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A Morphometric Study of Head in the Population of Young Chinese Adults

Estudio Morfométrico de la Cabeza en la Población de Adultos Jóvenes Chinos

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SUMMARY: Due to the complexity of head shape, limited 1D or 2D head anthropometry fail to fully capture its shape characteristics. Currently, there is limited research on clustering analysis of head shape from a shape difference perspective, especially for the head shape of Chinese people. Head shape is influenced by factors such as race, sex, and age, making it imperative to create a head shape database for Chinese individuals. In this study, three-dimensional head data of 339 Chinese young adult were collected, and the head shapes were clustered into 7 clusters using an improved k-medoids algorithm. The differences between clusters and the average head shape were further analyzed. It can be foreseen that the head shape database for Chinese young adult constructed in this study has important reference value for the ergonomic design of head-related products and head morphology research, among other fields.

KEY WORDS: Anthropometry; Three-Dimensional Head; Shape Clustering; Shape Difference.

INTRODUCTION

Head and facial anthropometry serves as the foundational data for the design of protective helmets and masks, medical research, and forensic science (Kim *et al*., 2003; Lee & Park, 2008; Du *et al*., 2008; Chuan *et al*., 2010). Traditional anthropometric methods have focused primarily on describing and analyzing differences in head shape based solely on dimensions, which provides design references for related products. However, the shape of the head and face is complex, and sparse characteristic dimensions often cannot characterize the shape properties of the head and face (Luximon *et al*., 2012). Nevertheless, these properties are particularly important in designing protective helmets and masks that have high adaptability. Protective helmets and masks are essential defenses for ensuring the safety of riders and medical personnel. An ill-fitting helmet or mask will directly reduce the user's usage rate and protective effect.

To obtain more detailed 3D human body data, researchers have turned to CT scanning technology (Niu *et al*., 2009). While this method provides detailed information, its high cost and complex data processing make it unsuitable for large-scale data collection. However, with the advancements in 3D scanning and graphics processing, more scholars and institutions are utilizing 3D laser scanners to capture high-resolution head and face 3D data for research on head and facial shape differences. For example, the CAESAR (Civilian American and European Surface Anthropometry Resource) project obtained 3D data on over 4,000 human bodies from the United States, the Netherlands, and Italy (Robinette *et al*., 2002). Similarly, the NIOSH (National Institute of Occupational Safety and Health) project collected head and facial data from 1,013 American workers (Zhuang *et al*., 2005), while the Size China project captured head 3D data of over 2,000 Chinese women and men of various ages ranging from 18 to 70 years old and from different regions (Ball & Molenbroek, 2008).

Based on collected 3D data of the head and face, researchers conducted a statistical analysis of the head and facial shapes of different populations and constructed

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statistical shape models of specific populations for the study of differences in head and facial shapes (such as racial, sex, and age differences) and the ergonomic design of head and facial related products. Ball *et al*. (2010) compared and analyzed the differences in head shapes between Chinese and Caucasian populations based on the head database from the CAESAR and SizeChina projects and found that the head shapes of Asians are significantly different from those of Caucasians, including wider and rounder side views and flatter back. Similar studies include Luximon *et al*. (2012), who randomly selected 144 (72 females and 72 males) 3D head and face data from the SizeChina project for principal component analysis, quantifying the variation of head and facial shapes under different principal components, and indicating that Chinese males have significantly larger head and facial sizes than females; Zhang *et al*. (2022a,b, 2023) conducted research on the sex and age differences in the shape of the adult head and face, and sex-specific changes in the shape of children's head and face, based on the construction of statistical shape models. The study results provide a reliable data foundation for the customized design, virtual fitting, and suitability assessment of head and face-related products for specific populations. To enhance the efficiency of custom design for head and face-related products, Lacko *et al*. (2015, 2017) integrated five typical facial dimensions and employed principal component analysis and regression analysis to establish a method for predicting head and face models. Deviation analysis indicated that the mean deviation between the predicted and original models was 1.60 ± 0.3mm. Utilizing the predicted model, a brain-computer interface headphone design was accomplished (Verwulgen *et al*., 2018). In the field of head shape clustering research, Zhuang *et al*. (2010, 2013) employed principal component analysis to produce five head and face models, which were used for mass customization of masks. Yu *et al*. (2012) used facial characteristic dimensions that impact mask adaptability and created five Chinese head and face models using principal component analysis, namely: small, medium, large, long/narrow, and short/wide. However, limited facial characteristic dimensions may not fully capture the differences in head and face shapes among samples. Thus, the reliability of head and face templates obtained via clustering based on key dimensions still requires verification.

Additionally, Zhang *et al*. (2022a,b) have identified the optimal number of clusters for the facial shapes of both Chinese males and females to be six through the utilization of different clustering algorithms and evaluation methods. These clustering results serve as a useful reference for mass customized design of facial-related products. Ellena *et al*. (2017, 2018a,b) have implemented an enhanced hierarchical clustering algorithm to group the head shapes of Australian cyclists into four clusters, calculating the mean head shape of each cluster which was then utilized as the basis for mass customized design of helmets. The Helmet Fit Index (HFI), which considers the Standoff Distance (SOD), Gap Uniformity (GU), and Head Protection Proportion (HPP), was used to conduct quantitative fit evaluations of the helmet liners (Ellena *et al*., 2016; Pang *et al*., 2018). Thai *et al*. (2015) have demonstrated that head shapes vary based on ethnic groups, age, and sex, thus indicating that the design of head-related products for Chinese individuals cannot solely rely on foreign standards. Currently, there is a limited number of studies that investigate the clustering of Chinese head shapes from a shape difference perspective. This study aims to construct a three-dimensional head shape database of young Chinese males utilizing the improved k-medoids algorithm proposed by Lacko *et al*. (2017) and systematically investigate the variations in head shapes.

MATERIAL AND METHOD

Data collection. The samples consisted of 339 young adults from China, aged between 18 and 30 years old, with a mean age of 20.4±2.3 years. Any individuals with a history of craniofacial trauma, congenital anomalies, or surgery were excluded from participation. As shown in Figure 1, the heads and faces were scanned by using an HandSCAN scanner with an accuracy of 0.1mm and VX-elements software (CREAFORM, Canada).

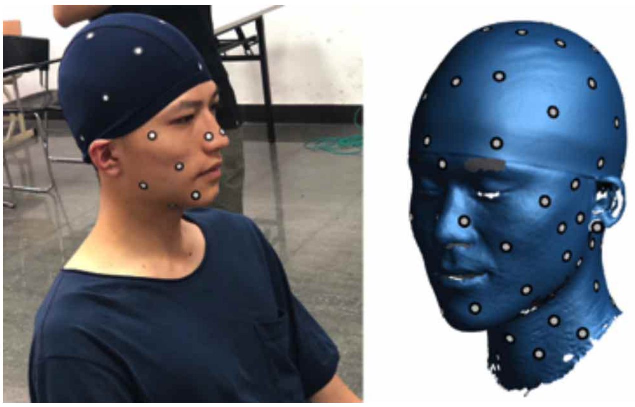

Fig. 1. Scanned three-dimensional head and face.

Data pre-processing. The scanned head and face mesh had problems such as protrusions, spikes, missing data, and uneven surfaces. In this study, the reverse engineering software Geomagic Wrap was used to preprocess the model using the mesh doctor, repair, and smoothing tools, as shown in Figure 2. Since the scanned head and face models varied in position and orientation at different locations on the head during scanning, as shown in Figure 3A, sagittal (green plane), horizontal (red plane), and coronal (yellow plane) planes were created to align the models. Finally, the thickness offset method for hair (HTO) proposed by Ellena *et al*. (2016) was used to offset the mesh faces of the head, in order to restore the true shape of the sample head, as shown in Figure 3B.

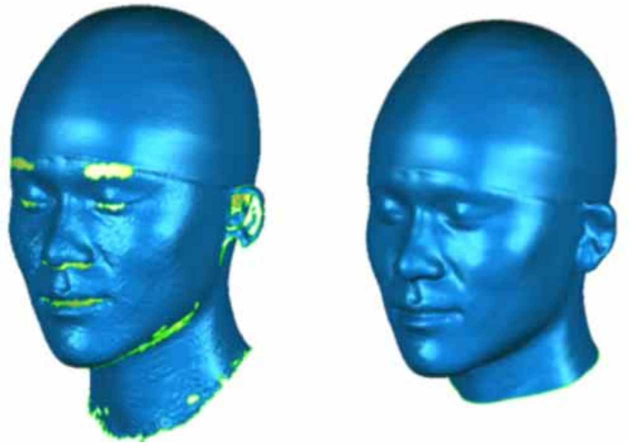

Fig. 2. Pre-processing of the head and face mesh.

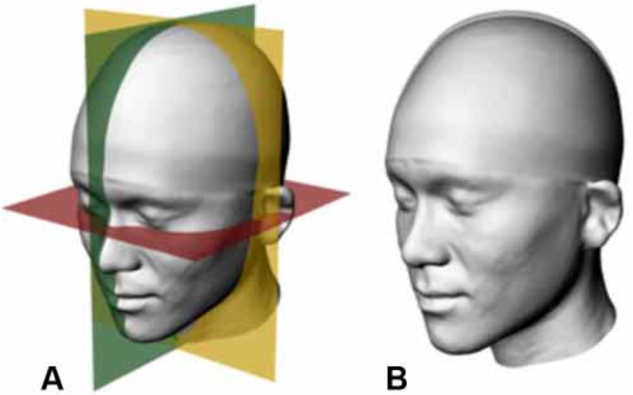

Fig. 3. Data pre-processing. (A) Head alignment; (B) Head offset.

Head shape of clustering. The head region was identified and extracted according to the national standard GB/T24429-2009 (Fig. 4A). As the collected head meshes were constructed by different numbers of point clouds, it was necessary to convert all the collected models into comparable and analyzable surfaces. As shown in Figure 4B, 600 data points with the same properties were extracted from each sample head mesh model. Then, as illustrated in Figure 4C, the NURBS surface interpolation algorithm was further applied to convert all sample head meshes into NURBS surfaces composed of 600 data points. The maximum deviations between all reconstructed surfaces and their original mesh models is less than 0.4mm.

Based on the extracted data points, this study employed an improved k-medoids algorithm proposed by Lacko *et al*. (2017) to perform cluster analysis on the reconstructed head models. To ensure small intra-cluster sample differences and large inter-cluster sample differences in the clustering results, it is necessary to evaluate whether assigning a sample to the nearest cluster will cause overlap between that cluster and any other cluster in all feature dimensions. Furthermore, this study sets the distance threshold between corresponding characteristic points of the samples to 15mm, in order to address the problem of large local differences between samples within clusters.

RESULTS AND DISCUSSION

339 head shapes were clustered into 7 clusters, and Figure 5 shows the medoid surface of head for each cluster as well as the mean head shape of all 339 samples. Table I lists the number of samples in each cluster, as well as 5 key head dimensions, such as (1) Head Circumference(HC), (2) Head Length (HL), (3) Head Width (HW), (4) Sagittal Arc (SA), and (5) Coronal Arc (CA). The definitions of the above dimensions can be found in Figure 6.

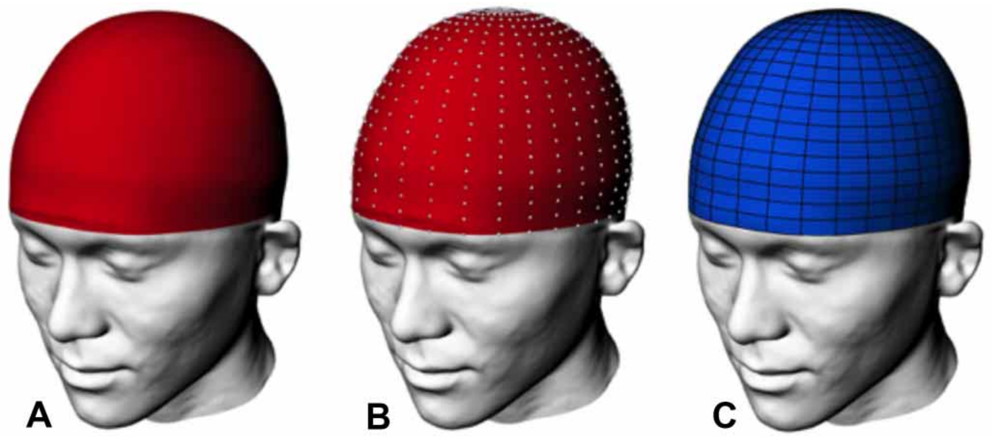

Fig. 4. Extraction and reconstruction of the head region: (A) Extraction of the head region; (B) Extraction of data points in the head region; (C) Surface reconstruction of the head region.

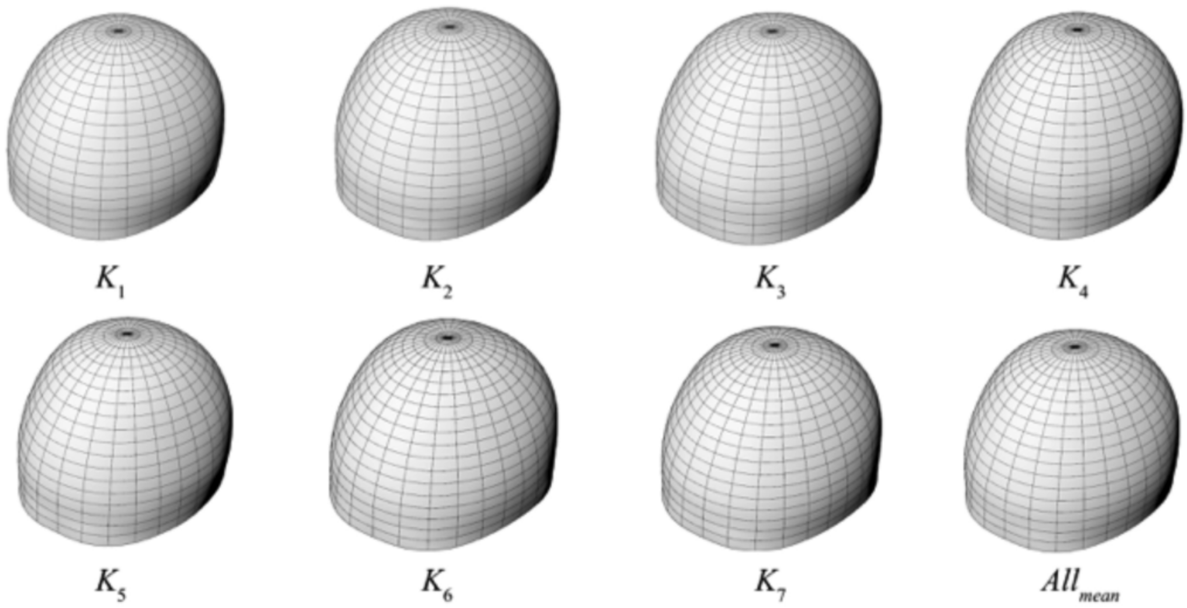

Fig. 5. The medoid surface of head for each cluster and the mean shape of head for all 339 participants.

Table I. The number of samples and the key dimensions of medoid surface of head for each cluster.

Clusters	Number of samples	HC/*mm*	HL/*mm*	HW/*mm*	SA/*mm*	CA/*mm*
1	25	547.20	184.63	164.29	297.31	369.18
2	44	572.17	191.20	171.29	323.32	402.34
3	50	552.87	186.76	164.54	322.61	380.99
4	35	557.06	187.24	167.78	321.93	392.85
5	69	551.85	189.73	161.65	329.06	393.45
6	57	566.59	195.69	163.29	324.62	381.88
7	59	569.34	195.03	166.58	327.78	407.64
All_{mean}	339	559.77	184.33	164.36	323.50	390.87

The mean head circumference and head length measured in this study are very close to the mean head circumference of 561 mm and head length of 184mm listed in the national standard GB/T2428-1998, but slightly smaller than the mean head circumference of 565mm and head length of 188 mm listed by Ball & Molenbroek (2008) in the SizeChina project. The mean head width measured in this article is larger than the mean head width of 154 mm listed in GB/T2428-1998 and the mean head width of 158 mm in SizeChina. The mean Coronal arc measured in this article is greater than the 361mm listed in GB/T2428-1998, but the Sagittal arc is smaller than the 349mm listed in GB/T2428-1998. Ellena *et al*. (2016) used an improved hierarchical clustering algorithm to cluster the head shapes of 190 Australian cyclists into four groups, and calculated the Sagittal and Coronal arc of each group's mean head shape, with the Sagittal arc ranging from 302 mm to 373.9 mm and the Coronal arc ranging from 353mm to 411.2 mm. In this study, the Sagittal arc of each group's head shape range from 369.18 mm to 407.64 mm, and the Coronal arc range from 297.31 mm to 329.06 mm. The measurement results further support the findings of Ball *et al*. (2010) that the shape of the Chinese head is more rounded and has a flatter back and forehead compared to that of Caucasians. All the dimensions of the head in GB/T2428-1998 were measured manually, and after excluding the errors caused by manual measurement, the increase in the Coronal arc and head width may be attributed to the fact that the head shape of young Chinese males has become wider and more rounded in recent decades.

Figure 7 shows the deviation analysis of the medoid surfaces of some inter-cluster heads, and Table II displays the maximum deviation values of all the medoid surfaces. Figure 8 depicts the intersecting lines between the medoid surfaces of each cluster's head and the mean head surface of all samples with their Sagittal, Coronal, and Horizontal planes. Based on Table I and Figure 7, although the key dimensions of the medoid surfaces of some inter-cluster heads have small differences, such as the differences in head circumference, head length, and head width between the medoid surfaces of cluster K3 and K5 are 1.02 mm, -2.97 mm, and 2.89 mm, respectively, the differences between the two surfaces are significant, with a maximum positive deviation value of 7.07 mm. Conversely, although the difference in Sagittal arc between the medoid surfaces of cluster K3 and K5 is -6.45 mm, the maximum positive deviation value between the two surfaces is 5.32mm. Therefore, limited head size standards cannot solely serve as the basis for head morphology research, helmet design, or head plastic surgery, and the entire shape information of the head must be taken into account.

Based on Figure 7 and Table II, it is evident that there are significant differences in the medoid surfaces of the heads among all clusters. The maximum difference is between the head medoid surfaces of cluster K1 and K2, with a maximum positive deviation of 19.36 mm, followed by a maximum positive deviation of 17.64 mm between cluster K1 and K7. The maximum positive deviation between cluster K3 and

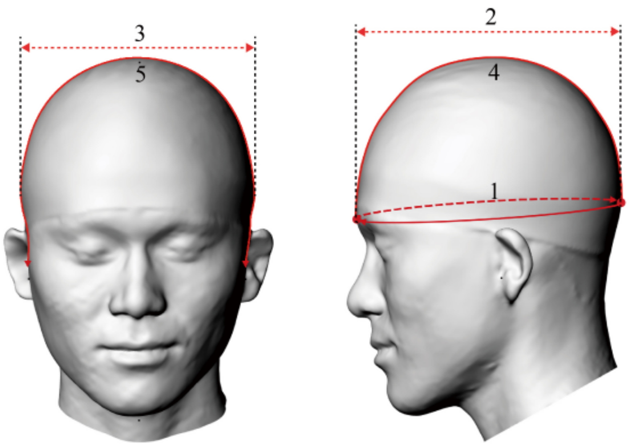

Fig. 6. Five dimensions of the head.

K7 is 13.71mm, with a maximum negative deviation of 0, while the maximum positive deviation between cluster K5 and K7 is 8.31mm, with a maximum negative deviation of 0. This indicates that there is no overlap in the medoid surfaces of head of cluster K7 with those of cluster K3 and

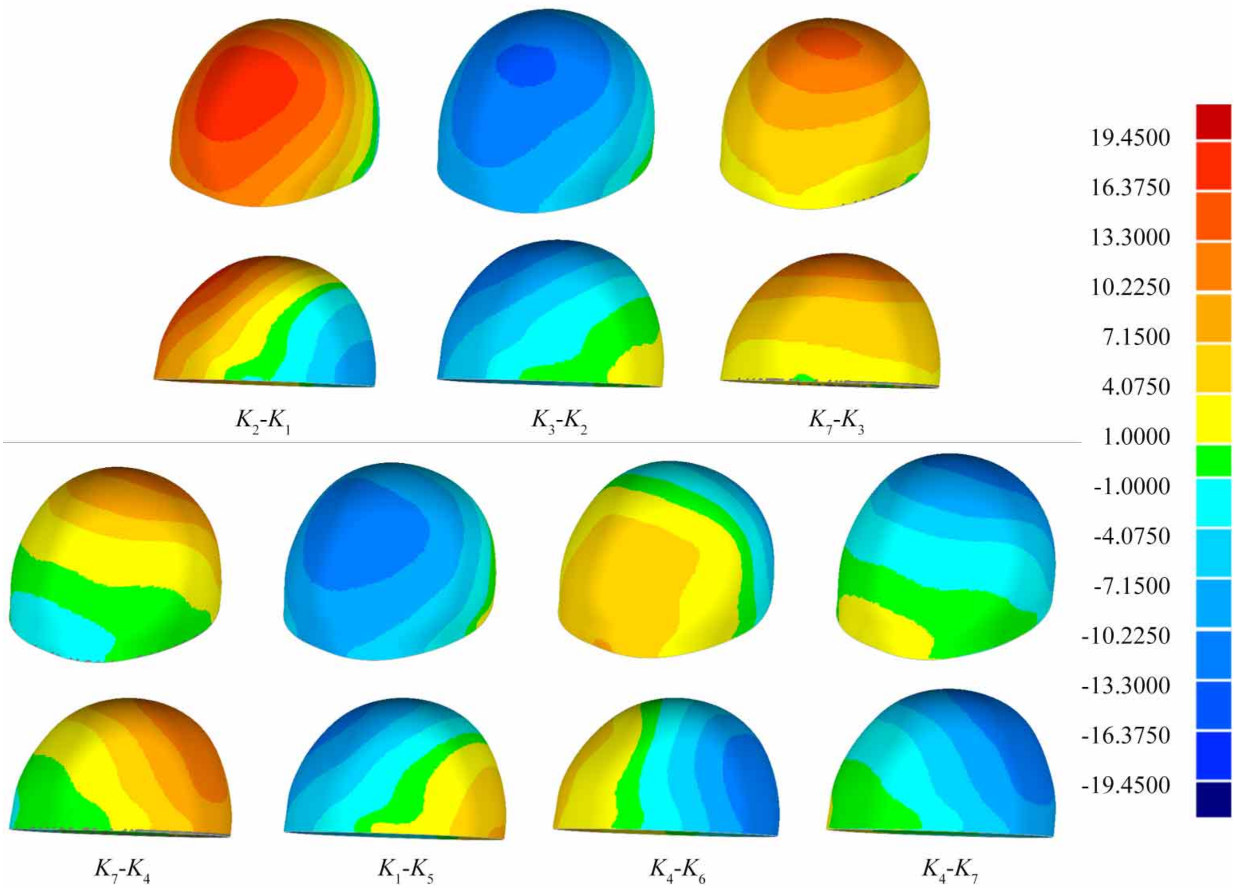

Fig. 7. The deviation analysis involves comparing the medoid surface of the head for each cluster with the mean head shape of all participants: K1- Allmean; K2- Allmean; K3- Allmean.

Table II. The deviation analysis between the medoid surface of the head for each cluster (mm).

Cluster	Deviation analysis		K_1	K_2	K_3	K_4	K_5	K_6	K_7
K_1	Maximum	Positive	/	19.36	6.20	12.85	12.67	7.71	17.64
	Distance	Negative	/	-9.67	-6.78	-11.50	-7.73	-0.40	-2.77
K_2	Maximum	Positive	9.67	/	3.04	0.96	2.10	9.51	7.31
	Distance	Negative	-19.36	/	-13.64	-8.17	-6.80	-11.91	-5.36
K_3	Maximum	Positive	6.78	13.64	/	6.73	7.07	7.88	13.71
	Distance	Negative	-6.20	-3.04	/	-4.83	-1.17	-0.90	0
K_4	Maximum	Positive	11.50	8.17	4.83	/	5.32	12.63	12.44
	Distance	Negative	-12.85	-0.96	-6.73	/	-3.75	-7.35	-2.96
K_5	Maximum	Positive	7.73	6.80	1.17	3.75	/	7.51	8.31
	Distance	Negative	-12.67	-2.10	-7.07	-5.32	/	-5.19	0
K_6	Maximum	Positive	0.40	11.91	0.90	7.35	5.19	/	10.18
	Distance	Negative	-7.71	-9.51	-7.88	-12.63	-7.51	/	-2.85
K_7	Maximum	Positive	2.77	5.36	0	2.96	0	2.85	/
	Distance	Negative	-17.64	-7.31	-13.71	-12.44	-8.31	-10.18	/

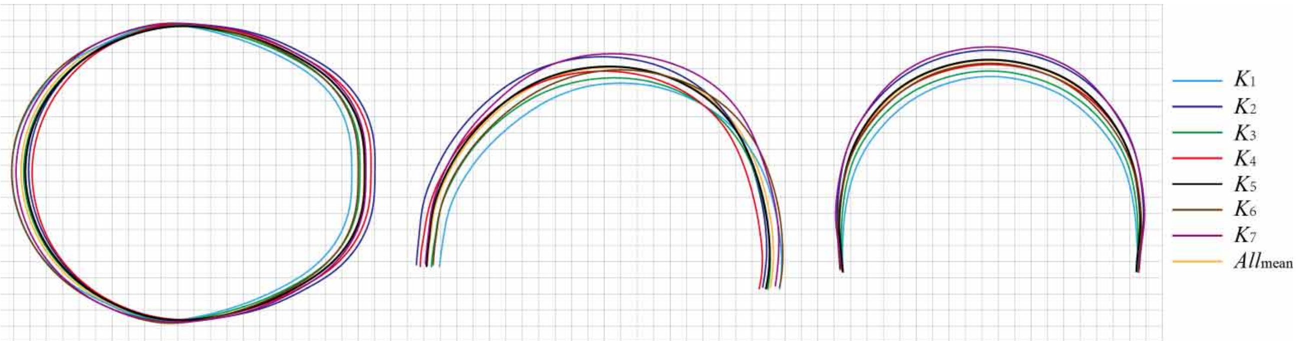

Fig. 8. The intersection lines between the medoid surface of each cluster head and the sagittal, coronal, and horizontal planes.

K5. Furthermore, combining Table II and Figure 8, it can be concluded that among all seven clustering groups, cluster K1 has the smallest head shape, while cluster K2 has the largest head shape.

Figure 9 shows the results of deviation analysis between the medoid surface of each cluster head and the mean surface of all sample heads. Table III displays the maximum deviation, mean deviation, and standard deviation between the medoid surface of each cluster head and the mean surface of all sample heads. The analysis results show that there is a large difference between the medoid surface of cluster K1 and the mean head surface, with a maximum negative deviation value of -11.28mm. The maximum negative deviation value between the medoid surface of cluster K3 and the mean head surface is -6.20mm, and the maximum positive deviation value is 0. In contrast, the maximum positive deviation value between the medoid surface of cluster K7 and the mean head surface is 7.67mm, and the maximum negative deviation value is 0. As shown in Figure 8, the intersection lines between the medoid surfaces of clusters K3 and K7 and the mean head surface do not overlap at all. This indicates that the medoid surface of cluster K3 is completely smaller than the mean head surface, while the medoid surface of cluster K7 is completely larger than the mean head surface. Except for clusters K3 and K7, there is overlap between the medoid surface of each cluster head and the mean head surface. Therefore, it is not advisable to use only the mean head surface or simply offset the mean head surface to obtain head models of different sizes for helmet product design or medical reconstruction purposes.

As shown in Tables I and III, the medoid surface of head for cluster K4 has a small dimension difference compared to the mean head surface, but their maximum negative deviation value between surfaces is -7.22mm, occurring at the end of the occipital and parietal regions. As shown in Table I and Figure 9, the head circumference dimension of cluster K5 differs by 7.92mm from the mean head surface, but the maximum negative deviation between the two surfaces is only -2.41mm. This result further supports Ellena *et al*. (2016, 2017, 2018a,b) assertion that helmet manufacturers using only limited dimensions as parameters for helmet design or compatibility evaluation is definitely not ideal.

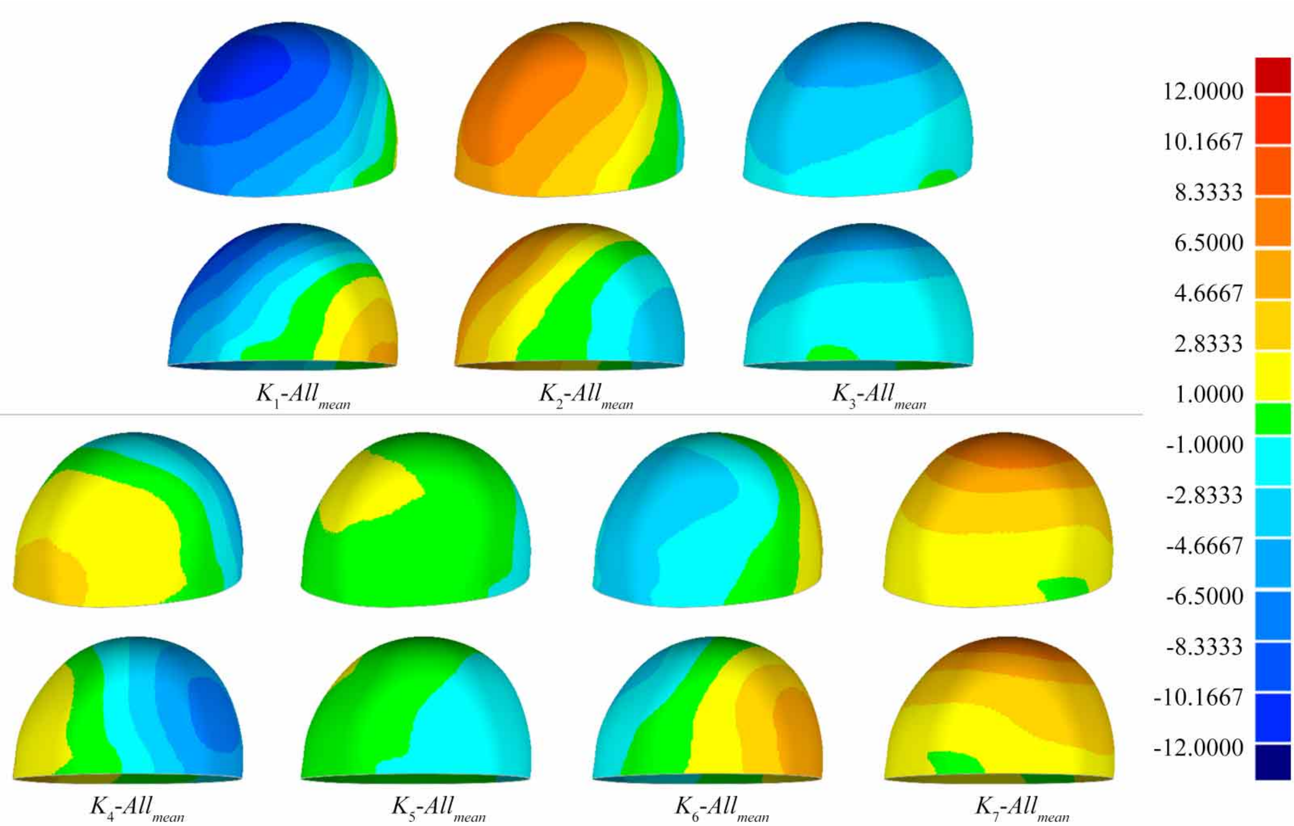

Fig. 9. The deviation analysis involves comparing the medoid surface of the head for each cluster with the mean head shape of all participants: K1- Allmean; K2- Allmean; K3- Allmean.

Table III. The deviation analysis involves comparing the medoid surface of the head for each cluster with the mean head shape of all participants (mm).

Deviation analysis		K_1	K_2	K_3	K_4	K_5	K_6	K_7
Maximum	Positive	5.36	8.14	0	4.11	1.41	5.45	7.67
Distance	Negative	-11.28	-4.32	-6.20	-7.22	-2.41	-3.81	0
Average	Positive	2.31	4.71	0	1.71	0.65	2.78	3.83
Distance	Negative	-6.14	-2.05	-3.17	-3.43	-1.09	-2.08	0
Standard Deviation		4.47	3.60	1.48	3.07	1.02	2.77	2.01

CONCLUSIONS

This study uses an improved k-medoids algorithm to cluster 339 Chinese young male head shapes into 7 clusters from the perspective of head shape differences, and calculates the medoid surface of head for each cluster to build a database of head shapes for Chinese young men. These intuitive data can be used for diagnosing congenital malformations, head plastic surgery, and especially in the ergonomic design of helmet products.

Future research will be conducted in three areas: (1) studying the facial differences among the Chinese population to build a complete head and facial model database; (2) investigating the differences in head shape among Chinese individuals under 18 and over 30 years of age, while also exploring sex differences in head shape; and (3) exploring the relationship between head shape and other physical characteristics such as height and weight, to better understand the overall shape of the human body.

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HUANG, Y.; ZHU, Z.; ZHU, J.; YE, M. & ZHANG, K. Estudio morfométrico de la cabeza en la población de adultos jóvenes chinos. *Int. J. Morphol., 41(3)*:873-880, 2023.

RESUMEN: Debido a la complejidad de la forma de la cabeza, la antropometría limitada de ésta, en 1D o 2D, no logra capturar completamente sus características de forma. Actualmente, existen estudios limitados sobre el análisis de agrupamiento de la forma de la cabeza, desde una perspectiva de diferencia de forma, especialmente en el caso de la población china. La forma de la cabeza está influenciada por factores como la raza, el sexo y la edad, por lo que resulta imperativo crear una base de datos sobre la forma de la cabeza de los individuos chinos. En este estudio, se recopilaron datos tridimensionales de la cabeza de 339 adultos jóvenes chinos, y las formas de la cabeza se agruparon en 7 grupos utilizando un algoritmo k-medoids mejorado. Las diferencias entre los grupos y la forma promedio de la cabeza se analizaron a profundidad. Se puede prever que la base de datos sobre la forma de la cabeza de adultos jóvenes chinos construida en este estudio, tiene un valor de referencia importante para el diseño ergonómico de productos relacionados con la morfología de la cabeza, entre otros campos.

PALABRAS CLAVE: Antropometría; Cabeza Tridimensional; Aglomeración de formas; Diferencia de forma.

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