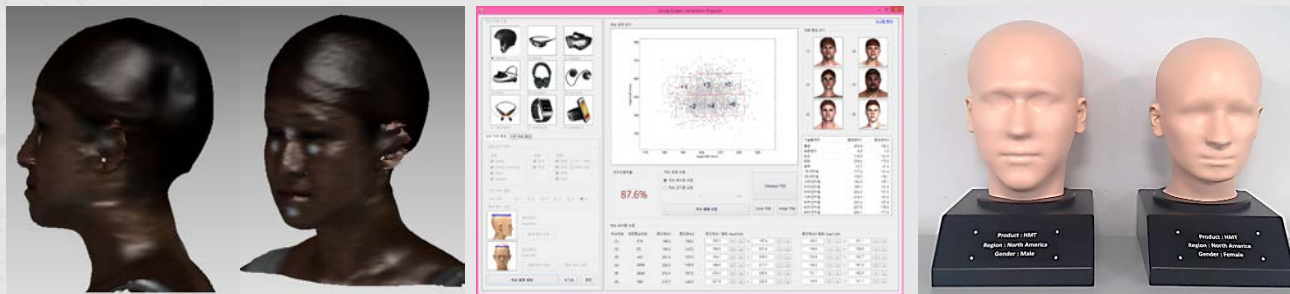




Ranked No. 1 in 2012-2014
at the "Times 100 under 50"
Young University Rankings



Development of Headforms and an Anthropometric Sizing Analysis System (3D-ASAS) for Head-Related Product Designs



Wonsup Lee^{1,2}, Baekhee Lee², Sungho Kim², Hayoung Jung², Ilguen Bok³,
Chulwoo Kim³, Ochaekwon³, Teukgyu Choi⁴, and **Heecheon You²**

¹Faculty of Industrial Design Engineering, Delft University of Technology, Delft, The Netherlands

²**Department of Industrial and Management Engineering, Pohang University of Science and Technology, Pohang, South Korea**

³Design Team, Mobile Communication Division, Samsung Electronics, Seoul, South Korea

⁴Humanopia, Co. Ltd., Pohang, South Korea

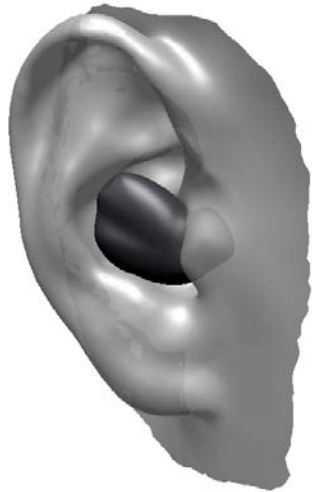
Contents

- **Introduction**
 - Background
 - Objectives of the Study
- **Analysis of CAESAR 3D Scan Data**
- **Development of 3D-ASAS**
- **Development of headforms**
- **Discussion**

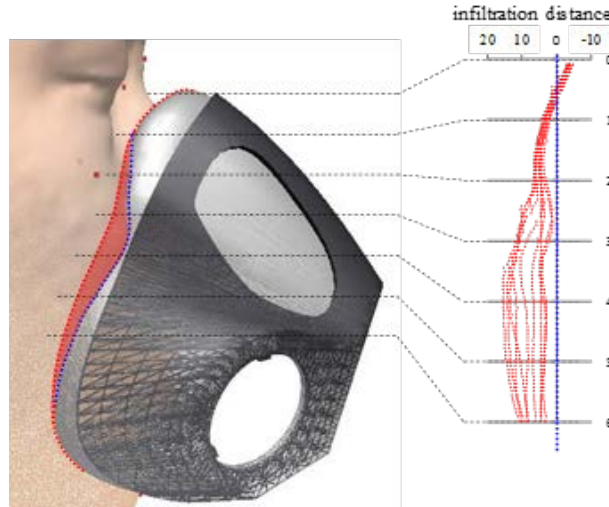
Usefulness of 3D Body Scans for Product Design

- Support **various and detailed measurements**
- Support **complex dimensions (e.g., curvature, shape, area, volume)** which are **directly applicable to product designs**

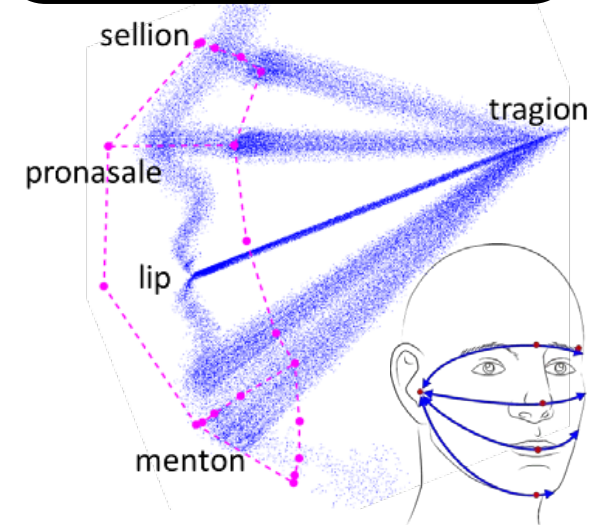
Design of earset based on size and shape of **representative ear** found from 300 ears



Virtual fit analysis for an **optimal design** of pilot's oxygen mask by applying all 336 3D facial shapes



Design of dust-proof mask based on **key 3D curvatures of the face** ($N = 336$)



Application of 3D scan images to the product designs (Lee et al., 2015)

CAESAR Database

- **Civilian American European Surface Anthropometry Resource (CAESAR)**
 - ✓ Survey year: 1998 ~ 2001
 - ✓ Sample size
 - **2,400 North Americans (USA, Canadian)**
 - 2,000 Europeans (Dutch, Italian)
 - ✓ Ethnicity
 - Caucasian (82%; $N = 3,500$)
 - African American (6%; $N = 300$)
 - others (Asian, Hispanic, and ethnic minorities; 12%; $N = 600$)
 - ✓ Age: 18 ~ 65
 - ✓ Database
 - 3D scan images (3 postures)
 - 80 landmarks
 - 40 traditional measurements
 - 60 3D measurements
 - demographic information



Needs of Post-Processing of CAESAR Image

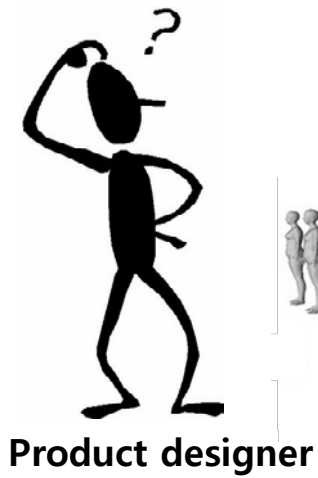
- Poor quality or unnatural shape in CAESAR 3D heads
 - ✓ **Large uncaptured area** on the left side of head
 - ✓ Lots of **holes**
 - ✓ **Unnaturally volumized hair**

⇒ **Post-processing** is required for **better use to the product design**



Needs of Sizing System and RHMs Analysis System

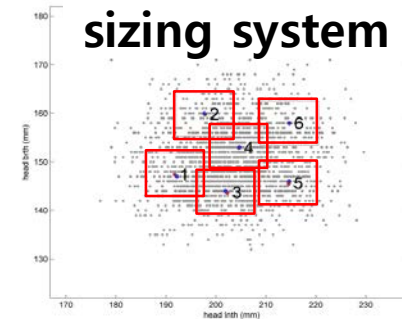
- **Sizing system** and **representative human models (RHMs)** are more useful than raw 3D scan database for product designers



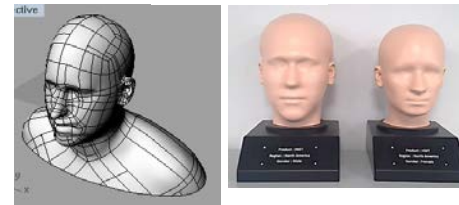
hundreds of
raw 3D scan images



Vs.



RHMs



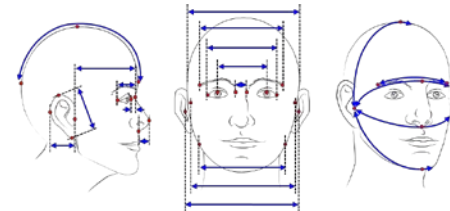
- However, **statistical analyses of sizing system and RHMs are quite complex** to be performed by product designers

⇒ **A computerized program is required for easy and convenient analyses of sizing system and RHMs for PD practitioners**

Objectives

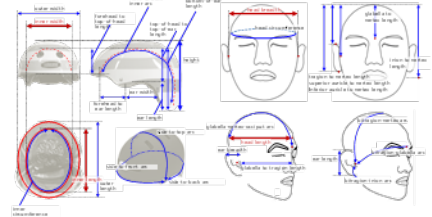
Development of Headforms and an Anthropometric Sizing Analysis System (3D-ASAS) for Head-Related Product Designs

1. Identification of **design dimensions** and **head anthropometric dimensions** for head-related product designs
2. **Post-processing of CAESAR 3D head images** for the measurement of head dimensions
3. Development of a **computerized system (3D-ASAS)** which supports the **product design** in terms of anthropometric analysis, sizing system generation, and RHMs analysis
4. Utilization of 3D-ASAS to develop **digital and physical headforms** applicable to the product design



Approach

S1 Identification of **product design dimensions** and related **head anthropometric dimensions**



S2 **Post-processing** of CAESAR 3D heads



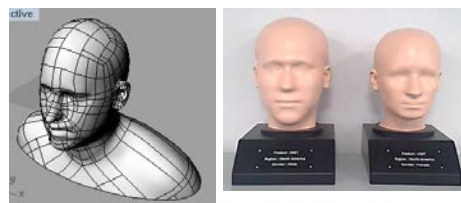
S3 **Landmarking** and **anthropometric measurement** of CAESAR heads



S4 Development of **3D-ASAS**



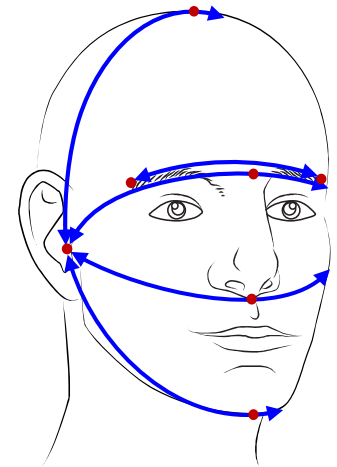
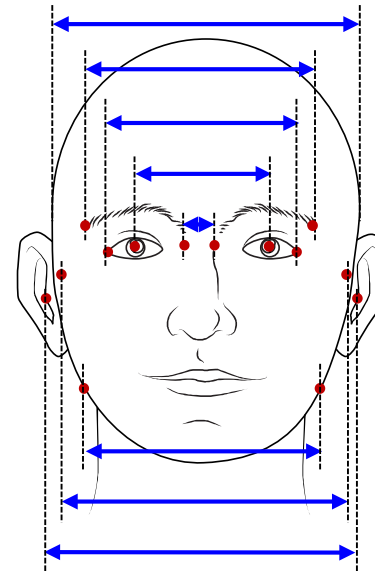
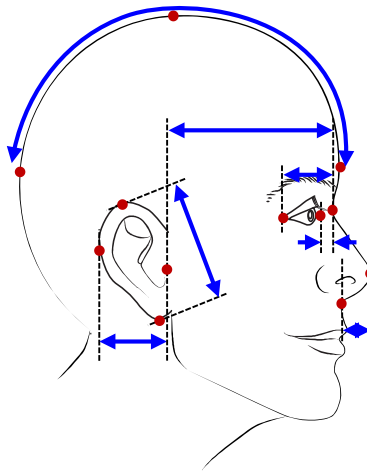
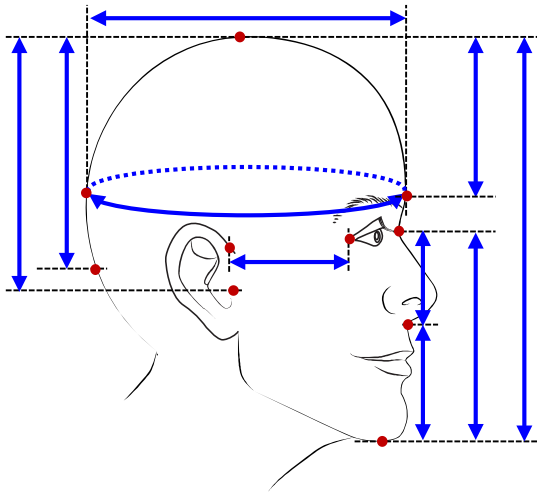
S5 Development of **headforms**



S1. Identification of Head Anthropometric Dimensions

- Identified **122 head dimensions** by referring to 18 previous studies
 - ✓ Length dimensions: 53
 - ✓ Depth dimensions: 29
 - ✓ Width dimensions: 18
 - ✓ Circumference/arc dimensions: 22

Illustration of head and facial dimensions



Type of Products

- Determined **7 head-related products** through discussion of a panel of ergonomists and expert product designers



helmet



glasses



google



HMD



headphone:
headband type



headphone:
neckband type

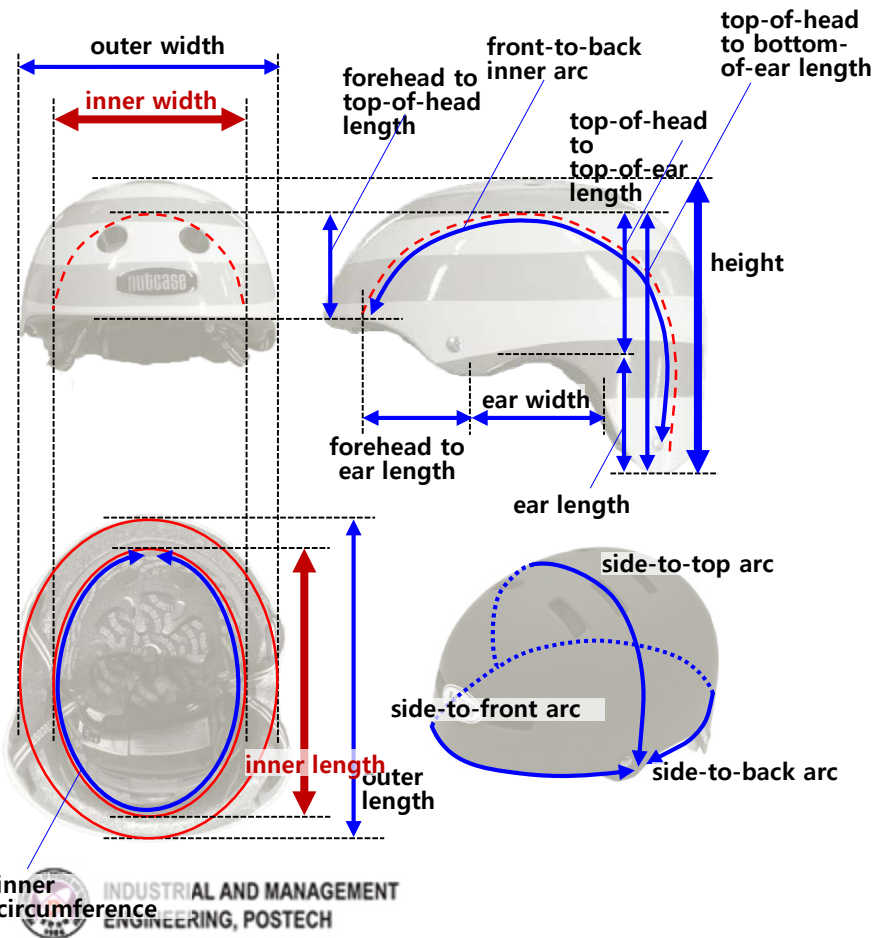


neckband

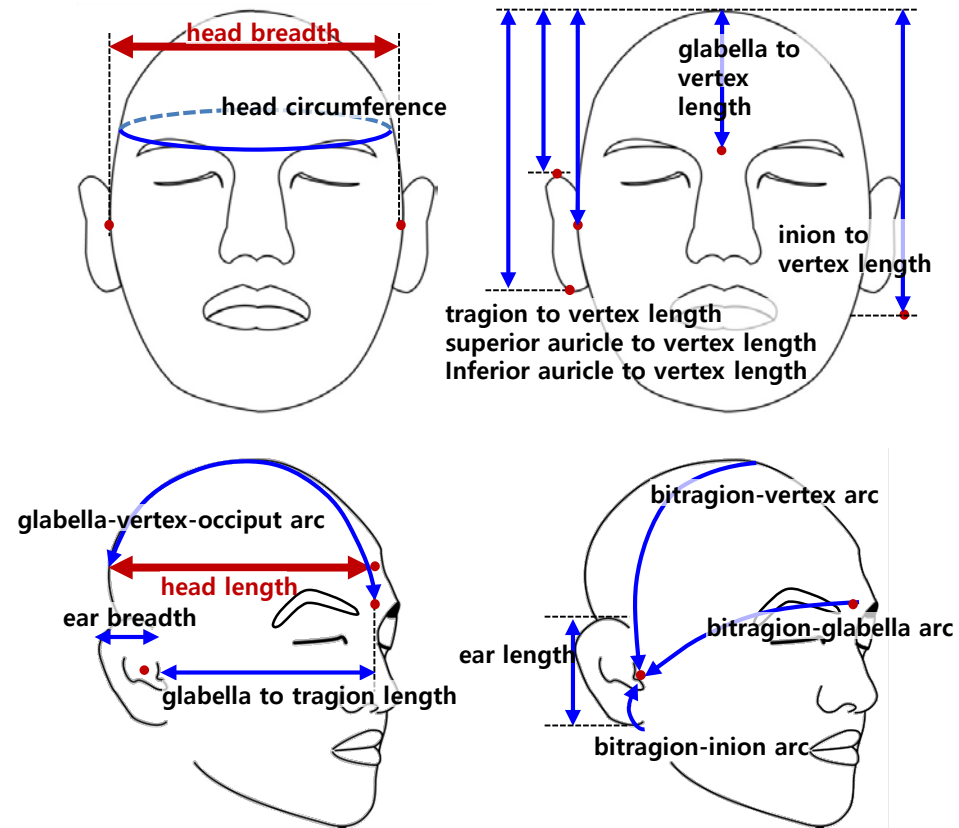
Design Dimensions and Related Head Dimensions: Helmet

- Identified **design dimensions** and **related head dimensions** for each product

Design dimensions (16)










Head dimensions (18)



red: key dimensions

Key Design & Anthropometric Dimensions

- Identified **key design dimensions** and **related key anthropometric dimensions** for each product

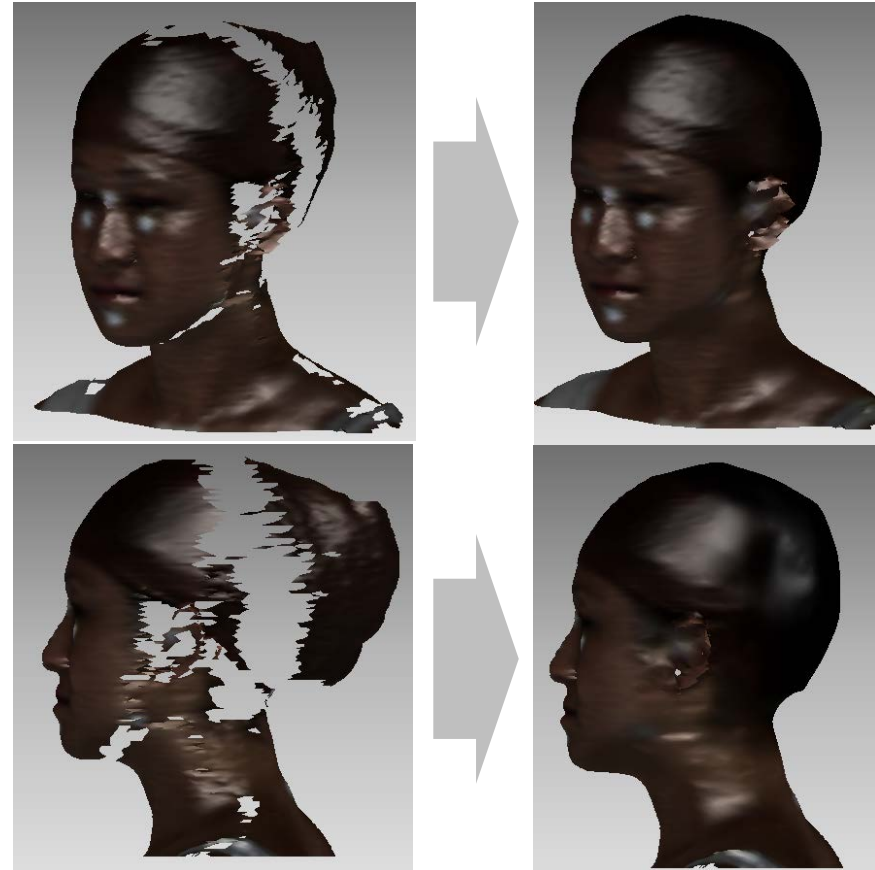
No.	Product type		Key design dimension	Related key anthropometric dimension
1	Helmet		inner length	head length
			inner width	head breadth
2	glasses		width	biocular breadth
			frame length	otobasion superius to ectocanthus length
3	goggle		glass arc	bizygofrontale arc
			frame length	otobasion superius to ectocanthus length
4	HMD		forehead arc	bizygofrontale arc
			zygomatic arc	bizygomat-subnasale arc
5	headphone: headband type		headband length	bitragion-vertex arc
			inner width	bitragion breadth
6	headphone: neckband type		neckband arc	bitragion-inion arc
			inner width	bitragion breadth
7	neckband		circumference	neck circumference

S2. Sample of CAESAR Post-Processed

No.	Category	Male		Female	
1	Used in this study (N = 2,299)	1,086	96.8%	1,213	96.1%
	- Caucasian	862	76.8%	956	75.8%
	- African American	111	9.9%	147	11.6%
	- Asian	81	7.2%	92	7.3%
	- Hispanic	32	2.9%	18	1.4%
2	Excluded samples	36	3.2%	49	3.9%
	- Ethnic minorities	23	2.0%	41	3.2%
	- Heads have huge uncaptured area	7	0.6%	1	0.1%
	- Heads much deformed during scanning	2	0.2%	5	0.4%
	- Heads with no ethnic information	2	0.2%	1	0.1%
	- Inappropriate data structure	2	0.2%	-	-
	- Head with eye patch	-	-	1	0.1%
	total	1,122	100%	1,262	100%
				2,384	

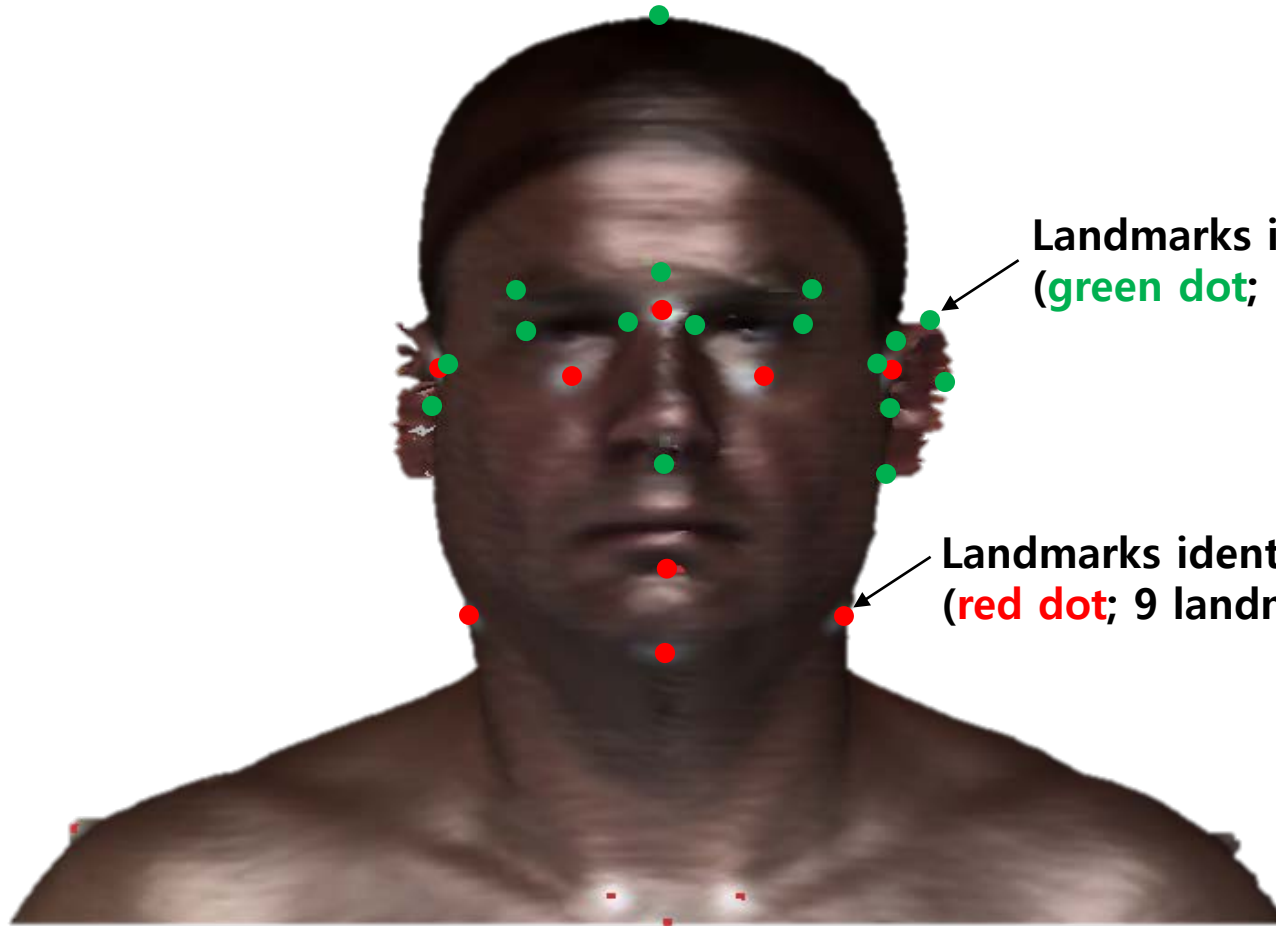
Post-Processing of CAESAR Heads

- **Manual post-processing** of 2,299 CAESAR heads
 - ✓ Hole-filling
 - ✓ Modification of hair style
 - ✓ Smoothing
 - ✓ Elimination of unnatural features
 - ✓ Rotation of head
 - ✓ Landmarking
- Processing time: 260h



S3. Landmarks Used in This Study

- **Manual identification of 19 additional landmarks** for the measurement of 30 head dimensions



Landmarks identified in this research
(**green dot**; 19 landmarks on the head)

Landmarks identified in CAESAR database
(**red dot**; 9 landmarks on the head)

Measurements: Caucasian Male

- All head dimensions were automatically measured using a Matlab program by ethnic group

No.	Anthropometric dimensions	N	Mean	SD	Min	Max	Percentile			
							1 st	5 th	95 th	99 th
1	head height	854	229.7	12.8	193.9	274.6	200.7	208.9	250.2	259.3
2	head length	862	195.4	9.3	169.0	219.0	174.0	180.0	210.0	214.0
3	head breadth	854	151.5	6.9	135.0	172.0	137.0	141.0	163.0	167.0
4	head circumference	854	568.1	20.8	512.0	622.0	522.0	534.0	602.0	613.0
5	face length	854	123.8	9.0	101.7	159.7	105.4	109.9	139.1	148.9
6	face width	862	144.3	8.8	119.0	171.7	126.8	131.1	159.5	167.5
7	inion to vertex length	857	164.3	10.6	132.9	195.4	141.6	147.5	182.6	188.8
8	glabella to vertex length	862	88.1	7.1	69.7	107.3	72.4	76.3	99.6	104.0
9	tragion to vertex length	859	141.1	7.1	120.8	162.2	125.3	129.8	153.6	158.8
10	menton to subnasale length	854	70.9	7.0	51.8	107.2	56.8	60.4	82.7	90.1
11	ear length	861	58.2	5.9	40.1	75.2	45.6	48.9	68.3	71.4
12	nose length	862	53.0	4.1	41.1	64.4	44.1	46.5	59.9	62.3
13	sellion to ectocanthus length	860	18.9	3.5	8.8	29.6	10.8	13.1	24.9	26.9
14	sellion to tragion length	861	93.3	6.0	75.4	111.2	80.5	83.6	102.9	108.0
15	nose protrusion	862	16.1	2.8	6.7	25.9	9.3	11.5	20.7	23.0
:	:	:	:	:	:	:	:	:	:	:

S4. Development of 3D Anthropometric Sizing Analysis System (3D-ASAS)

3D Anthropometric Sizing Analysis System
[-] [x]

Target Product

Helmet

Glasses

Goggles

HMD

Headband Type

Neckband Type

Necklace type

New Sizing System | Existing Sizing System

Target Population

Ethnicity

- Caucasian
- African American
- Asian
- Hispanic

Gender

- Male
- Female

Age

- 20s 18 to 19
- 30s over 50s
- 40s
- 50s

Sizing System

Number of sizes: 1 2 3 4 5 6

Key Dimension (KD) Selection

KD 1
head length

KD 2
head breadth

Sizing System for Helmet Design

head length (mm)

head breadth (mm)

Accommodation (%)

72.0%

Sizing System Modification

Modification by Each Size

Modification for All Sizes

x mm

Modification by Each Size

Size no.	Representative Head no.	KD 1	KD 2	Range of KD1 (head length)		Range of KD2 (head breadth)	
(1)	1061	192.2	147.0	186.0	↑ ↓ ~ 197.6	142.8	↑ ↓ ~ 151.9
(2)	667	197.7	160.0	192.0	↑ ↓ ~ 203.6	155.2	↑ ↓ ~ 164.4
(3)	1908	202.0	144.0	196.5	↑ ↓ ~ 208.1	13.91	↑ ↓ ~ 148.2
(4)	2744	204.7	153.0	198.8	↑ ↓ ~ 210.5	148.3	↑ ↓ ~ 157.5
(5)	58	214.7	146.0	208.8	↑ ↓ ~ 220.4	141.0	↑ ↓ ~ 150.1
(6)	2035	214.7	158.0	208.9	↑ ↓ ~ 220.5	153.4	↑ ↓ ~ 162.5

Representative Heads

기술통계치	변수1	변수2	대표1	대표2	대표all
평균	203.6	150.5	382	59	1612
표준편차	8.9	6.9	0	0	0
최소	176.9	132.0	2585	2838	2585
최대	229.6	172.0	2439	2	629
범위	52.7	40.0	0	0	0
1퍼센타일	183.8	136.0	1167	321	1869
5퍼센타일	188.7	140.0	1556	219	1249
10퍼센타일	192.3	142.0	142	14	2359
25퍼센타일	197.7	145.0	653	15	1955
50퍼센타일	203.4	150.0	429	59	1612
75퍼센타일	209.9	155.0	1966	27	1542
90퍼센타일	215.5	160.0	1598	16	1598
95퍼센타일	218.3	163.0	1080	57	2044
99퍼센타일	223.3	167.0	1533	73	493

System Interface: Input

The screenshot shows a software interface for creating a sizing system. It is divided into four main sections, each highlighted with a colored border and a corresponding callout:

- Target Product:** A grid of product images with radio buttons for selection. The 'Helmet' option is selected.
- Target Population:** A form with three columns: Ethnicity (Caucasian, African American, Asian, Hispanic), Gender (Male, Female), and Age (20s, 30s, 40s, 50s, 18 to 19, over 50s). All options are checked.
- Sizing System:** A row of radio buttons labeled 'Number of sizes' with values 1, 2, 3, 4, 5, and 6. The '6' option is selected.
- Key Dimension (KD) Selection:** Two anthropometric dimensions are shown: KD 1 (head length) and KD 2 (head breadth). Each has a 'Modification' button. A 'Delete' button is also present.

At the bottom of the interface are buttons for 'Generation of Sizing System', 'Default', and 'Exit'.

S1. Selection of target product

S2. Selection of target population

This detailed view shows the 'Target Population' section. It contains three columns of checkboxes:

- Ethnicity:** Caucasian, African American, Asian, Hispanic (all checked).
- Gender:** Male, Female (both checked).
- Age:** 20s, 30s, 40s, 50s (all checked); 18 to 19, over 50s (unchecked).

S3. Selection of number of size categories for sizing system

This detailed view shows the 'Sizing System' section. It features a row of radio buttons labeled 'Number of sizes' with values 1, 2, 3, 4, 5, and 6. The '1' option is selected.

S4. Selection of key anthropometric dimensions

System Interface: Output

Representative heads according to the sizing system

Sizing system

3D Anthropometric Sizing Analysis System

Sizing System for Helmet Design

head breadth (mm)

head length (mm)

Representative Heads

기술통계지	변수1	변수2	대표1	대표2	대표all
평균	203.6	150.5	382	59	1612
표준편차	8.9	6.9	0	0	0
최소	176.9	132.0	2585	2838	2585
최대	229.6	172.0	2439	2	629
범위	52.7	40.0	0	0	0
1퍼센타일	183.8	136.0	1167	321	1869
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95퍼센타일	218.3	163.0	1080	57	2044
99퍼센타일	223.3	167.0	1533	73	493

Accommodation (%)

72.0%

Sizing System Modification

Modification by Each Size

Modification for All Sizes

mm

Save Database

Save as Excel File

Save as PNG

Modification by Each Size

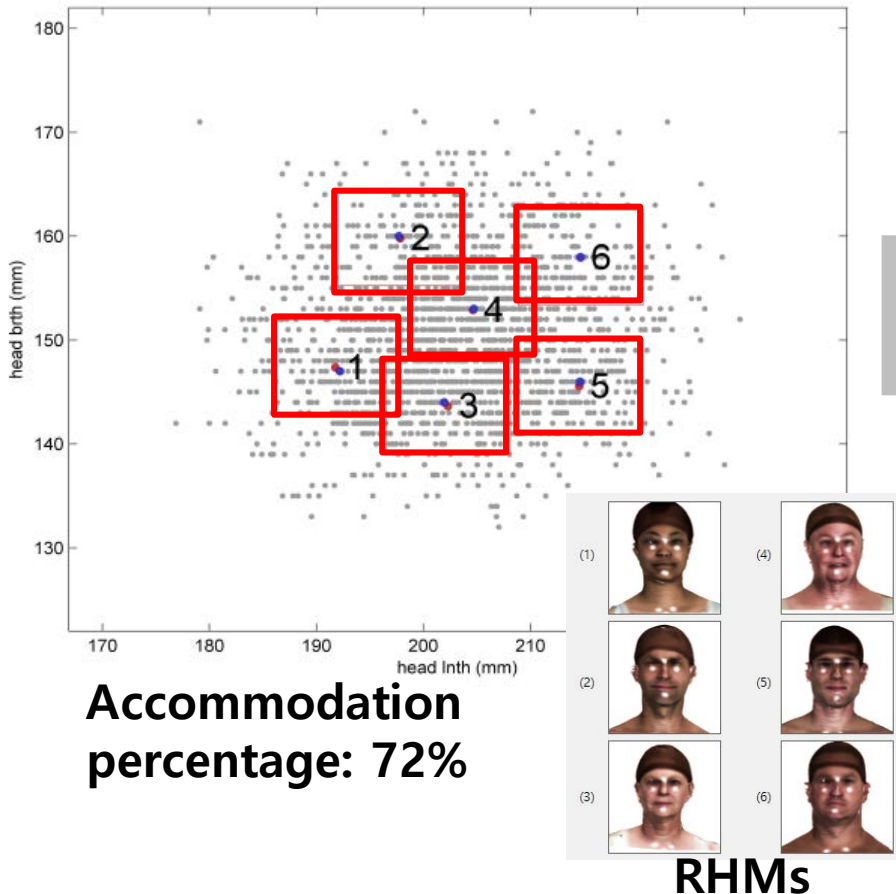
Size no.	Representative Head no.	KD 1	KD 2	Range of KD1 (head length)		Range of KD2 (head breadth)	
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(6)	2035	214.7	158.0	208.9	220.5	153.4	162.5

Accommodation percentage of the generated sizing system

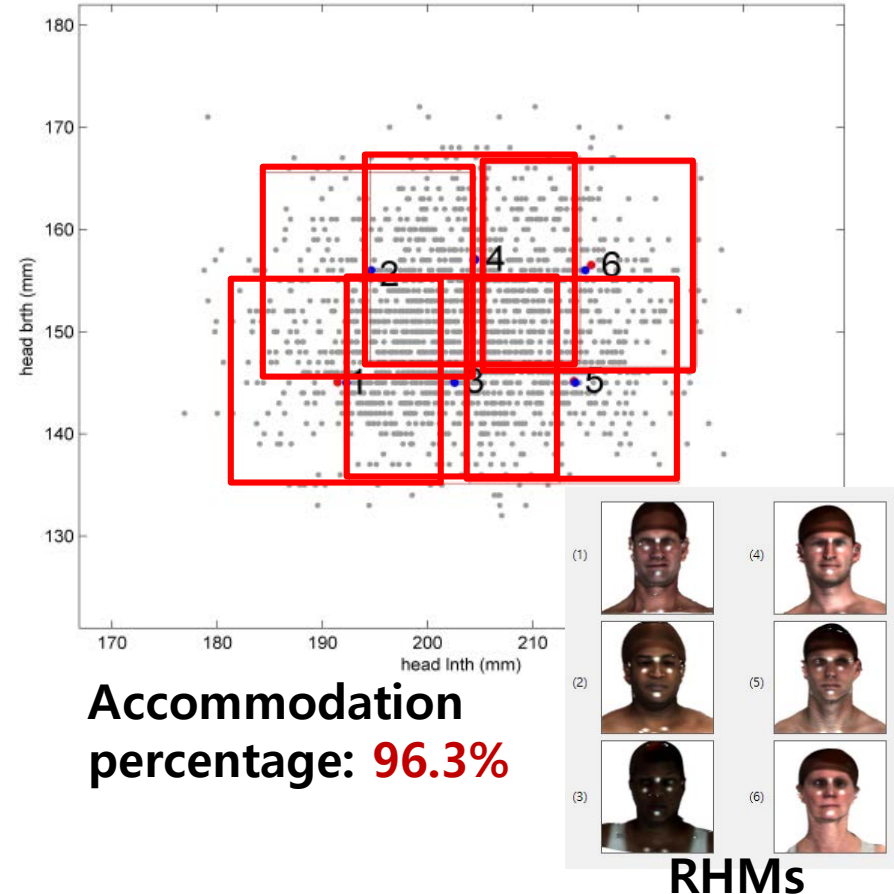
Interface for adjustment of the sizing system

Adjustment of Sizing System (Illustrated)

Initial sizing system recommended by 3D-ASAS



Manually adjusted sizing system for better accommodation



Demonstration of 3D-ASAS

video

(<https://www.youtube.com/watch?v=xZQUeWhfqXk>)



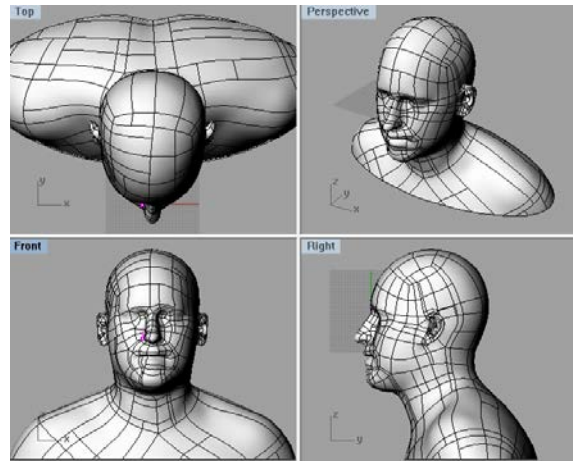
Development of Headforms

- **Digital and 3D-printed physical headforms** developed based on RHMs extracted through 3D-ASAS

Original CAESAR scan
(format: point cloud mesh)



Edited model
(format: **NURBS**)



3D printed model



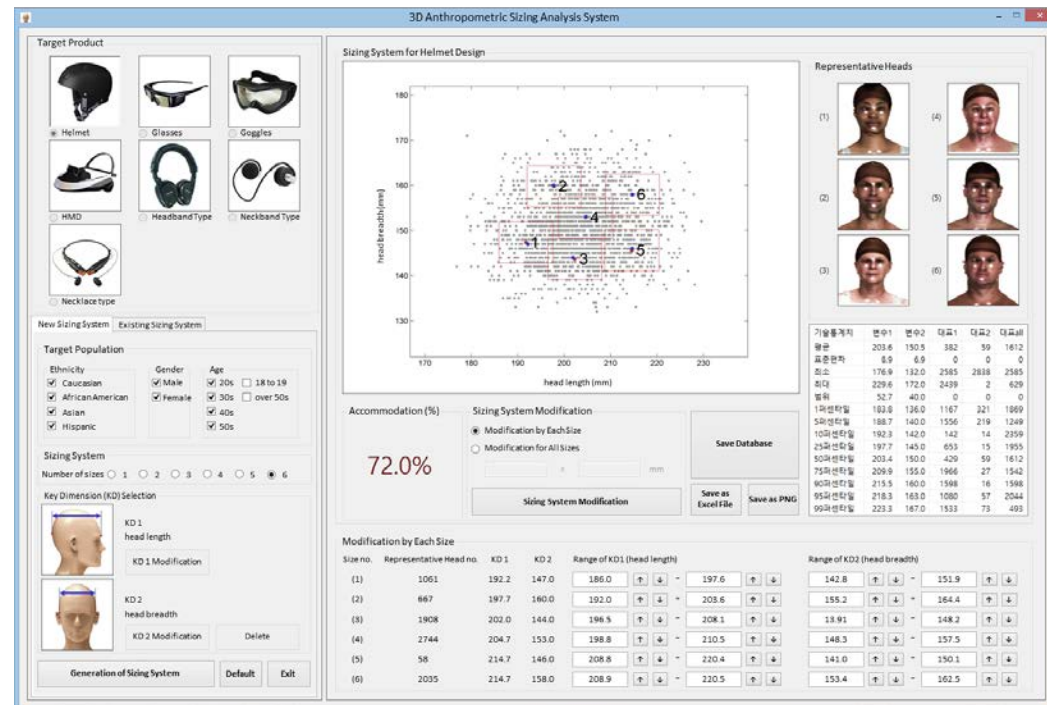
Contribution: Improvement of CAESAR Heads

- This study devoted effort to **improve quality of CAESAR 3D head images** for its **useful application to the head-related product designs**
- Improved database ($N = 2,299$) is **applicable to further head and facial anthropometric studies**
 - ✓ Post measurement
 - ✓ Shape analysis
 - ✓ Virtual fitting



Contribution: 3D-ASAS

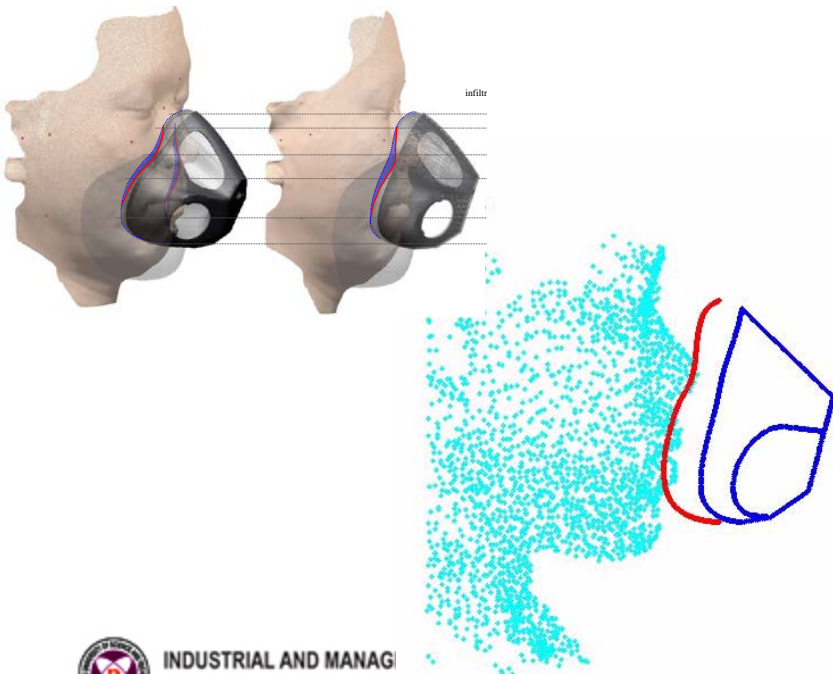
- 3D anthropometric sizing analysis system (**3D-ASAS**) was developed for a **convenient utilization in the product design process**
- System function and interface were developed **based on PD practitioners' needs**
 - ✓ User-friendly interface
 - ✓ Descriptive statistics of measurements
 - ✓ Statistic-based analysis
 - ✓ Generation of sizing system
 - ✓ Recommendation of RHM's
 - ✓ Save and load results



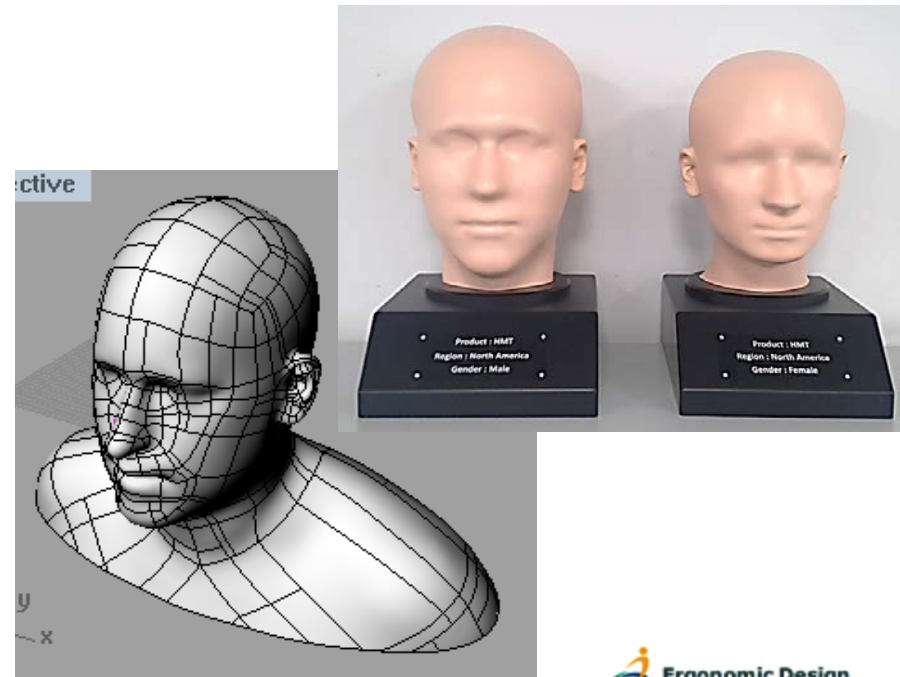
Applications

- Improved CAESAR heads and 3D-ASAS can be applied to find **an optimal shape of product through virtual fit analysis**
- Digital and physical headforms can be utilized to **product design and usability evaluation phases** in PD process

Illustration of the virtual fit analysis for oxygen mask design



Digital and physical headforms of RHM





Ranked No. 1 in 2012-2014
at the "Times 100 under 50"
Young University Rankings

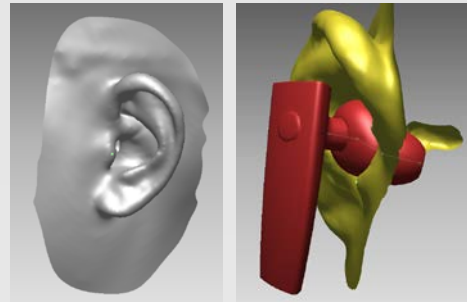


Q & A

Ergonomic Design Technology Lab
at Pohang University of Science and Technology
<http://edt.postech.ac.kr>



CAESAR Head Data Improvement



Ear Anthropometry



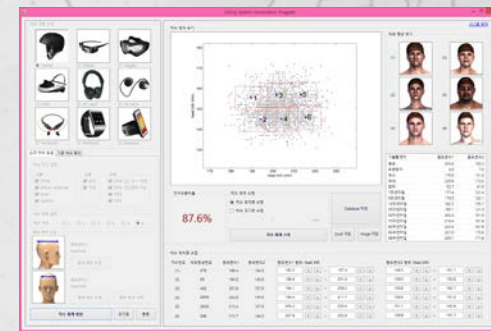
Hip Protector



Representative Models



Virtual Fit Analysis



Sizing Analysis System