Measuring Chinese Heads and Faces

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ABSTRACT
The Size China 3D anthropometric survey used a combination of traditional anthropometric methods and current laser scanning technologies to create a high resolution 3D digital database of the Chinese head shape. The survey followed international standards for the collection of statistically accurate 3D data on Chinese head shape. Scanning was done at seven different sites across mainland China, collecting data for use in the design of "Chinese fit" products for the head and face.

1. INTRODUCTION
Many different kinds of headgear today satisfy important human practical and symbolic needs in areas ranging from health care to fashion. To ensure that headgear fits properly, designers must rely on anthropometric data to provide information on the size and geometry of the human head.
However, traditional anthropometric head data has suffered from two limitations. First, the complex geometry of the head and face is not well described by traditional univariate measurements, which capture head length, width and circumference only as numerical values. Secondly, univariate anthropometric surveys have traditionally examined only Western populations, with few surveys collecting data on Chinese populations.
The limitations implicit to numerical univariate data have been recently overcome with the application of digital 3D scanning to anthropometric research. Using 3D scanning, researchers can obtain true 3D spatial co-ordinates for the complex geometry of human body shape.
The problems caused by ethnically skewed data have also been addressed by recent 3D scanning projects completed on groups in Korea and Japan. However, these scanning studies were addressed at defining the size and shape of the body overall, for applications in the clothing and intimate apparel industries. As a result, they did not capture a very high resolution on small and geometrically complex parts of the body like feet, hands, heads and ears, because the realistic upper limit of an individual computer file is limited to about 20MB. A whole-body 3D scan at a file size of 20MB gives only a low-resolution description of the head and face. At the same time, the head is very demanding in terms of fit because many head products must be physically rigid to serve their function. Unlike clothing, rigid helmets cannot flex or stretch to suit variations in body shape. What are the best methods to capture high resolution 3D data for Chinese head and faces?
SizeChina aimed to overcome the limitations of previous surveys by applying digital scanning methods to the Chinese head alone to achieve high-resolution results.[1] As a late-generation anthropometric study, SizeChina was able to benefit from "best practices" developed in previous studies. Existing international anthropometric standards provided clear guidance on the type of data required, as well as the procedure required to calculating the number of subjects needed to achieve significant results.[2][3]

2. PLANNING THE SURVEY
2.1 Sampling Locations
Popular opinion in China has long suggested that a size difference exists between larger people to the north, and smaller people to the south. In undertaking the first-ever 3D anthropometric survey of head shape in China, the opportunity existed to collect data that could substantiate or refute that common idea. To capture variations, sites were chosen that were widely spread across different regions of the mainland, and which also met the project criteria of regional diversity. The six sites selected coincided with the sampling locations of a traditional anthropometric survey that was conducted in mainland China in 1988.[4] Hong Kong was the site for the initial training and refining of the measurements methods

The seven sites were:
- Hong Kong — the home site for training and establishment of protocols;
- Guangzhou — in the south of China;
- Huangzhou — in coastal/central China;
- Chanquin — south/east central China;
- Lanzhou — north/east central China;
- Beijing — north/east China;
- Shenyang — far northern China.

Figure 1: Scanning Locations in China

2.2 Subject Demographics

Traditionally, much traditional anthropometric data was originally collected by the military to meet needs in the development of uniforms and equipment. Military studies have always suffered from restricted demographics, because they primarily survey young males of military fitness. Subjects who are older or younger than military age are excluded, as are the physically disabled, while women are under-represented.

The goal of the SizeChina survey was to be as inclusive as possible in the recruitment of subjects. Three age groups were established: 18-30, 30-50, and 50-70+; with men and women surveyed separately, for a total of six categories. No restrictions were placed on the height, weight or social status of subjects. All individuals were of the Han ethnic group. All subjects were paid volunteers and the survey followed ethical research guidelines.

2.3 Number of Subjects Needed

In collecting anthropometric data, the number of subjects needed for a study is normally calculated based on the variability of the dimensions being surveyed, and on the level of accuracy and precision required for the final data. Guidance on making the calculations is provided in The ISO (International Organization for Standardization) standard 15535:2006, "General requirements for establishing anthropometric databases," the description of which is as follows:

ISO 15535:2006 specifies general requirements for anthropometric databases and their associated reports that contain measurements be taken in accordance with ISO 7250 ["Basic body measurements for technological design"]. It provides necessary information, such as characteristics of the user population, sampling methods, measurement items and statistics, to make international comparison possible among various population segments.[5]

For SizeChina, the size of the sample needed was calculated independently for each of the six locations so that each would stand alone as a significant survey in itself. The extent of anthropometric variability within China was relatively unknown. Treating each of the sites separately permitted their results to be compared to one another.

To calculate the necessary size of the survey, ISO 15535:2006 stipulates the use of the coefficient of variation of a key dimension obtained from a previous survey. Since no previous surveys of Chinese head and face size were available, we took a figure from a U.S. Army head survey to serve as a comparison benchmark.[6] The variation co-efficient is not itself a dimension, but only a measure of how much a particular dimension varies across the population. While American head measurements are clearly different from Chinese head measurements, there was no reason to assume that either group has a broader range of variation. It can be safely assumed that both groups vary by the same relative amount.

The minimum sample size of the group needed at each survey site, *n*, was calculated using the following formula:

$$\mathrm{CV} = \frac{\mathrm{SD}}{x} \times 100$$

where:
1.96 is the critical value (z value) from a standard normal distribution for a 95% confidence interval; and CV is the coefficient of variation with mean *x*; and SD is the standard deviation of the population for the body dimension in question; and *a* is the percentage of relative accuracy desired.

The Menton-Sellion Length describing the length of the face was selected for use as the key dimension for our calculation, because it provides a key dimension commonly used by designers in sizing devices made for facial protection as well as a good overall measure of face size. Using its coefficient of variation, calculations showed that a sample size of 254 at each site would yield results with 1% accuracy at the 5th and 95th percentiles.

When the 254 subjects to be surveyed at each site were divided into the three age categories and two sexes, a total of 43 people were needed in each category. This was rounded up to require 45

people in each group, for ease of communication with the local sites. The total number of subjects required at each site therefore increased to 270 subjects, up from the required 245, increasing the redundancy of the survey at each location.

Table 1: Sampling Matrix for Each Location

AT EACH LOCATION			
Age	**Male**	**Female**	
18 - 30	45	45	
31 - 50	45	45	
51 - 70	45	45	
Gender Total	**135**	**135**	
Location Total			**270**

Based on this matrix, the total number of individuals surveyed across all six sites was 1,620. With each of the six sites alone calculated to be statistically significant in terms of the survey data, the study overall became highly redundant, making its results extremely reliable. The 400 children surveyed were in addition to the 1,620 adults.

Table 2: Sampling Matrix for the Entire Survey

LOCATION	**Site Total**
Lanzhou	270
Shanghai	270
Beijing	270
Chengdu	270
Xian	270
Guangzhou	270
SURVEY TOTAL	**1620**

3. SCANNING PROCESS

3.1 Physical Field Conditions

Scanning under field conditions presented challenges not found in a static laboratory setting. Each of the six locations varied widely in terms of the physical spaces provided for operations, the organizational support available, and the living conditions for visiting staff. However, specifications provided in advance to each local contract officer defined the minimum type and number of physical spaces necessary.

The critical location was the lab environment for the scanning itself, which required the following physical features:

- a minimum of 20 square meters of area, approximately square in shape;
- proximity to restrooms;
- even fluorescent lighting at a bright level;
- no exterior windows (or windows that could be shielded);
- air conditioning, heating or fans as required for comfort;
- no carpeting to impinge on equipment installation;
- minimum of 5 separately fused 110 V outlets for equipment;
- secure locks for use at the end of the day, or monitoring by security.
- -minimum of 3 broadband internet connections for data transmission.

All of these criteria were essential for smooth operation of the test equipment. For example, direct sunlight interferes with the operation of the scanning laser, increasing scan "noise" and decreasing the amount of detail captured.

Participating sites were compensated financially for their collaboration in the project, and recognized in public communications for their supportive role.

3.2 Field Staff

The traveling survey team consisted of three trained anthropometrists and one professional photographer. The team spent a total of eight months traveling with their equipment to the different locations, reaching the sites by air travel where possible, but also traveling by land in a rented truck over gravel roads. The Cyberware 3030 Color 3D Scanner traveling with them had been selected in part for its mechanical durability and ease of set-up, and performed without problems during the entire period.

At each location, approximately ten local staff members were hired to assist the visiting team, as the three experts alone were not sufficient to process the three to four hundred subjects passing through each location. Local staff members were recruited in advance of the arrival of the team by the local liaison officer working with the partnering organization at the site.

Our initial request for 270 subjects was surpassed at every location, and the survey was able to scan 15% more subjects than anticipated.

3.2 Subject Scanning

3.2.1 Recruiting

Recruiting of the subjects was done in advance by the local liaison officer of the host organization following the sampling matrix specification provided by the Hong Kong team.. Each recruit was given an appointment time, and told to expect the entire process to take 30 minutes. In expectation of "no shows" among the recruits, each site scheduled more than 270 subjects to ensure the full number were met however the number of "no shows" was consistently lower than expected.

3.2.2 Video introduction

At Station 1, "Video Introduction," subjects were invited to sit in groups of 5- 10 in a quiet area to watch a short 4 minute Mandarin-language video program describing the project. Made in Hong Kong by project staff, the video provided background about the significance of the goals of the project and its methodology. It also provided general instructions about how to help achieve a good scanning result.

3.2.3 Survey

At Station 2, subjects filled in a questionnaire to document basic information about age, gender, family background, the location where they grew up, and so forth. Each subject was assigned a scan reference number. Subjects carried the survey questionnaire with them throughout the rest of the scanning process, to allow further information to be added at each station. Scan subjects also signed a release form for the use of their demographic, digital and photographic data.

3.2.4 Reference numbering

The unique reference number assigned to each subject was noted on the questionnaire and also printed onto an adhesive label to be fastened to the subject's upper left shoulder. In that position, the number could be seen in photographs to serve as a reference double check if required later. Reference numbers were used to avoid the use of names, which would have violated ethical confidentiality. Subject names were not recorded.

3.2.5 Photography

At Station 3, "Photography," subjects posed for high-resolution photographs of a front view and side profile, taken against a neutral gray backdrop. For these photos, the people were asked to relax their faces, avoiding posing or smiling. The photographs served two purposes. They provided a visual reference for comparison against the 3D scans in the event of confusion in the numerical reference system. In addition, they serve as an archived resource that may find future use in emerging new areas of research, such as photogrammetric 3D modeling and facial recognition technology research.

3.2.6 Traditional anthropometric measurements

At Station 4, traditional anthropometric measurements were recorded for each subject. Height and weight were measured with a medical quality scale brought by the traveling team, and calibrated at each site to ensure accuracy and consistency. Measurements of the length and width of the head were taken using an anthropometer (a specialized form of caliper), and the circumference of the head measured using a tape measure.

Despite the fact that SizeChina was planned as a 3D scanning survey, traditional measurements remained important. Traditional measurements served as a double check on the accuracy of the scan information, and also provided a benchmark for compensatory calculation of hair thickness effects as recorded by the laser. They also served an important role as a sorting tool used during the later data processing stage of the project. Entered into cross-referenced spreadsheets, traditional univariate measurements lend themselves to the easy comparison and sorting of different groups.

The specifics of all of head measurements followed the guidelines of ISO 7250, "Basic human body dimensions for technological design".[7] Where the other stations employed local recruits trained to follow the project procedure, this station was manned at all times by one of the project's own anthropologists. The measurements obtained were manually recorded on each subject's questionnaire.

3.2.7 Landmarking

A second anthropometric expert from the core team was located at Station 5, "Landmarking." Here, physical palpation of the subject's head was used to locate bony landmarks on the skull below. Fifteen standard facial landmarks were referenced in the survey, eleven of which required palpation to be located. Palpated landmarks were marked on the skin, using an eyebrow pencil to make a small 2 mm dot. These small black dots were then covered by 5 mm adhesive backed red dot purchased at a stationary store. The larger red dot is used to enhance the visual contrast between the skin and the landmark location on the 3D scan file. The red dot also makes it easier for the CAD operator to identify landmark locations during scan processing as it sits above the surface of the skin.

Each anthropometric study uses different land marks as no standard exists that defines a consistent set of parameters. Our specific selections of landmarks were recommended for use in SizeChina by an anthropometric consultant, who did an analysis of the project requirements to identify landmarks that offered a high level of descriptive accuracy in combination with computing economy.

The landmarks used were:
— Chin: the most protruding forward point on the bottom edge of the lower jawbone;
— Ectocanthus: the outside corner of the right eye formed by the meeting of the upper and lower eyelids (this point did not need to be marked with eyebrow pencil as it was self-evident in the scans);
— Frontotemporale, right and left: the point of deepest indentation of the temporal crest of the frontal bone above the brow-ridges;
— Glabella: the anterior point on the frontal bone, midway between the bony brow-ridges;
— Infraorbitale, right and left: the lowest point on the anterior border of the bony eye socket;
— Pronasale: the point of the anterior projection of the tip of the nose (self-evident and unmarked);
— Sellion: the point of the deepest depression of the nasal bones at the top of the nose;
— Top of head: the highest point on the head when the head is held with the Frankfort plane horizontal (self-evident and unmarked);
— Tragion, right and left: the superior point on the juncture of the cartilaginous flap (tragus) of the ear with the head;
— Zygofrontale, right and left: the lateral point of the frontal bone on its zygomatic process.

3.2.8 Wig cap

At Station 6, subjects put on a tight fitting nylon wig cap, taking care to tuck it all strands of hair under the edges of the cap, particularly around the ear. The wig cap served two purposes. By compressing the excess volume of fluffy hair styles, it better revealed the underlying shape of the head. The wig cap also reduced the reflective shine that is typical of black Chinese hair. Left uncovered, a shiny black surface would reflect the scanning laser, leaving holes in the 3D data.

3.2.9 Scanning

At Station 7, each subject was seated in a chair positioned inside the scanning set-up, and, at last, scanned. The team's third traveling anthropology expert was positioned at Station 7 to operate the scanner.

The scanner head array of the Cyberware 3030 Color 3D scanner is comprised of the laser itself, plus a beam splitter, mirrors, and a receiving camera. This entire scanner head assembly is mounted so that it can rotate about the head of the seated subject. As it moves, it captures one vertical contour at a time as a line of spatially defined points. When the full rotation has been completed, the full 3D volume of the head is defined as a " point cloud" of three-dimensional points in space.

During scanning, spatial information is fed directly into a computer for immediate display as an image on a video screen. The image is composed of the cloud of 3D points, each of which is defined by its individual X, Y, and Z coordinates. If the scan is successful, the displayed image will provide an accurate representation of the scanned subject with an estimated error of approximately plus–or-minus 1 mm per axis".[8]

Because the light moves very quickly, there is little effect from movement during the recording of any one vertical contour. However, it takes 17 seconds for the scanner to complete a full revolution around the head. During that time, head movement will cause improper integration between the vertical scans. Typical head movements include a sudden movement, or twitch; and a slow drifting movement. In all cases, individual vertical contours remain accurate, but movement during the scan will cause an incomplete integration between the vertical lines.

Such errors create a data gap or "closure gap" between the start and finish of the scan. This gap appears visually as an apparent space at the back of the head where the profiles do not line up. Visual assessment of closure gap is a quick and effective way to judge a scan's quality. Because the captured image is displayed immediately, the quality of the scan can be assessed while the subject is still seated. In the case of any evident movement or other errors, such as those caused by environmental noise, the subject can be scanned a second or even third time.

During the scanning process, 17% of first scans of adults were repeated after the first scan was rejected as unsuitable. A very few elderly people suffering from slight tremors or shaking proved unable to participate in the scanning part of the survey altogether.

In the separate survey of children, when children under the age of five were scanned, the rejection rate was close to 100%, because such young children were unable to sit still for the full 17 seconds it took to complete one rotation of the scanner. Further experiments on very young children were conducted using a different system, photogammetry, at the Hong Kong Polytechnic University but the slow speed of the software and the fragility of the physical system proved to be of limited effectiveness at this time.

Figure 2: 3D scan images of a subject in the 30-50 year old range.

3.2.10 Data check

After visual confirmation that the scanning was satisfactory, subjects proceeded to the last step, Station 8. Here, a locally-trained clerk collected questionnaire forms and wig caps from the subjects and confirmed that the forms were properly completed. Each participant then received a financial gratuity, as well as a souvenir printed copy of their personal 3D scan.

At a nearby grooming area, subjects removed all sticky labels, washed off the eyebrow pencil and said goodbye. The entire process from video to wash-up typically took about 30-40 minutes.

3.2.11 Data entry and backup

Managing the storage, archiving and transmission of the large amounts of data produced by a scanning survey collects required creative use of a variety of formats and media. Overall, the SizeChina survey generated a full terabyte of data including scans, photography and documentation. With individual scan files exceeding 20 MB in size, scan data could not be stored in the field laptops used to operate and monitor the scanner. External storage drives were utilized with DVD back-up copies made at each location at the end of each working day, to be shipped to Hong Kong via courier at the end of each location study. On two separate instances, the back-up copies proved invaluable when external hard-drives experienced equipment failure under field conditions, losing several days worth of data.

The handwritten survey questionnaire information was manually entered into computer spreadsheet software on site, and transmitted back to Hong Kong electronically via email. The original paper questionnaires and subject release forms were packed for shipping back to Hong Kong with the project equipment, where they were archived for future

4. DISCUSSION

During the eight month site survey process of the SizeChina project, a traveling team composed of three anthropometric experts plus a photographer traveled to six different sites on the mainland of China, bringing with them a 3D laser scanner and other equipment. Local institutional partners at each site provided the necessary physical facilities to house the scanning process, as well as recruiting approximately ten local staff at each location to help with management and data collection. At each site, 270 volunteer subjects were recruited to participate in the study, covering a full range of ages from 18 to 75+, in both sexes.

In setting up this study, SizeChina researchers were able to benefit from the prior existence of international standards for the collection of anthropometric data. Selection of the number and variety of subjects measured was planned in accordance with ISO 15535:2006, "General requirements for establishing anthropometric databases." Anatomical landmarks used in the data collection process matched the requirements of ISO 7250, "Basic body measurements for technological design."

At the same time as digitally scanning more than 2000 subjects, the team also collected traditional anthropometric data as well, to facilitate later double-checking and sorting of the digital data.
The creation of the SizeChina 3D database will allow researchers to discover if significant differences exist between North and South Chinese populations. The 3D data may also be used to discover the differences between Chinese and Western head and face shapes.

5. CONCLUSION

The survey collected the 3D data needed to determine the shape of the Chinese head. The high resolution 3D data collected for implementation into design practice allows for the creation of objects tailored to the Chinese head. The problems of low resolution full body scans as a basis for design practice have been overcome.

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