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Conference Paper · August 2024

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University of Malaya
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Analyzing Gender-Related Variations in Head Morphology among Malaysian Adults

Zhuoman Liu[1[0000-0002-2991-5242]], Yan Luximon[1*[0000-0003-2843-847X]], Wei Lin Ng[2], and Eric Chung[2]

[1] School of Design, The Hong Kong Polytechnic University, Hong Kong SAR, China
[2] Department of Biomedical Imaging, University of Malaya, Kuala Lumpur, Malaysia
*yan.luximon@polyu.edu.hk

Abstract. Head-related product design is significantly enhanced by a thorough understanding of the morphological differences in human heads between genders. Existing head variation studies primarily focus on overall size and facial landmarks originating from facial recognition technologies, limiting the scope to facial features. Our research proposes a more comprehensive framework, establishing thirty distinct landmarks encompassing the entire head, utilizing Computed Tomography (CT) imaging to explore morphological diversity between genders in Malaysian adults. We divided the study group by gender to validate the precision of these landmarks in capturing morphologic variances, employing the Intraclass Correlation Coefficient (ICC) for reliability assessment. Through rigorous statistical analysis, the study examines the differences and correlations in head morphology between gender groups at anatomical landmark locations. The study offers valuable insights into the morphological variations in human heads, providing insights for further research in head-related product design and anthropological fields.

Keywords: Head Morphology Analysis, Anatomical Landmarks, Computed Tomography Data.

1 Introduction

Understanding the morphological differences in human heads, particularly in relation to gender, is critical for the development of head-related products and for gaining insights into human variation and evolution. Previous studies have mainly focused on facial features, driven by advances in facial landmark detection technology [1]. These studies typically emphasize overall size and facial landmarks, providing a limited perspective on the full scope of head diversity [2].

However, there is a growing recognition of the need for a more comprehensive approach to analyze head morphologic variations. Our research aims to bridge this gap by establishing a framework that incorporates thirty distinct landmarks across the entire head. Gender differences in head morphology have implications for both health and ergonomic product design [3, 4, 5]. Our study subdivides the Malaysian adults into two gender groups, *i.e.*, male and female, and employs the Intraclass Correlation Coefficient

(ICC) [6] to assess the reliability of these landmarks in capturing morphological variances. After validating the reliability of the landmarks, this study analyzes the correlation of head morphology between different gender groups in Malaysia based on the annotated landmarks.

2 Method

2.1 CT Data Collection and Preprocessing

In the study, we collected CT scans from 30 Malaysian adults aged between 20 and 65 years. To ensure gender balance, the collected data come from an equal number of male and female participants. For detailed analysis, we processed the CT scans using Materialise Mimics software to construct 3D meshes of the head surface.

2.2 Landmarks for Head Surface

In this study, we establish thirty distinct anatomical landmarks for analyzing head morphology as shown in Fig. 1. These landmarks are strategically selected to cover the entire head, including facial, occipital, and auriculotemporal regions. The definitions for the majority of these landmarks draw upon [7]. Additionally, to provide a more comprehensive analysis of the occipital region, we introduce three specific landmarks (landmark 21, 22, and 24) to further enhancing the morphological study. Besides, the Helix points on the ear (landmark 16 and 20) are located on the same horizontal plane as the occipital landmarks. We manually label the anatomical landmarks following the above definitions on all scans. Notably, we performed twice manual labelling on these scans to subsequently verify the reliability of the labelled landmarks. These landmarks are designed to accurately capture individual variations in head shape and size, facilitating in-depth morphological analysis.

1	Sellion	16	Left Helix
2	Subnasale	17	Right TEA
3	Philtrum	18	Right Tragion
4	Labrale Superius	19	Right Otobasion Inferius
5	Left Cheilion	20	Right Helix
6	Right Cheilion	21	Left Occiput
7	Sublabiale	22	Occiput
8	Chin	23	Left Zygofrontale
9	Left Gonion	24	Right Occiput
10	Right Gonion	25	Right Nasal Root Point
11	Vertex (Top of head)	26	Right Zygofrontale
12	Left Nasal Root Point	27	Rhinoan
13	Left Top of Ear Attachment (TEA)	28	Pronasale
14	Left Tragion	29	Left Alare
15	Left Otobasion Inferius	30	Right Alare

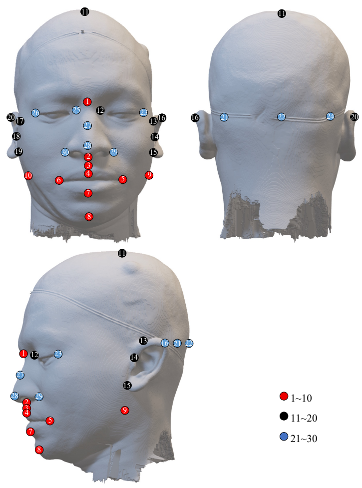

Fig. 1. Illustration of landmarks for head surface.

2.3 Variance Analysis and Reliability Testing

To comprehend the variations in head morphology, the study performs statistical analyses on the mean values and the standard deviation of the length of a set of dimensions based on identified landmarks. The dimensions are defined horizontally, vertically and in depth as shown in Fig. 2. We apply Welch's T-Test [8] to investigate the morphological differences across different gender groups. Our study splits the landmark data into two gender groups: male and female, each comprising fifteen observations to compute correlations. Additionally, we extended the variance analysis to gender-specific data, with fifteen observations each for male and female groups. Our analysis highlighted significant morphological differences within gender groups in Sec. 3.1.

Moreover, we employ the Intraclass Correlation (ICC) analysis to ensure the reliability and consistency of the labeled anatomical landmarks. This correlation analysis is a widely recognized method for assessing reliability of quantitative measurements made by different observers. This approach has been effectively utilized in various studies [9, 10]. We perform twice manual annotation for landmark identification to acquire two sets of landmarks. The ICC analysis is executed using a two-way random effects model with average measures for absolute agreement. By employing ICC to assess the test-retest reliability of these landmarks, we show the validity and consistency of our findings in Sec. 3.2.

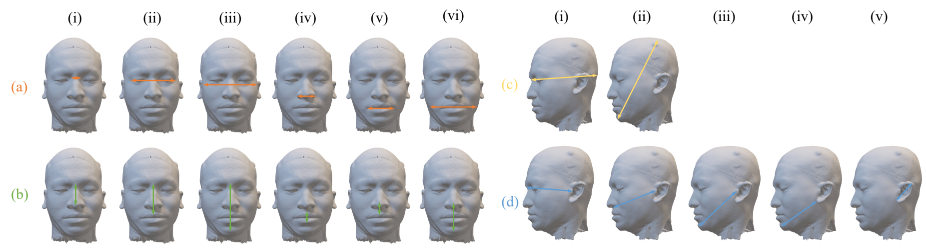

Fig. 2. Illustration of different dimensions on landmarks.

3 Experimental Results

3.1 Statistical Differences on Dimension Length

In our study, we analyze head morphology by categorizing the dimensions derived from the landmarks into four groups: (a) horizontal dimensions; (b) vertical dimensions; (c) depth-oriented dimensions; and (d) depth-oriented dimensions differentiated by left and right sides based on ear location, each labeled from (i) to (vi) as shown in Fig. 2. It is noted that the CT scans were acquired with the participants in a lying position, and the dimension lengths of the soft tissues were related to the different positions.

For all participants, we calculated the mean and standard deviation (S.D.) of each dimension across gender. In addition, we assessed the correlation of dimension length within different genders, with the significance level set at 0.05, as shown in Table 1. Our analyses showed that there were significant gender differences in several dimensions: **(a)** horizontal measures, such as face width (iii) and nose width (iv) between genders; **(b)** vertical measures, such as the distance from the nose to the upper lip (v) between genders; and **(c-d)** depth measurements, including the distance from the eyes, nose, and chin to the ears, as well as the size of the ears, also showed significant gender differences. Moreover, in general, the dimension lengths of the head surface are larger for male than for female. The differences in horizontal, vertical, and depth-oriented dimensions, especially in facial recognition areas, indicate underlying biological variations. For some dimensions that are not significantly different, larger datasets might be required for further validation.

Table 1. Results of gender-related variances for different dimensions. P-values with # indicate statistically significant difference in dimension lengths among genders.

Dimension		Male	Female	Gender-related variance
		Mean ± S.D. (mm)	Mean ± S.D. (mm)	*p-value*
(a)	**(i)**	21.73 ± 2.24	20.84 ± 2.53	0.329
	(ii)	103.07 ± 5.54	103.78 ± 6.26	0.752
	(iii)	159.89 ± 6.94	152.98 ± 4.42	0.004#
	(iv)	43.63 ± 2.82	40.13 ± 2.80	0.003#
	(v)	58.21 ± 5.65	56.69 ± 5.54	0.477
	(vi)	142.68 ± 14.51	133.96 ± 9.73	0.072
(b)	**(i)**	45.92 ± 3.79	45.09 ± 3.99	0.578
	(ii)	65.72 ± 6.06	64.78 ± 4.89	0.815
	(iii)	114.91 ± 6.20	111.01 ± 7.07	0.131
	(iv)	25.69 ± 3.24	26.69 ± 5.30	0.551
	(v)	17.85 ± 2.04	15.25 ± 1.80	0.001#
	(vi)	77.72 ± 5.55	73.80 ± 7.05	0.113
(c)	**(i)**	186.74 ± 8.50	175.55 ± 5.77	0.000#
	(ii)	242.16 ± 10.25	230.89 ± 6.93	0.002#
(d) (*Left*)	**(i)**	125.14 ± 6.07	117.39 ± 3.59	0.000#
	(ii)	130.14 ± 6.31	123.41 ± 5.02	0.004#
	(iii)	149.77 ± 9.05	140.33 ± 7.11	0.005#
	(iv)	133.67 ± 10.90	123.73 ± 8.68	0.013#
	(v)	61.36 ± 5.27	57.34 ± 4.89	0.045#
(d) (*Right*)	**(i)**	124.59 ± 6.01	117.27 ± 5.74	0.003#
	(ii)	130.20 ± 5.65	123.42 ± 7.02	0.009#
	(iii)	149.91 ± 7.10	141.26 ± 7.84	0.005#
	(iv)	132.23 ± 10.90	122.63 ± 7.83	0.012#
	(v)	60.65 ± 5.72	59.02 ± 3.75	0.380

3.2 Reliability Tests

To evaluate the consistency of landmarks from twice manual annotations, we utilized the Intraclass Correlation Coefficient (ICC) method. The ICC values ranged significantly across landmarks, indicating varied levels of consistency. Notably, landmarks such as 1, 4, 8, and 19 demonstrated excellent reliability with ICCs higher than 0.95, and confidence intervals suggesting a substantial agreement among measurements. Conversely, certain landmarks, like 9 and 10, showed lower reliability, with ICCs of 0.16 and 0.06, respectively, since these two landmarks are the locations of the lower jaws, which are roughly larger areas and more challenging to maintain consistency in their labelling. As shown in Table 1, a significant majority, 22 out of the 30 evaluated landmarks, demonstrated excellent reliability. The high ICC values for most landmarks validate the reliability of our manual labeling method, confirming their effectiveness in capturing consistent anatomical landmarks from CT scans.

Table 2. Results of ICC analysis for landmarks. ICC values with underline indicate excellent reliability of the corresponding landmarks.

Land-mark	Intraclass Correla-	95% Confidence Interval		**Land-mark**	Intraclass Correla-	95% Confidence Interval	
		Lower Bound	Upper Bound			Lower Bound	Upper Bound
1	0.99	0.97	0.99	**16**	0.89	-0.09	0.97
2	0.75	0.21	0.90	**17**	0.90	0.80	0.95
3	0.90	0.79	0.95	**18**	0.86	0.71	0.93
4	0.99	0.97	0.99	**19**	0.97	0.93	0.98
5	0.75	0.46	0.88	**20**	0.95	0.70	0.99
6	0.92	0.67	0.97	**21**	0.43	-0.23	0.75
7	0.89	0.77	0.95	**22**	0.82	0.62	0.92
8	0.97	0.89	0.99	**23**	0.91	0.80	0.96
9	0.16	-0.18	0.49	**24**	0.50	-0.22	0.79
10	0.06	-0.16	0.33	**25**	0.83	-0.16	0.96
11	0.46	-0.11	0.74	**26**	0.94	0.88	0.97
12	0.86	0.36	0.95	**27**	0.45	-0.10	0.74
13	0.77	0.46	0.89	**28**	0.45	-0.07	0.73
14	0.92	0.84	0.96	**29**	0.90	0.78	0.95
15	0.92	0.84	0.96	**30**	0.66	0.31	0.84

4 Conclusion

This study provides important insights into gender-related variations in head morphology among Malaysian adults using a comprehensive landmark-based anthropometric approach. Our findings indicate significant differences between genders with high reliability of landmark annotation. This highlights the importance of considering these differences in head-related product design and anthropometric measurements for more personalized applications.

Acknowledgement

The work described in this paper was supported by a grant from the Research Grants Council of the Hong Kong Special Administrative Region, China (Project No. GRF/PolyU 15606321) and a grant from The Hong Kong Polytechnic University (Project No. P0031501).

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