Analyzing Shape of Faces of Hypertensive and Non-Hypertensive Males Using Geometric Morphometric Methods

Christine Cherry E. Solon, Mark Anthony J. Torres, and Cesar G. Demayo
Department of Biological Sciences, College of Science and Mathematics, MSU-Iligan Institute of Technology
Iligan City, Philippines
Emails: {solonchristine, torres.markanthony, cgdemayo}@gmail.com

***Abstract*—Geometric morphometric tools were used to analyze the shape of the faces of 84 hypertensive and non-hypertensive males. Image analysis was done on the forty one (41) landmarks of the face. Landmarking was done in three replicates making sure that one session is well spaced from another to minimize bias. The pooled data were fed into the SAGE program, which performed Principal Component Analysis, Analysis of Variance (ANOVA) and Procrustes Fit. Results revealed a higher fluctuating asymmetry in hypertensive male subjects compared to the non-hypertensives. This is further supported by the differences shown by scatterplot analysis.**

***Index Terms*—Geometric morphometrics. SAGE, analysis of variance, scatterplot, procrustes**

I. INTRODUCTION

The area of biological shape analysis has greatly advanced through the years especially with advances in digital imaging, computer applications, geometry and statistics. The changes have been due also to the development and adoption of methods to analyze the Cartesian coordinates of anatomical landmarks. These geometric morphometric (GM) methods focus on the retention of geometric information throughout a study and provide efficient, statistically powerful analyses that can readily relate abstract, multivariate results to the physical structure of the original specimens [1]. GM has matured through the years with great understanding of the methodology [2].

Physical anthropology has played a central role in both the development and the early adoption of these methods, just as it has done in the realm of general statistics, where it has served as a major motivating and contributing force behind much innovation. This review surveys the current state of GM, the role of anthropologists in its development, recent applications of GM in physical anthropology, and GM-based methods newly introduced to, or by, anthropology, which are likely to impact future research.

This study aims to determine if there is variation in the facial features of adult hypertensive and non-hypertensive males and to identify the specific feature changes that can be associated with hypertension. The analyses utilize configurations of facial landmarks and are carried out using geometric morphometric methods. It specifically aims to check symmetry and asymmetry of the faces using frontal images of hypertensive and non-hypertensive groups.

Analysis of the face has been gaining popularity in studies related to health. The face, being the first aspect of a person that can be noticed, bears specific points that manifest health issues that have mostly internal expression. Ruling out the normal variation, there are distinct changes that can be indicative of a health problem [3], [4], [5], [6]. Craniofacial anthropometry has been done in several studies from looking into the association with increased susceptibility to certain diseases thus aiding in the understanding the functionality of certain components like paranasal sinuses[7].

Hypertension causes 4.5% of the global disease burden [8]. Based on surveys conducted by the Philippine Society of Hypertension (PSH), the prevalence of hypertension in the adult population the Philippines has been increasing from 16% in 2003 to 21% in 2008 [9]. In the US, adult males had higher overall mean arterial pressure in normotensive and hypertensive individuals compared to females. This was found in all ethnic groups [10]. In the Philippines, statistical surveys conducted by the Department of Health found diseases of the vascular system, under which hypertension belongs, as the second leading cause of mortality in 2001 onwards [11].

II. METHODS

A survey was made for both hypertensive and non-hypertensive men after they were formally asked to participate in the study. Formal consent from the participants was secured and their identity was made confidential. Upon approval, the digital images of faces of eighty-four males: hypertensive (N=42) and non-hypertensive (N=42) from the same age group were digitized using tpsDig2. Object symmetry, where frontal face images are utilized, is applicable in this case and a single landmark configuration provides information about asymmetry and about the left-right average of shape. This single configuration contains all the information that analyses of matching symmetry consider separately for

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the left and right sides, but it also contains additional information on the arrangement of the two halves relative to each other [12]. Measurement error is assessed by digitizing each landmark configuration thrice in three different sessions and computing the differences between replicates, all of which will be done using tps series of programs [13].

Fig. 1 shows the location of the landmarks used in the frontal face images. These landmarks were specifically chosen because they are distinct in all the samples. Short descriptions of the landmarks are included in Table 1.Position figures and tables at the tops and bottoms of columns.

Landmarking was done using tpsDig2 three times, once in three different sessions thus completing three replicates. This is needed to quantify and minimize measurement error [14]. Landmarked images were saved as TPS files then pooled. Analysis was then done using SAGE (Symmetry and Asymmetry in Geometric data) version 1.04 [15].

Procrustes methods analyze shape by superimposing configurations of landmarks into two or more specimens to achieve an overall best fit [16]. In studies of asymmetry, the Procrustes method proceeds in several steps: (a) reflect the landmark configuration of one body side to its mirror image to align corresponding landmarks of both sides; (b) scale the configurations to unit centroid size; (c) superimpose the left and right configurations so that they have the same centroid (the point of mean *x and x* and *y* coordinates for each configuration is shifted usually to the coordinates [0, 0]; and (d) rotate the configurations against each other around their centroid to achieve an optimal fit of corresponding landmarks. This portion of the analysis was automatically done by SAGE producing the procrustes fitted images.

Another function of SAGE is Procrustes ANOVA. It can show whether the variation that exists is significant or not. The effects are described as: (a) among-specimen effect which stands for individual shape variation; (b) main effect for the sides that express directly asymmetry in shape; (c) side X specimen interaction which serves as a measure of fluctuating asymmetry; the deviation of each individual's asymmetry from the overall average of symmetry in shape, and (d) measurement error which refers to the variability among replicates [17] .

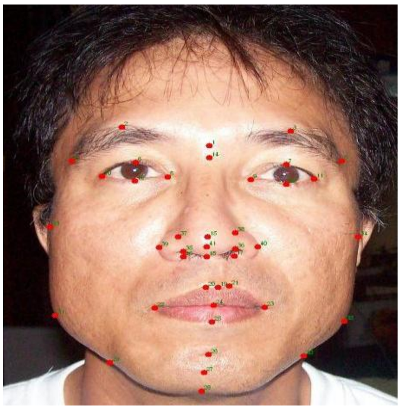

Figure 1. Landmarks on the frontal face image. *(photograph used with permission from the subject)*

TABLE I. CRANIOFACIAL LANDMARKS (FRONTAL IMAGE).

No.	Landmark	Region	Definition/Description
1	Nasion (n)	Face	The midpoint of the nasofrontal suture
2, 3	Superciliare (sci)	Orbits	The highest point on the upper margin of the middle portion of the eyebrow
4, 5	Frontozygomaticus (fz)	Head	The most lateral point on the frontozygomatic suture
6, 7	Palpebrale superius (ps)	Orbits	The highest point on the upper margin of the middle portion of the eyelid
8, 9	Endocanthion (en)	Orbits	The inner corner of the eye fissure where the eyelids meet, not the caruncles (the red eminences at the medial angles of the eyes)
10, 11	Exocanthion (ex)	Orbits	The outer corner of the eye fissure where the eyelids meet
12, 13	Palpebrale inferius (pi)	Orbits	The lowest point in the middle of the margin of the lower eyelid
14	Sellion (s)	Nose	The deepest point of the nasofrontal angle
15	Pronasale (prn)	Nose	The most protruded point of the nasal tip
16, 17	Lateral subalare	Nose	Medial to alare (the most lateral point on the nasal ala), it is the inner wall of the nose
18	Subnasale (sn)	Face	The junction between the lower border of the nasal septum (the partition that divides the nostrils) and the cutaneous portion of the upper lip in the midline
19	Labiale superius (ls)	Orolabial	The midpoint of the vermilion border of the upper lip
20, 21	Crista philter (cph)	Orolabial	The point on the crest of the philtrum, the vertical groove in the median portion of the upper lip, just above the vermilion border
22, 23	Cheilion (ch)	Orolabial	The outer corner of the mouth where the outer edges of the upper and lower vermilions meet
24	Stomion (sto)	Orolabial	The midpoint of the labial fissure when the lips are closed naturally
25	Labiale inferius (li)	Orolabial	The midpoint of the vermilion border of the lower lip
26	Sublabiale (sl)	Face	The midpoint of the labiomental sulcus
27	Pogonion (pg)	Face	The most anterior point in the middle of the soft tissue chin
28	Gnathion (gn) or menton	Face	The lowest point in the middling on the lower border of the chin
29, 30	Tubercular	face	The slight depression of the jawline somewhere between the gnathion and the gonion
313 2	Gonion (go)	Face	The most lateral point at the angle of the mandible
33, 34	Zygion (zy)	Face	The most lateral point on the zygomatic arch
35, 36	Supra subalare	Nose	the slight notch on the anterior nasal wall somewhere between the alare and pronasale; usually at the level of the subalare
37, 38	Lateral pronasale	Nose	Slight depression on each side of the pronasale
39, 40	Superior alare	Nose	The outer margin of the most flared portion of the nose
41	Infrapronasale	Nose	The point below pronasale, usually the point between the pronasale and the subnasale

Principal Component Analysis (PCA) was used to investigate in more details, the patterns of joint displacements of landmarks. The first few principal components (PCs) account for most of the total variation contained in the dataset and therefore can summarize multidimensional variation effectively in far fewer dimensions than originally included in the analysis. PCA also analyzes and displays patterns of variation so that they can be interpreted biologically. The PCs can be viewed as features of shape variation that are mutually uncorrelated, and therefore can be examined one by one and these PC coefficients are displayed directly as movements of landmarks [17]. PCA was done by SAGE producing the deformations showing the variations at specific sites and involving specific landmarks.

III. Results and Discussion

Analysis of the pooled images was done using the software SAGE (Symmetry and Asymmetry in Geometric Data) Version 1.04 [15]. First the pooled front images were loaded with their appropriate identification protocols and pairing of landmarks. Procrustes superimposition of all original and reflected configurations produced a symmetric consensus configuration, the average image eliminating the size differences. Fig. 2 shows the procrustes fitted frontal face images for male samples.

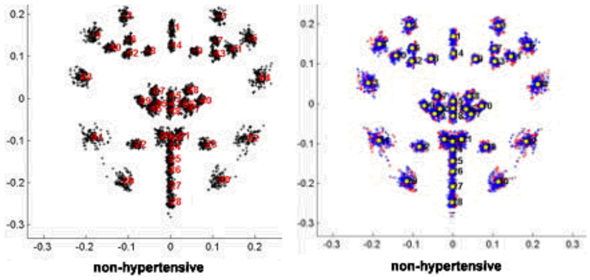

Figure 2. Procrustes fit of images of non- and hypertensive males

Partitioning the variation around this consensus by Procrustes ANOVA (Table II) indicated that among male samples from the two groups (non-hypertensive and hypertensive), variation in symmetric shape (individual) as well as fluctuating asymmetry (individual X side interaction) account for much of the total variation. Individual variation, directional asymmetry and fluctuating asymmetry (FA) are highly significant statistically (P < 0.000). The hypertensive males, however, show more individual variation and FA compared to the control group as supported by higher F ratios.

To identify the direction of landmark displacements principal component analysis was carried out. Results for male frontal face images are in Fig. 3 (non-hypertensive) Fig. 4 (hypertensive). Principal component analysis show the number of variables from the 41 landmarks for each individual was reduced to 4 to 5 principal components for each individual, which includes more than 70% of the information of the original dataset (Table III). For principal component 1, the non-hypertensive group has a wider range than the hypertensive group although both groups include positive and negative eigenvalues. For component 2, the non-hypertensive group shows almost similar range with hypertensive group although the former fall within the positive eigenvalues while the latter into the negative values.

ANOVA results show that hypertensive individuals have higher fluctuating asymmetry compared to non-hypertensive individuals, reinforcing the relationships between facial symmetry and judgments of apparent health [41] and the relationship of fluctuating asymmetry and physical health among young adults [42]. Associations of facial fluctuating asymmetry with respiratory infection were also shown [43].

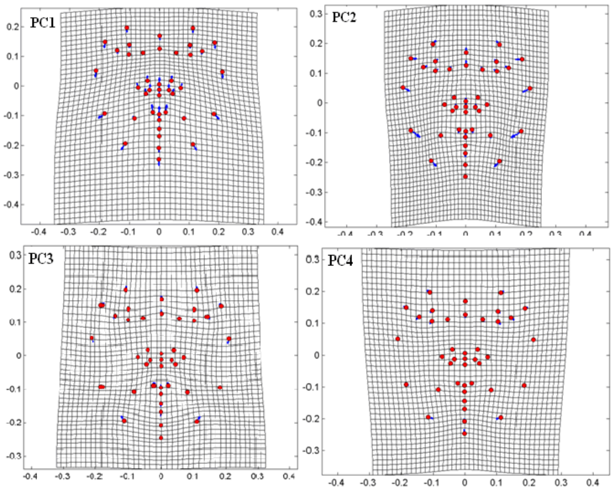

Figure 3. PCA results for individual variation of frontal images of non-hypertensive males.

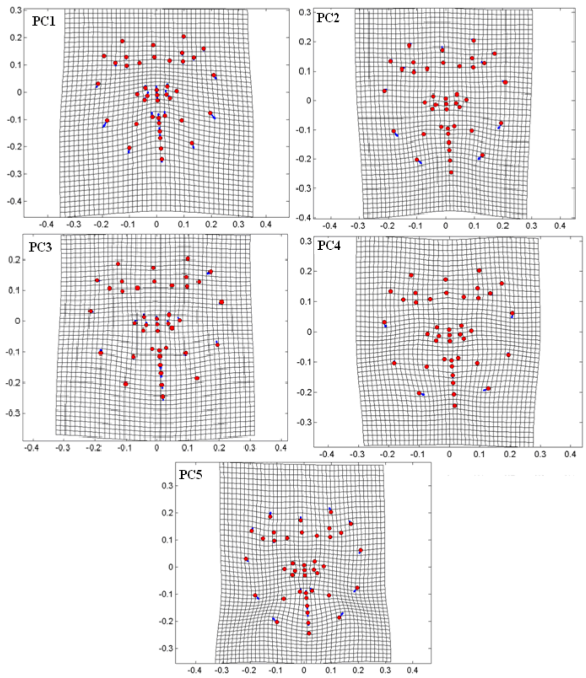

Figure 4. PCA results for individual variation of frontal images of hypertensive males.

TABLE II. Procrustes ANOVA in Frontal Face Images of Male Individuals.

	Individual	Side	Interaction	Measurement Error
Non-hypertensive				
SS	0.949	0.019	0.176	0.126
Df	1599	39	1599	6552
MS	0.001	0.001	0.000	0
F	5.403	4.495	5.694	--
P	**<0.000**	**<0.000**	**<0.000**	--
Hypertensive				
SS	1.17	0.011	0.160	0.069
Df	1599	39	1599	6552
MS	0.001	0.000	0.000	0
F	7.320	2.891	9.466	--
P	**<0.000**	**<0.000**	**<0.000**	--

TABLE III. PCA IMPLIED DEFORMATION FOR INDIVIDUAL VARIATION OF HYPERTENSIVE AND NON-HYPERTENSIVE MALE FACE.

	Non-hypertensive
PC1 (33.95%)	Landmarks of the cheek (33, 34) and chin (27, 28) greatly displaced posteriorly; posterior and leftward shift of jaw (29, 31); posterior and rightward shift of left jaw (30 and 32); eyebrows (2, 3) posteriorly displaced; sides of eyebrow show posterior, slight oblique and outward displacements (4 to the right and 5 to the left); anterior and slightly oblique displacements of the nose (15-18 and 35-41) and upper lip (19-21, 24). Overall there's a widening as well as a little elongation of the face in the posterior direction
PC2 (20.23%)	Posteromedial displacement of 31 and 32 (angles of jaws), 29, 30 (lower jaws), 33, 34 (cheeks); medial displacement of 4 and 5 (eyebrows); anteromedial shift of 2 and 3 (eyebrows); 1 and 14 (between the eyes) shift anteriorly; slight anterior movement of nose (15,35,36,41) and slight posterior shifts of upper lip (19-21) and chin (26); Overall there's a narrowing of the face.
PC3 (10.08%)	Lower jaw (29, 30) shift anterolaterally; cheeks (33, 34) posteromedially; eyebrows (2, 3) and nasion (1), upper lip (19-21) anteriorly; lower lip (25, 26) posteriorly. Overall there's narrowing of the upper part of the cheeks
PC4 (7.064%)	Posteromedial displacements of 29 and 30 (lower jaw); moderate anterior movement of 28 (chin); anterolateral movement of eyebrows (2, 3); posterolateral shifts of eyes (10, 13); medial shifts of 4 and 5 (eyebrows)
	Hypertensive
PC1 (36.51%)	greater degree of posterolateral displacement of landmarks 33, 34 (cheeks), 31, 32 (angles of jaws) and 29, 30 (lower jaw) causing widening of face at this region; anterior shifts of nose (15, 18, 35-38, 41) and mouth (19-21, 24, 25); posterior shift of chin (28) and slightly of the eye (10-13). Overall, there is widening and elongation of the face.
PC2 (15.40%)	Posteromedial displacements of the jaw (29-32); anteromedial shift of the nasion (1) and eyebrows (2, 3); medial shift of eyes (10, 11) and cheeks (33, 34)
PC 3 (9.105%)	Posterior shifts of chin (26-28); anterior shifts of angles of jaws (31, 32) and nose (15, 35-41); posteromedial displacements of eyebrows (4, 5) pushing the corners of the eyes towards the midline
PC4 (6.53%)	Posteromedial displacement of the jaws (29-32) causing narrowing of the face in this region
PC5 (5.82%)	Lower jaw (29, 30) shifted anterolaterally; angles of the jaws (31, 32) posterolaterally; nasion (1), eyebrows (2,3) shifted anteriorly; eyebrows (4,5) anteromedially; cheeks (33, 34) posterolaterally causing narrowing of face in the cheek region; anteriorward shift of 19-21 (upper lip) and posteriorward shift of 25 (lower lip), 26, 27 (chin)

Scatterplot of PCA show that the facial shapes of males (non-hypertensive and hypertensive) greatly vary, further supporting the shape differences seen in female hypertensive and non-hypertensive groups [24]. This is in line with the results of the study showing the distinct differences of craniofacial shapes of males and females [44].

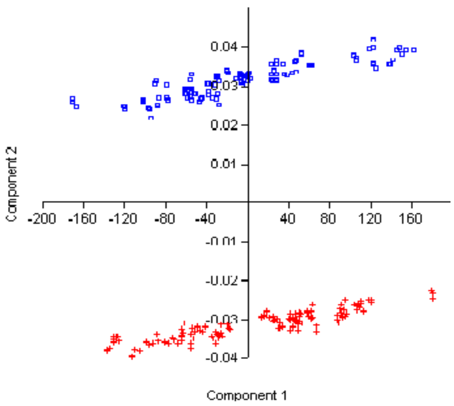

Figure 5. Scatterplot showing relationship between and among non-hypertensive (blue) and hypertensive (red) males in terms of frontal images.

The results presented show related results to studies on facial changes in people with chronic diseases like diabetes, hypertension and arthritis [18], [19], [20], [21], [22], [23], [24], behavioral disorders like schizophrenia [4], [25], [26], [5], [27], [6], [28], [18], [29], fetal alcohol syndrome [30], [31], [32], [33], [34], [35], [36], [37], [38], Rubinstein-Taybi syndrome and thalassemia intermedia [39], diet [40] and the environment [19]. It can also be that most individuals with hypertension are fat and usually appears as having thicker skin on the face and in most cases, characterized by puffiness around the eyes, just like in diabetics [23]. Hypertension is caused by a multitude of factors ranging from heredity to stress in terms of development, nutrition environmental disturbances and could be partly due to morphological changes brought about by these various stresses [41], [42], [43], [44].

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Christine Cheerry E. Solon is an professor of biology of the Department of Biological Sciences, MSU-Iligan Institute of Technology, Iligan City, Philippines. She is teaching general biology, genetics, and developmental biology subjects. Her research interests include studies on insect vectors of diseases and human disorders (Email: abakk5@yahoo.com).

Mark Anthony J. Torres is Associate Professor of Biology of the Department of Biological Sciences, College of Science & Mathematics, MSU-Iligan Institute of Technology, Iligan City, Philippines. He is an active researcher in biology and currently a director of the Institute for Peace and Development of MSU-IIT (e-mail:torres.markanthony@gmail.com).

Cesar G. Demayo is the current chairman and Professor of the Department of Biological Sciences, College of Science and Mathematics, MSU-Iligan Institute of Technology, Iligan City, Philippines. His researches include environmental toxicology, biodiversity and genetics. He is an active member of the Philippine Society for the Study of Nature and the Pest Management Council of the Philippines. (e-mail:cgdemayo@gmail.com).