Statistical analysis of the differences of head and face features between terracotta warriors and modern multi ethnic groups based on 3D information extraction

Yungang Hu1*, Jingyang Wang1, a and Dexing Lan2, b

1 School of Geomatics and Urban Spatial Informatics, Beijing University of Civil Engineering and Architecture, Key Laboratory for Architectural Heritage Fine Reconstruction & Health Monitoring, Beijing 100044, China

2 Department of Key Scientific Research Base of Ancient Polychrome Pottery Conservation, Emperor Qinshihuang’s Mausoleum Museum, Xian, Shanxi 710600, China

a email: 18295688720@163.com, b email: lands2000@163.com

* Corresponding author’s e-mail: huyungang@bucea.edu.cn

Abstract: The terracotta warriors excavated from Qin Shihuang’s mausoleum are precious materials of the Qin Dynasty. They have great historical, scientific and artistic research value and are considered to be the true portrayal of the Qin people. In anthropology, the measurement of head and face features is one of the important means to analyze the ethnic relationship. In this paper, the 3D laser scanner is used to collect the high-precision 3D point cloud data of the terracotta warriors, extract the head and face features of the terracotta warriors, and variance analyze (ANOVA) and cluster analysis with the collected head and face features of 29 modern ethnic groups. Variance analysis shows that there is no significant difference between the terracotta warriors and modern people in the shape of morphological facial length, bizygomatic breadth, nose height, the height of mucrons lips, and mouth breadth. Cluster analysis based on head and face features shows that the terracotta warriors belong to the same group with 10 ethnic groups including Mongolian, and they have more similar head and face features.

1. Introduction

The archaeological discovery of the terracotta warriors in the 1970s is known as "one of the great discoveries in the history of Archaeology in the 20th century". At present, more than 2000 pieces have been unearthed, but they have not been fully excavated[1], but they also provide invaluable materials for studying military, political, economic, cultural, scientific, and technological aspects of the Qin Dynasty[2].

Both artists and archaeologists believe that each terracotta has a different face, which is a portrait of a real person. For example, He[3] and Cui[4] analyzed the similarity between terracotta warriors and real people from sculpture art. The research of Komlos[5] on the height measurement data of more than 700 terracotta warriors showed that the height of the terracotta warriors is close to people in the current era. Bevan[6] used the computer vision method to obtain the 3D model data of the 30 terracotta warrior ears and statistically concluded that the ears of the terracotta warriors and the ears of modern people are almost the same. These digital quantitative studies preliminarily confirmed that the terracotta warriors
2. Research method

2.1. Extraction of head and face features

The head and face features in anthropometry are based on five measurement dimensions, including height, length, breadth, angle, circumference and radian, and then are subdivided into 54 features, such as the horizontal circumference of the head, maximum head breadth, etc. Meanwhile, 19 characteristic indexes, such as morphological facial index and nasal index, are derived from these 54 characteristics. These characteristics and indexes are clearly defined in the Anthropometric manual \[14\], and are specifically described in Chinese national and international standards related to anthropometry \[15\]. Among them, 8 facial features are often selected from 54 features: including interocular breadth, bicocular breadth, morphological facial length, bizygomatic breadth, nose breadth, nose height, the height of mucons lips, and mouth breadth. For relevant definitions and measurement methods, please refer to Anthropometric terminology \[16\] and Anthropometric methods \[17\], as shown in Figure 1.

---

Figure 1 Schematic diagram of measurement features
The selected eight head and face features are represented by the linear distance between two feature points. Therefore, in the process of extraction, it is necessary to accurately calibrate the key points. These feature points include corner points (ectocanthions, cheilions), inflection points (sellions, gnathions, zygions, alares, subnasales) and lip midpoint (labrale superius, labrale inferius). The selection of key feature points was done by manual multiple point selection, and the average value of coordinates is obtained. As the high-precision 3D data model is a vector model, after adjusting the position of the model, the local position of the key feature points is enlarged, and the key feature points are selected manually five times. Moreover, the 3D coordinates of the key feature points are obtained through the calculation of the average value. Finally, according to the distance formula between the two points, the corresponding head and face feature values are obtained, and ensuring the reliability of the sample value.

2.2. Analysis method of head and face features between terracotta warriors and modern ethnic groups
In order to analyze the differences and similarities between the head and face features of terracotta warriors and modern ethnic groups, this paper obtains the head and face features of 29 modern ethnic groups from many literatures as the data for subsequent statistical analysis [18-45].

(1) Variance analysis
Variance analysis (ANOVA), also known as "F test", is invented by R. A. Fisher, which is used to test the significance of the difference between two or more samples [46]. For example, the effect of soil, fertilizer, sunshine time and other factors on the yield of a certain crop, and the insecticidal effect of different chemicals on crop pests can be verified by variance analysis. In the variance analysis, if P value is less than 0.05, there is significant difference in the representative objects, otherwise, if P value is greater than 0.05, there is no significant difference in the representative objects [47]. In this paper, the variance analysis is used to verify whether there are significant differences between the terracotta warriors and 29 modern nationalities of the eight head and face features.

(2) Cluster analysis
The method of cluster analysis is often used in the classification of races in anthropology [48-50]. The purpose of cluster analysis is to divide objects into several clusters based on their similarity, so that objects in the same cluster are highly correlated, while objects in different clusters are low correlated [51]. The specific step includes: calculate the distance between characteristic values between two clusters, merge the two clusters with the smallest distance into a new cluster, and take the average value as the feature value of the new cluster. Then, repeat the process until all clusters are merged into one and the clustering ends [52]. Euclidean distance is commonly used in clustering calculation, which is used to measure the distance of individuals in space. The larger the distance is, the greater will be the gap is; otherwise, it will be closed. The calculation formula is as follows (1):

$$D_{ij} = \sqrt{\sum_{t=1}^{m}(x_t - y_t)^2}$$

(1)

3. Results and statistical analysis

3.1. Head and face feature extraction of terracotta warriors
According to the method described in 2.1, the head and face features of terracotta warriors and horses are extracted. The results are shown in Table 1.

| Table 1 Measurements of head features of terracotta warriors |
|----------------------------------|
|                         | biocular breadth | interocular breadth | morphological facial length | bizygomatic breadth | nose breadth | nose height | height of mucons lips | mouth breadth |
| G8-23                 | 103.36           | 41.94              | 115.91                     | 146.38             | 46.79        | 48.16       | 26.32               | 44.89        |
| G8-25, 70, 96         | 110.02           | 50.74              | 124.56                     | 144.09             | 51.24        | 52.40       | 22.30               | 58.72        |
| G8-33                 | 115.30           | 53.13              | 136.95                     | 154.38             | 54.57        | 55.43       | 19.83               | 58.23        |
| G8-34                 | 107.77           | 37.91              | 134.49                     | 151.10             | 56.16        | 53.19       | 22.34               | 58.67        |
| G8-35                 | 115.30           | 50.22              | 127.72                     | 158.52             | 55.67        | 56.10       | 20.32               | 50.77        |
| G8-77                 | 104.86           | 41.83              | 127.07                     | 143.17             | 48.50        | 53.97       | 18.09               | 53.27        |
| G9-8                  | 101.02           | 47.83              | 122.17                     | 140.84             | 46.22        | 53.79       | 22.81               | 49.68        |
| G9-10                 | 110.66           | 48.70              | 144.11                     | 149.87             | 48.95        | 65.82       | 20.81               | 58.19        |
| G10-15                | 105.53           | 49.97              | 123.75                     | 139.00             | 52.31        | 51.18       | 18.50               | 59.70        |
| G10-16                | 120.89           | 56.98              | 141.54                     | 149.95             | 52.84        | 59.94       | 25.47               | 66.23        |
| G10-26                | 97.44            | 41.88              | 129.36                     | 142.35             | 45.96        | 58.89       | 22.58               | 54.76        |

3
3.2. Variance analysis results

According to the head and face features of modern ethnic groups collected in 2.2, the data are extracted from table 1 and analyzed by variance. The results are shown in Table 2.

| Ethnic groups | Morphological facial length | Bizygomatic breadth | Nose height | Height of mucous lips | Mouth breadth | Biocular breadth | Interocular breadth |
|---------------|-----------------------------|--------------------|-------------|----------------------|--------------|-----------------|---------------------|
| Terracotta Warriors (mean ± SD) | 129.63 ±6.82 | 143.47 ±7.26 | 54.78 ±5.13 | 39.82 ±5.13 | 19.70 ±2.71 | 55.57 ±5.07 | 107.10 ±5.24 |
| Dongxiang | 128.66 | 140.14 | 56.36 | 35.95 | 16.17 | 52.80 | 87.68 |
| Uzbeck | 127.40 | 142.30 | 53.60 | 38.30 | 19.70 | 52.80 | 91.20 |
| Dong | 113.68 | 131.26 | 49.08 | 38.85 | 19.04 | 50.38 | 86.39 |
| Ban’an | 128.63 | 140.33 | 56.06 | 35.41 | 15.15 | 50.14 | 86.39 |
| Dai | 126.60 | 141.80 | 51.70 | 38.80 | 16.60 | 50.20 | 89.80 |
| Khruus | 123.40 | 141.20 | 57.60 | 38.70 | 19.60 | 51.50 | 93.70 |
| Kazakh | 125.60 | 150.40 | 56.20 | 35.50 | 16.60 | 50.30 | 100.10 |
| Hui | 121.27 | 141.65 | 50.66 | 37.30 | 17.26 | 49.41 | 86.40 |
| Tajik | 124.42 | 139.08 | 55.07 | 32.24 | 15.26 | 52.87 | 100.11 |
| Zhuang | 121.10 | 142.70 | 53.80 | 40.40 | 21.14 | 49.50 | 92.00 |
| Huyi | 125.30 | 140.30 | 58.30 | 38.70 | 15.80 | 50.50 | 85.70 |
| Yi | 128.30 | 142.80 | 51.30 | 38.10 | 17.10 | 56.00 | 89.60 |
| Jingpo | 123.74 | 139.53 | 51.87 | 38.94 | 18.22 | 53.32 | 102.72 |
| Korean | 125.47 | 142.98 | 55.62 | 37.51 | 18.81 | 50.98 | 98.51 |
| Kirgiz | 126.99 | 149.37 | 56.88 | 38.38 | 18.97 | 52.54 | 91.65 |
| Han (North) | 126.80 | 142.80 | 53.90 | 38.70 | 16.30 | 51.60 | 91.80 |
| Han (South) | 124.10 | 144.80 | 54.30 | 38.90 | 16.60 | 51.20 | 89.80 |
| Man | 125.34 | 144.85 | 53.13 | 37.36 | 18.77 | 50.94 | 94.46 |
| Naxi | 124.97 | 141.18 | 56.80 | 38.57 | 15.93 | 53.35 | 100.18 |
| Uighur | 126.00 | 145.00 | 56.30 | 35.00 | 16.10 | 49.60 | 97.50 |
| Miao | 116.38 | 127.62 | 51.08 | 37.34 | 15.04 | 50.58 | 96.53 |
| Mongolian | 121.90 | 146.60 | 51.90 | 38.90 | 17.20 | 54.90 | 106.50 |
| Tibetan | 115.10 | 138.56 | 52.91 | 32.11 | 15.84 | 52.76 | 101.95 |
| Yugur | 135.03 | 130.67 | 62.94 | 37.40 | 16.50 | 50.10 | 90.75 |
| Hezhe | 121.60 | 143.10 | 52.70 | 38.10 | 17.10 | 48.80 | 90.30 |
| Daur | 121.30 | 143.70 | 50.40 | 36.20 | 17.30 | 50.60 | 104.10 |
| Xibo | 133.27 | 147.68 | 58.40 | 38.48 | 18.07 | 52.90 | 103.10 |
| Li | 121.02 | 140.39 | 54.98 | 40.35 | 22.36 | 47.66 | 94.07 |
| F value | 0.862 | 0.49 | 0.533 | 2.364 | 1.357 | 0.475 | 2.866 |
| P value | 0.654 | 0.97 | 0.952 | 0.012 | 0.208 | 0.975 | 0.005** |

* p<0.05  ** p<0.01

According to the results of variance analysis, it can be seen that the terracotta warriors and the modern ethnic groups, in the shape of morphological facial length, bizygomatic breadth, nose height, the height of mucous lips, and mouth breadth showed consistency, there was no difference (P > 0.05), in the interocular breadth, biocular breadth, nose breadth showed significant difference (P < 0.05).
3.3. Results of cluster analysis

According to the clustering method in 2.2 and the data in Table 2, the cluster diagram is generated by SPSS software. The results are shown in Figure 2.

![Cluster analysis chart]

From the results of cluster analysis, we can see that these ethnic groups are divided into three groups, as shown in Figure 1. The terracotta warriors belong to the same ethnic group with the Mongolian, Jingpo, Xibo, Naxi, Korean, Daur, Kazak, Uygur, Tajik and Tibetan, which indicates that the terracotta warriors are closer to these ethnic groups in head and face features.

4. Conclusion

The head and face features of 30 terracotta warriors were extracted by combining surveying and anthropometry. Combining archaeology and anthropology, this paper makes variance analysis and cluster analysis on the head and face features of terracotta warriors and 29 modern ethnic groups. The results show that the head and face of the terracotta warriors present different features, which supports the research of art and archaeologists in the form of data. According to the results of variance analysis and cluster analysis, there is no significant difference between the terracotta warriors and modern ethnic groups in the shape of morphological facial length, bizygomatic breadth, nose height, the height of mumps lips, and mouth breadth. Moreover, the head and face features of the terracotta warriors are more similar to those of the Mongolian, Jingpo, Xibo, Naxi, Korean, Daur, Kazak, Uygur, Tajik and Tibetan.

Reference

[1] Zhao Z, Xiao WG, Xia JX, et al. (2015). Excavation report of No.1 terra cotta warriors and horses burial pit in the mausoleum of the first emperor of Qin Dynasty from 2009 to 2011. Cultural relics (09), 4-38 + 2 + 1 Doi: 10.13619/j.cnki.cn11-1532/k.2015.09.001
[2] Fei YC. (2017). The significance of the discovery of terracotta warriors and horses to the study of ancient military and sculpture art. Comparative study on cultural innovation (28), 20-21
[3] He XL (1987). Inheritance, fusion and the crystallization of the spirit of the times -- and an exploration of the artistic origin of the realism of the terracotta warriors. Wenbo (01), 51-54
[4] Cui BL(2009). On the realistic style and cultural connotation of Qin Figurine Sculpture (Master's thesis, Shandong University). http://fagz208e51c2dd88406685526280e50de659s6bnq56bxuowo6upu.fyac.oca.swupl.edu.cn/KCMS/detail/detail.aspx?dbname=CMFD2010&filename=2009245896.nh
[5] Komlos, J. (2003). The size of the Chinese terracotta warriors-3rd century BC. Antiquity, 77(296).
[6] Andrew, Bevan, Xiuzhen, et al. Computer vision, archaeological classification and China's terracotta warriors[J]. Journal of Archaeological Science, 2014.
[7] Yong W, Wu ZZ, Wu ML, et al. (2016). 3D human head and face measurement point recognition based on template deformation. Ergonomics (01), 1-6 Doi: 10.13837/j.issn.1006-8309.2016.01.0001.
[8] Richmond, S. , Howe, L. J. , Lewis, S. , et al. (2018). Facial genetics: a brief overview. Frontiers in Genetics, 9.
[9] Cole, J. B. , Manyama, M. , Larson, J. R. , et al. (2017). Human facial shape and size heritability and genetic correlations. Genetics, 205(2), 967.
[10] Foat, F. W. G. (1915). Anthropometry of greek statues. Journal of Hellenic Studies, 35, 225-259.
[11] Siromoney, G. & Govindaraju, M. B. (1980). An application of component analysis to the study of south indian sculptures. Computers & the Humanities, 14(1), 29-37.
[12] Mather, & George. (2010). Head-body ratio as a visual cue for stature in people and sculptural art. Perception, 39(10), 1390-5.
[13] Starbuck, John, & M. (2014). Quantitative evaluation of the facial morphology of a tolteca figurine from mexico using geometric morphometric approaches. International Journal of Morphology, 32(2), 499-509.
[14] Shao XQ (1985). Anthropometric manual [M]. Shanghai: Shanghai dictionary press
[15] Fang F, Zhang WY, Zhang WB, et al. (2005). Study on anthropometric standards. Journal of Donghua University (NATURAL SCIENCE EDITION) (01), 132-138
[16] GB / T 3975-1983 (1984) Anthropometric terminology [S]. China Standard Press
[17] GB / T 5703-1985 (1986) Anthropometric methods [S]. China Standard Press
[18] Yu KL, Zheng LB, Li YL, et al. (2016). Differences in head and facial morphology between northern and Southern Han Chinese. Acta Anatomica Sinica (03), 404-408 Doi:10.16098/ j.issn.0529-1356.2016.03.020.
[19] Zheng LB, Zhu Q, Wang QL, et al. (1997). Study on physical characteristics of Ningxia Hui nationality. Acta Anthropologica Sinica (01) Doi:10.16359/j.cnki.cn11-1963/q.1997.01.002.
[20] Zhu Q, & Zhang XL. (1993). Physique, somatotype and changes of Mongolian in the past half century. Acta Anthropologica Sinica, 012 (004), 347-356 Doi:10.16359/j.cnki.cn11-1963/q.1993.04.00
[21] AI QH, Xiao H, Zhao JX, et al. (1993). Study on physical characteristics of Uygur nationality. Acta Anthropologica Sinica (04), 357-365 Doi:10.16359/j.cnki.cn11-1963/q.1993.04.007.
[22] Zheng LB, Zhang SL, Lu SH, et al. (2005). Study on physical characteristics of Buyi Nationality. Acta Anthropologica Sinica (02), 137-144 Doi:10.16359/j.cnki.cn11-1963/q.2005.02.004.
[23] Zheng LB, Lu SH, Yu HX et al. (2007). Physical characteristics of Wa nationality. Acta Anthropologica Sinica (03), 249-258 Doi:10.16359/j.cnki.cn11-1963/q.2007.03.001.
[24] Zheng LB, Cui J, Lu SH, et al. (2004). Study on physical characteristics of Uzbek nationality. Acta Anthropologica Sinica (01), 35-45Doi:10.16359/j.cnki.cn11-1963/q.2004.01.005.
[25] Zheng LB, Lu SH, Chen YY, et al. (2007). Physical characteristics of Chinese Kemu people. Acta Anthropologica Sinica (01), 45-53Doi:10.16359/j.cnki.cn11-1963/q.2007.01.005.
[26] Dai YJ, Yang DY. (1991). Study on physical characteristics of Dongxiang Nationality in Gansu Province. Acta Anthropologica Sinica (02), 127-134Doi:10.16359/j.cnki.cn11-1963/q.1991.02.005.
[27] Hai XJ, Dai YJ. (2005). Head and face characteristics of Chinese Tibetans. Health Vocational Education (19), 120-123
[28] Cui J, Shao XZ, Wang JL, et al. (1991). Investigation on the physical characteristics of Kazak nationality in Xinjiang. Acta Anthropologica Sinica (04), 305-313 Doi:10.16359/j.cnki.cn11-1963/q.1991.04.005.
[29] Shi QD, Hu JQ, Yang HY. (1983). Investigation of the physical characteristics of Daur nationality in Heilongjiang Province. Journal of Anthropology (01), 60-71 Doi:10.16359/j.cnki.cn11-1963/q.1983.01.007.
[30] Pang ZY, Li PC, Liang MK, et al. (1987). A physical survey of Miao and Yi Nationalities in de'e, Guangxi. Acta Anthropologica Sinica (04), 324-335 Doi:10.16359/j.cnki.cn11-1963/q.1987.04.008.

[31] Shao XZ, Cui J, Zhu XA, et al. (1987). Physical characteristics of Kirgiz nationality in Tekes County, Xinjiang. Acta Anthropologica Sinica (04), 315-323 Doi:10.16359/j.cnki.cn11-1963/q.1987.04.007.

[32] Li M, Yu FC, Liu GH, et al. (1989). Physical characteristics of Jingpo nationality in Yunnan Province. Acta Anthropologica Sinica (01), 8-16 Doi:10.16359/j.cnki.cn11-1963/q.1989.01.002.

[33] Shi QD, Hu JQ, Zhao GX. (1987). Physical characteristics of Hezhe nationality. Acta Anthropologica Sinica (04), 336-342 + 373 Doi:10.16359/j.cnki.cn11-1963/q.1987.04.009.

[34] Han XJ, He X, Duan XJ, et al. (1993). Investigation on physical characteristics of Man nationality in Jilin Province. Acta Anthropologica Sinica (01), 55-63 Doi:10.16359/j.cnki.cn11-1963/q.1993.01.007.

[35] Shao XZ, Wang DL, Cui J, et al. (1984). Investigation on the physical characteristics of Xibo Nationality in Qapqal, Xinjiang. Acta Anthropologica Sinica (04), 349-362 Doi:10.16359/j.cnki.cn11-1963/q.1984.04.008.

[36] Shao XZ, Cui J, Wang JL, et al. (1990). Physical characteristics of Tajik Nationality in Tashkurgan, Xinjiang. Acta Anthropologica Sinica (02), 113-121 Doi:10.16359/j.cnki.cn11-1963/q.1990.02.003.

[37] Liu GH, Yu FC, Li M, et al. (1992). Physical characteristics of Naxi nationality in Yunnan Province. Acta Anthropologica Sinica (01), 13-19 Doi:10.16359/j.cnki.cn11-1963/q.1992.01.003.

[38] Dai YJ, Ding JS, Zou ZB. (1987). A preliminary study on the physical characteristics of Yugur nationality in Gansu Province. Acta Anthropologica Sinica (03), 227-235 Doi:10.16359/j.cnki.cn11-1963/q.1987.03.010.

[39] Pi JH, Wu YZ, Lei MZ. (2007). Measurement and analysis of head and face physique of Miao Nationality in Western Hunan. Ergonomics (04), 19-21 + 32 Doi:10.13837/j.issn.1006-8309.2007.04.001.

[40] Pi JH, Wu YZ, She CW. (2003). Analysis of the physical characteristics of the head and face of Dong nationality adults in Hunan Province. Anatomical study (03), 221-223.

[41] Zhang ZB, & Zhang JJ. (1982). A study on the physical characteristics of Li Nationality in Hainan Island. Acta Anthropologica Sinica (01), 55-73 + 108.

[42] Zhang ZB, Zhang JJ. (1983). Physical characteristics of Zhuang Nationality in Guangxi. Acta Anthropologica Sinica (03), 260-271 Doi:10.16359/j.cnki.cn11-1963/q.1983.03.007.

[43] Zhang XH, Zheng LB, Yu KL, et al. (2016). Age change of facial morphology of Dai nationality in Xishuangbanna. Journal of Nanjing Normal University (NATURAL SCIENCE EDITION) (01), 79-85.

[44] Yang DY, Dai YJ. (1990). Physical characteristics of Bao’an nationality in Gansu Province. Acta Anthropologica Sinica (01), 55-63 Doi:10.16359/j.cnki.cn11-1963/q.1990.01.010.

[45] Jin CZ, Jin DZ, Yu DY. (1998). Comparison of head and face physical characteristics of Koreans in China and North Korea. Journal of Anatomy (03), 3-5.

[46] Statistics group, Institute of mathematics, Chinese Academy of Sciences. (1977). Variance analysis. Science Press.

[47] Liu RQ. (2007) SPSS statistical software [M]. Beijing: China traditional Chinese Medicine Press.

[48] Li YL. (2018). Cluster analysis and principal component analysis of head and face indexes in Chinese rural Han men. Journal of anatomy (02), 190-195.

[49] Li SY, Zheng LB. (2005). Cluster analysis of head and face indices of 30 Chinese populations. Journal of Inner Mongolia Normal University (NATURAL SCIENCE CHINESE EDITION) (03), 365-368.
[50] Li ZJ, Duan XD & Wang CR. (2015). Cluster analysis of facial geometric features of six ethnic groups in China. Journal of Dalian University for Nationalities (01), 73-76. Doi:10.13744/j.cnki.cn21-1431/g4.2015.01.019

[51] Yang SY (2016). SPSS 22 Statistical Analysis Case Course [M]. China Water Resources and Hydropower Press.

[52] Fang KT(1978). Cluster analysis (I) [J]. Practice and understanding of mathematics, (1): 55-63