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Sexual Dimorphism in America: Geometric Morphometric Analysis of the Craniofacial Region*

ABSTRACT: One of the four pillars of the anthropological protocol is the estimation of sex. The protocol generally consists of linear metric analysis or visually assessing individual skeletal traits on the skull and pelvis based on an ordinal scale of 1–5, ranging from very masculine to very feminine. The morphologic traits are then some how averaged by the investigator to estimate sex. Some skulls may be misclassified because of apparent morphologic features that appear more or less robust due to size differences among individuals. The question of misclassification may be further exemplified in light of comparisons across populations that may differ not only in cranial robusticity but also in stature and general physique. The purpose of this study is to further examine the effect of size and sex on craniofacial shape among American populations to better understand the allometric foundation of skeletal traits currently used for sex estimation. Three-dimensional coordinates of 16 standard craniofacial landmarks were collected using a Microscribe-3DX digitizer. Data were collected for 118 American White and Black males and females from the W.M. Bass Donated Collection and the Forensic Data Bank. The MANCOVA procedure tested shape differences as a function of sex and size. Sex had a significant influence on shape for both American Whites ($F = 2.90$; d.f. = 19, 39; $p > F = 0.0024$) and Blacks ($F = 2.81$; d.f. = 19, 37; $p > F = 0.0035$), whereas size did not have a significant influence on shape in either Whites ($F = 1.69$; d.f. = 19, 39; $p > F = 0.08$) or Blacks ($F = 1.09$; d.f. = 19, 37; $p > F = 0.40$). Therefore, for each sex, individuals of various sizes were statistically the same shape. In other words, while significant differences were present between the size of males and females (males on average were larger), there was no size effect beyond that accounted for by sex differences in size. Moreover, the consistency between American groups is interesting as it suggests that population differences in sexual dimorphism may result more from human variation in size than allometric variation in craniofacial morphology.

KEYWORDS: forensic science, sexual dimorphism, sex estimation, geometric morphometrics

One of the four pillars of the anthropological protocol is the estimation of biological sex. Not only does the identification process begin with the estimation of sex, but also, standards for age and ancestry estimation cannot be adequately determined without this very basic assessment. Compared with other primates, human levels of sexual dimorphism are low. Nonetheless, males and females appear skeletally very different. Standard growth curves published by the Centers for Disease Control and Prevention in 2000 state the growth curves for males and females overlap by less than 1 SD (1). These differences are thought to be a result of sexual selection and sex-specific differences in energetic intake, nutrition, body composition, and genetics.

The anthroposcopic protocol for sex estimation used by forensic anthropologists, bioarchaeologists, and paleontologists throughout the world consists of visually assessing individual skeletal indicators of the cranium, mandible, and *Os coxae*. Rather than treating these indicators as dichotomous male or female traits, the protocol outlined in Buikstra and Ubelaker (2) rates the indicators on an ordinal scale. The scale ranges from 1 to 5 and can be interpreted as a range from "male" to "probable male" to "indeterminate" to "probable female" to "female." These morphologic traits are then *averaged* by the investigator to estimate sex. The "maleness" or "femaleness" among individuals of various populations may differ because of biologic differences in sexual dimorphism, stature and physique, and general robustness. Discriminant function analysis of linear measures is commonly used and is described in standard anthropology protocols (3–5). Metric studies have demonstrated quantified analysis of sex estimation increases accuracy. However, traditional linear measurements are not always able to capture the underlying shape differences because that variation may not lie along the span of the calipers (6). Therefore, applying existing discriminant functions on a population with greater cranial size could poorly classify, individuals, classifying too many females as males.

A study presented by Rosas and Bastir (7) investigating allometry through 2D geometric morphometrics and sexual dimorphism in a Portuguese population found that size and sex had a significant influence on shape of the craniofacial region. Interestingly, they found, (i) "no difference in the influence of size on shape between the sexes" and, (ii) "the influence of centroid size on shape (allometry) revealed a shift in the proportions of the neurocranium and the viscerocranium, with a marked allometric variation of the lower face." Additionally, they found that males exhibited a larger nasopharyngeal space than females so that male muscle attachment sites did appear more pronounced than females, and that females exhibited a smaller nasal aperture. In a more recent study, Pretorius et al. (8) report preliminary findings that the shapes of the eye orbits are more sexually dimorphic than the commonly used mandibular ramus.

These modern morphometric techniques may help us better understand the relationship between the size and shape of craniofacial features. Geometric morphometric modalities may make it possible to quantify the shape variables forensic anthropologists routinely use and point out new areas of the skeleton to use for estimation of sex from human remains.

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To better understand the allometric relationship of skeletal traits used for sex estimation, innovative techniques utilizing geometric morphometrics were used to investigate the effects of size and sex on shape within each sex for either group. The purpose of our study was to further examine the effect of size and sex on craniofacial shape in Americans to better understand the allometric foundation of the skeletal traits currently used for sex estimation from the skeleton and to investigate population variation.

Materials

For this investigation, 3D coordinates of 16 standard craniofacial landmarks (Table 1) were collected using a Microscribe-3DX digitizer and the program ThreeSkull, written by Steve Ousley (9). The sample totals 118 adults of known sex and ancestry, consisting of 30 White males, 30 White females, 29 Black males, and 29 Black females from the W.M. Bass Donated Collection and the Forensic Data Bank (The University of Tennessee, Knoxville). It should be noted that no landmarks around the alveolar processes or mandible were used, thereby avoiding potential artifacts due to age-related dental changes. Ages in all groups spanned adulthood making it unlikely that age-specific patterns would be a factor in our results.

Methods

A generalized Procrustes analysis (GPA) was used to bring all specimens into a common coordinate system. The GPA superimposition was performed using the program Morpheus et al., written by the third author (10). All specimens are scaled to unit centroid size (CS); the square root of the sum of squared distances of every landmark to their average location. Centroid size is used because it is the only size measure that is uncorrelated with shape variation for small, random, spherical variation at the landmarks (11). Translation and rotation parameters were estimated to minimize the sum of squared distances between landmarks of each skull and those of an iteratively computed mean configuration.

Resulting shape variables (superimposed coordinates) and CS were used in subsequent multivariate analyses. First, a principal component analysis (PCA) using the covariance (as opposed to the correlation) matrix was conducted on the GPA transformed variables to reduce the dimensionality of the data to meet the requirements of the parametric test. Second, a multivariate analysis of covariance (MANCOVA) was performed using the PCA scores to test whether size and sex have significant effects on the average shape of males and females for each ancestral group. The two groups were treated separately and a stepwise discriminant analysis of covariance was needed for Whites because standard PC selection (i.e., selecting the first few PCs) did not yield satisfactory classifications. Third, independent group *t*-tests were used to compare the mean CS of sexes for each ancestral group. Fourth, separate discriminant function analyses, using cross-validation, was carried out for American Whites and Blacks, separately, using only the shape variables and then using shape and CS. The multivariate analyses were performed using the SAS system for Windows Version 9.1.3 (SAS Institute, Inc., Cary, NC) (12).

TABLE 1—*List of landmarks.*

Landmark	Side
Alare	Right/left
Basion	Midline
Bregma	Midline
Frontomalare anterior	Right/left
Frontomalare temporale	Right/left
Lambda	Midline
Maximum malar projection	Left
Nasion	Midline
Opisthocranion	Midline
Opisthion	Midline
Subspinale	Midline
Frontotemporale	Right/left

Results

The MANCOVA results are presented in Table 2. The MANCOVA procedure detected no significant size × sex interaction for either group. Size does not have a significant effect on shape in either Whites or Blacks. This suggests that smaller and larger individuals within the same sex are similar in shape. Sex does have a significant influence on shape in both Whites and Blacks.

The independent group *t*-test shows that the male CS mean is significantly different from the female mean for both groups (Whites $t = -7.31$, $p < 0.0001$, d.f. = 29; Blacks $t = -7.17$, $p < .0001$, d.f. = 28). However, the sexes, themselves, do not differ across groups (females $t = 0.95$, $p = 0.346$, d.f. = 57; males $t = -0.91$, $p = 0.367$, d.f. = 57). Figure 1 presents box plots of CS for both American Whites and Blacks. Males and females differ significantly in size within each group. However, males from both ancestral groups and females from both ancestral groups do not differ significantly from each other. Further, females appear to be less variable with respect to CS as compared with the male distributions.

Separate discriminant function analyses for American Blacks and Whites were first performed using only the shape variables and

TABLE 2—*MANCOVA.*

	Wilks' Lambda	*F*	d.f.	$p > F$
Blacks				
Size × sex	0.541	1.61	19,36	0.1079
Sex	0.410	2.81	19,37	0.00035
Size	0.641	1.09	19,37	0.3976
Whites				
Size × sex	0.779	0.57	19,38	0.9059
Sex	0.415	2.90	19,39	0.0024
Size	0.549	1.69	19,39	0.0823

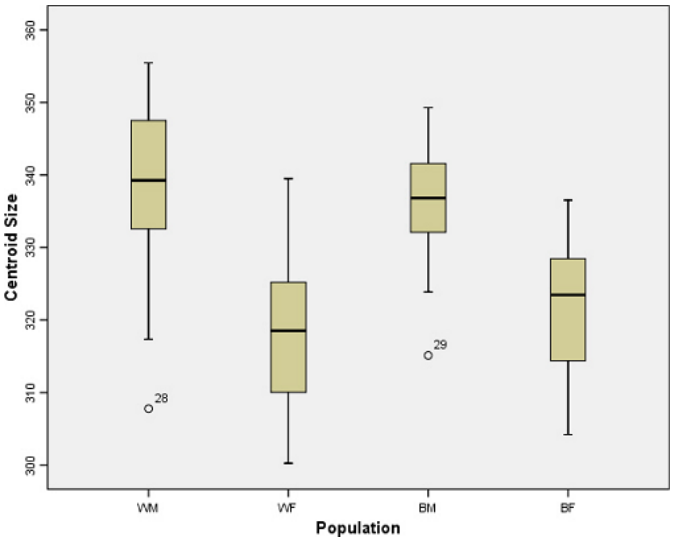

FIG. 1—*Distribution of centroid size by ancestry and sex.*

then using shape and CS. The American Black discriminant function was performed using the first three principal components—the best discriminators for this group. The sexing accuracy for American Blacks is 77.85% (79.31% for females and 75.86% for males) when using only the shape variables (Table 3). However, when CS is included in the discriminant function, the sexing accuracy increases to 93.10% for females and 86.21% for males (Table 4).

For the American White sample, a stepwise discriminant analysis was used to select the best variables for sexing because the first few principal components did not reflect much of the sexual variation. The sexing accuracy is 73.3% for females and 80.0% for males when using only the shape variables (Table 5). Interestingly, shape analysis results in a higher classification for males than females, among the White samples. When CS is included in the analysis, the correct classification increased to 90.0% for females and 83.3% for males (Table 6). In other words, White males are misclassified more frequently than females when using size and shape, but are better classified than females when shape alone is used.

Sex-specific shape differences are illustrated by plots showing different vectors originating at the landmarks of one specimen and directed towards the corresponding landmarks on the other specimen. The different vectors show the relative direction and magnitude of difference between one configuration and another. Figure 2 is a lateral view of the Black female mean compared with the Black male mean after superimposition by GPA. The dissimilarity between the two groups is suggested by the length of the vectors (which have been magnified by a factor of 4). Black females are shown to have asterion placed more anteriorly, lambda and basion oriented more superiorly, opisthocranion and subspinale placed farther posterior, and the maximum malar projection located inferior to those of males.

Sex-specific shape differences in American Whites are illustrated in Fig. 3 and demonstrate a slightly different pattern with White females having opisthocranion placed more superiorly, asterion is placed farther anteriorly, and subspinale is oriented posteriorly. This view shows the greater anterior placement of frontotemporale in American White females (Fig. 4).

TABLE 3—*American Black classification summary shape variables using cross-validation.*

Sex	Frequency of Female Classification (*n*)	Frequency of Male Classification (*n*)
Female	79.83 (23/29)	20.69 (6/29)
Male	24.14 (7/29)	75.86 (22/29)
Total	51.72 (30/58)	48.28 (28/58)

Values are represented as % (*n*).

TABLE 4—*American Black classification summary shape variables and centroid size using cross-validation.*

Sex	Frequency of Female Classification (*n*)	Frequency of Male Classification (*n*)
Female	93.10 (27/29)	6.90 (2/29)
Male	13.79 (7/29)	86.21 (25/29)
Total	53.45 (30/58)	46.55 (27/58)

Values are represented as % (*n*).

TABLE 5—*American White classification summary shape variables using cross-validation.*

Sex	Frequency of Female Classification (*n*)	Frequency of Male Classification (*n*)
Female	73.33 (22/30)	26.67 (8/30)
Male	20.0 (6/30)	80.0 (24/30)
Total	46.67 (28/60)	53.33 (32/60)

Values are represented as % (*n*).

TABLE 6—*American White classification summary shape variables and centroid size using cross-validation.*

Sex	Frequency of Female Classification (*n*)	Frequency of Male Classification (*n*)
Female	90.0 (27/30)	10.0 (3/30)
Male	16.67 (5/30)	83.30 (25/30)
Total	53.33 (32/60)	46.67 (28/60)

Values are represented as % (*n*).

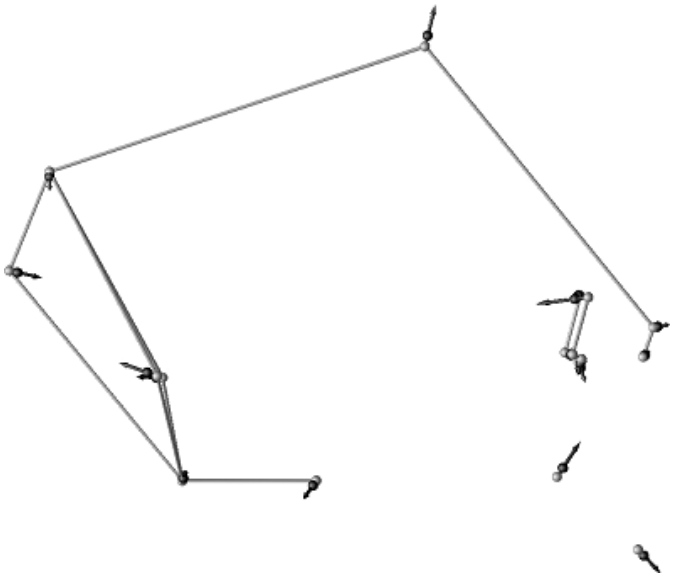

FIG. 2—*American Black females (dark colored spheres) and males (light colored spheres).*

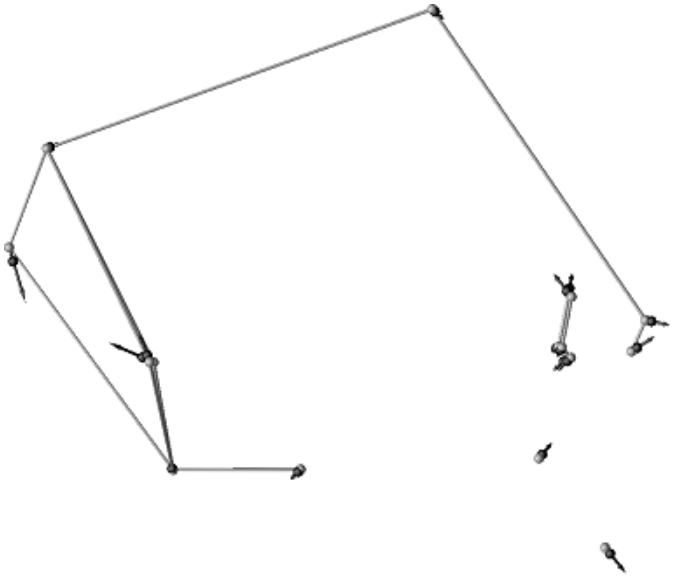

FIG. 3—*American White females (dark colored spheres) and males (light colored spheres).*

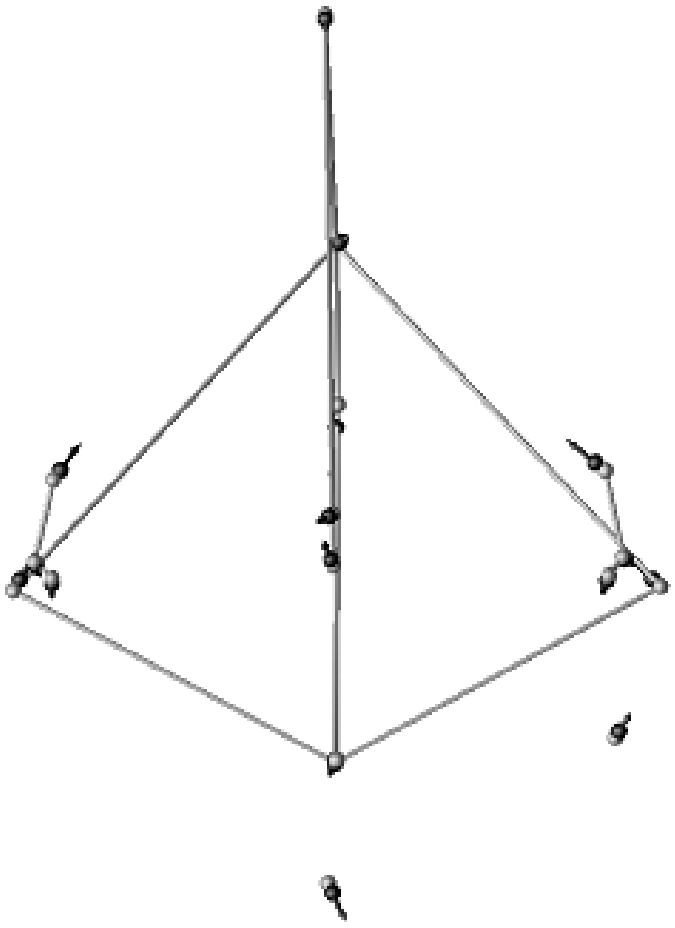

FIG. 4—*American White females (dark colored spheres) and males (light colored spheres).*

Discussion and Conclusion

This investigation found that sex, but not size, had a significant influence on shape in both American Whites and Blacks. In contrast to Rosas and Bastir, we found that size does not have a significant influence on shape in either Whites or Blacks. This means that smaller and larger individuals within the same sex in our samples are similar in shape, e.g., White females are of similar shape regardless of size. Moreover, the average cranial size of males was shown to be different than the female means in both groups showing that there is significant sexual dimorphism present. However, the pattern of sexual dimorphism in shape does differ among groups as shown in Figs. 2–4. Our results using size + shape outperformed discriminant functions developed from traditional metrics. The sexing accuracy for contemporary American Whites using traditional metrics is 87.5% (13) and range from 83.0% to 88.0% for the discriminant functions (published by Giles in 1970). The 14.0% and 17.0% increase in accuracy for both female groups when including CS is a function of females being smaller than males. The MANCOVA results indicate that sexual dimorphism is also based on underlying unique shape differences with slightly different patterns in each ancestral group, and it is not simply a matter of size. Thus, the information obtained using newer three-dimensional methods reveal specific patterns of sexual dimorphism that cannot be readily discerned by more traditional visual or metric methods.

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