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# On human biological diversity : variation in sexual dimorphism of the skull between African-Americans and European-Americans

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ON HUMAN BIOLOGICAL DIVERSITY:  
VARIATION IN SEXUAL DIMORPHISM OF THE SKULL BETWEEN  
AFRICAN-AMERICANS AND EUROPEAN-AMERICANS

A Thesis

Submitted to the Graduate Faculty of the  
Louisiana State University and  
Agricultural and Mechanical College  
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in

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by  
Amanda Grace Kittoe  
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## **ABSTRACT**

This study assesses sexual dimorphism of the skull in samples of African-Americans (AA) and European-Americans (EA). Morphology of the cranium is classically referenced as an indicator of sexual dimorphism in the fields of bioarchaeology and forensic anthropology. Variation in size and shape of cranial elements has been found to differ significantly between ancestral populations. Abundant research suggests that patterns of sexual dimorphism also vary between ancestries. This study uses a sample of 55 AA females, 50 AA males, 49 EA females, and 49 EA males from the Hamann-Todd Collection at the Cleveland Museum of Natural History and the WM Bass Donated Collection at the University of Tennessee, Knoxville. Twenty linear measurements were taken on the cranium and mandible, and 19 variables were analyzed. MANOVA determined that four variables (i.e. maximum cranial length, maximum cranial height, cranial base length and mandibular angle) have significant interaction between sex and ancestry, thereby, corroborating the evidence that there is ancestral variation in sexual dimorphism. The results of this study have implications for understanding evolution among anatomically modern humans after having migrated out of Africa. Additionally, the knowledge gained from this study further assists forensic anthropologists and bioarchaeologists in reconstructing biological profiles of individuals and pre-historical populations by providing a detailed description of the variation in sexual dimorphism between African-Americans and European-Americans.

## **CHAPTER 1: INTRODUCTION AND LITERATURE REVIEW**

### **1.1 Introduction**

The ability to differentiate males from females is fundamental to studies of human evolution and is particularly useful in applied fields such as forensic anthropology and bioarchaeology. Human evolutionists study sexual dimorphism to understand how and why *Homo sapiens* became less sexually dimorphic as they evolved from their pre-human ancestors. Forensic anthropologists use their knowledge of sexual dimorphism to identify the sex of an individual from his or her skeletal remains (White et al., 2012). Additionally, bioarchaeologists use their knowledge of sexual dimorphism to reconstruct the demographic profile of historic and prehistoric populations. Alongside sex, ancestral affinity is relevant to biological anthropology in general. Anthropologists have traditionally studied morphological variation between historically disparate groups of humans in order to understand biological adaptation in response to climate. While the biological concept of fixed races of humans is no longer accepted among many anthropologists (American Anthropological Association, 2011), forensic anthropologists are encouraged to understand ancestral variation within the confines of African-American and European-American ethnicities (Albanese and Saunders, 2006; Ousley et al., 2009).

The modern paradigm among forensic anthropologists is that predictive regression equations and discriminant formulae are population specific, which fosters the greatest accuracy when applied to the same ancestral population from which the formulae are derived (İşcan, 2005). Trotter and Gleser (1952) provide separate equations for stature estimation among African-Americans and European-Americans. Jantz (1992) applies the same concept of ancestral variation in stature estimation to a sample from a more recent generation and found varying degrees of secular change between the two ancestries, indicating that population variation



persists through time. Giles and Elliot (1963) and Giles (1964) pioneered research into population specific discriminant formulae for determining sex among African-Americans and European-Americans. The authors were later followed by Birkby (1966) who included Native Americans in the equations and found evidence supporting the need for population specific formulae. More recently, similar studies include populations such as South Africans (Franklin et al., 2008), Western Europeans (Ramsthaler et al., 2007), Central Europeans (Bigoni et al., 2010), Turks (Balci et al., 2005; Gungor et al., 2007), Lebanese (Ayoub et al., 2009), South Asians (Green and Curnoe, 2009; Naikmasur et al., 2010; Rooppakhun et al., 2010), and East Asians (İşcan et al., 1995). The widespread concern for population specific standards of sex determination brings to question how and why populations vary in their expression of sexual dimorphism. In light of this concern and in relevance to North America, the current study examines possible variations in sexual dimorphism between African-Americans and European-Americans in the skull. The null hypothesis that there is no variation in sexual dimorphism between the two ancestral groups is tested using multivariate analysis of variance.

## **1.2 Literature Review**

The skull is traditionally considered to be the best skeletal indicator of ancestry and the second best indicator of sex (next to the pelvis) (Bass, 2005; White et al., 2012); therefore, the skull is likely the best skeletal element to examine ancestral variation in sexual dimorphism between two groups. Previous research indicates that there is generally some degree of variation in the expression of sexual dimorphism across ancestral populations. The formulae derived from discriminant function analysis tend to yield less accuracy when applied to populations other than the original population from which the formulae are derived. Birkby (1966) discovered that the formula developed by Giles and Elliot (1962) and Giles (1964) for African-Americans and

European-Americans were not as effective in determining sex on a sample of Native Americans. Likewise, Ramsthaler et al. (2007) found that the formulae used in Fordisc®, which are based on North American samples, have less accuracy when used on a European sample. Furthermore, İşcan and Steyn (1999) found similar results when applying the formulae developed by Giles and Elliot (1962) to a South African sample. The decreased accuracy among the discriminant formulae suggests that sexual dimorphism is expressed differently across populations.

Despite African-Americans sharing nearly 20% of genetic variation with European-Americans in some cases (Parra et al., 1998), the two ancestral populations remain relatively dissimilar in their cranial morphologies. Giles and Elliot (1962) report between 82.6-88.1% accuracy when using discriminant function analysis to differentiate African-Americans from European-Americans which quantitatively supports the proposition of ancestral variation. In a more recent study, Ousley et al. (2009) provide robust statistical evidence that cranial variation persists between African-Americans and European-Americans. They explain that the American public's concept of social race perpetuates distinct distributions of gene frequencies between the two ethnic groups which are reflected in variation in cranial morphology. Henceforth, for the purposes of the current study, African-Americans and European-Americans can be considered as two separate populations defined by American social concepts of race.

While Giles and Elliot (1962) present evidence in favor of morphological variation between African-Americans and European-Americans, the authors contend that there is more variation between the sexes than between ancestries (Giles and Elliot, 1963; Giles, 1964). While the accuracies for sex determination reported by the authors (82-89% for the cranium and 85% for the mandible) are nearly identical to the accuracies reported for ancestral affiliation (82.6%

for males and 88.1% for females), the accuracies for sex determination do not change substantially when used on the counterpart population for which the formulae were based. The authors conclude that ancestral variation in sexual dimorphism between African-Americans and European-Americans is minimal; yet, they suggest further tests of this hypothesis.

Calcagno (1981) critiques the statistical methods employed by Giles and Elliot (1962, 1963) and Giles (1964) and adopts an alternative approach. Consequently, Calcagno (1981) reports accuracies as high as 96.0% among African-Americans and 95.9% among European-Americans when each group is assigned its own respective formulae. Conversely, as each group is assigned the formulae of its counterpart, accuracies are reduced to 85.0% among African-Americans and 85.6% among European-Americans. The decrease in accuracies when the applied discriminant formulae are switched strongly suggests that there are significant morphological variations in the expression of sexual dimorphism between African-Americans and European-Americans. The expectation in the current study is that there is variation in sexual dimorphism between African-Americans and European-Americans.

## **CHAPTER 2: MATERIALS AND METHODS**

### **2.1 Materials**

The sample consisted of 203 skulls from the William M. Bass Donated Skeletal Collection (WMB) at the University of Tennessee, Knoxville and the Hamann-Todd Collection (HT) at the Cleveland Museum of Natural History, Cleveland, Ohio. Information on age, sex and ancestry were self-reported among individuals from WMB. The individuals from the WMB represent a wide geographical range within the United States and lived during the second half of the 20<sup>th</sup> century. In contrast, information for age, sex and ancestry among individuals from HT were based on assessments made by medical examiners and anatomists. HT is comprised of individuals who lived during the latter part of the 19<sup>th</sup> century and early part of the 20<sup>th</sup> century (Kern, 2006). The sample composition was as follows: 55 African-American females (2 from WMB and 53 from HT), 50 African-American males (18 from WMB and 32 from HT), 49 European-American females (10 from WMB and 39 from HT) and 49 European-American males (45 from WMB and 4 from HT). All individuals were between the ages of 20-60 years. All 20 measurements were taken on 194 skulls; some measurements could not be taken on 9 skulls. Skulls with excessive tooth loss were not included in the study; however, details of the degree of tooth loss were not recorded.

### **2.2 Methods**

#### **2.2.1 Measurements and Variables**

Twenty measurements were taken on the skull; 14 of these measurements were of the cranium and 6 were of the mandible. Each measurement represents one variable, except for two measurements which were used to compute one variable (see Section 2.2.1, No. 13). Therefore, there were ultimately a total of 19 variables which were analyzed. Table 2.1 displays a summary

description of all variables. Most measurements of the cranium were taken according to the standards set by Moore-Jansen et al. (1994). Mastoid breadth was modeled after the study by Patil and Mody (2005), and mastoid flare was designed specifically for this study. Two mandibular measurements were not based on the methodology according to the Moore-Jansen et al. (1994) standards due to mechanical inconsistencies in mandibulometers between research collections. Sliding calipers were used to measure mandibular length and a protractor was used to measure the mandibular angle. All linear distances were recorded to the nearest 0.1 mm, and the mandibular angle was recorded to the nearest degree.

### **Cranial Measurements**

- 1. Maximum Cranial Breadth (Eu-Eu)** – maximum width of the skull in the coronal plane (Moore-Jansen et al., 1994). See Figure 2.1
- 2. Maximum Cranial Length (G-Op)** – distance from the most protruding aspect of the lower frontal bone to the most protruding aspect of the occipital bone (Moore-Jansen et al., 1994). See Figure 2.2.
- 3. Basion-Bregma Height (Ba-B)** – “cranial height,” distance from the lowest point on the anterior margin of the foramen magnum to bregma (point where frontal suture intersects coronal suture) (Moore-Jansen et al., 1994). See Figure 2.2.
- 4. Cranial Base Length (Ba-N)** – distance from the lowest point on the anterior margin of the foramen magnum to nasion (point of intersection of the nasio-frontal suture and the mid-sagittal plane) (Moore-Jansen et al., 1994). See Figure 2.3.
- 5. Basion-Prosthion Length (Ba-Pr)** – distance from the lowest point on the anterior margin of the foramen magnum to the most protruding part of the maxilla between the central incisors (Moore-Jansen et al., 1994). See Figure 2.3.

- 6. Bregma-Nasion (B-N)** – “frontal chord,” distance from nasion to bregma (Moore-Jansen et al., 1994). See Figure 2.2.
- 7. Upper Facial Height (N-Pr)** – distance from nasion to prosthion (Moore-Jansen et al., 1994). See Figure 2.1.
- 8. Nasal Height (N-Ns)** – distance from nasion to nasospinale (lowest point on the inferior margin of the nasal aperture as projected in the mid-sagittal plane) (Moore-Jansen et al., 1994). See Figure 2.1.
- 9. Nasal Breadth (Al-Al)** – maximum breadth of the nasal aperture (Moore-Jansen et al., 1994). See Figure 2.1.
- 10. Bizygomatic Breadth (Zy-Zy)** – distance between the most lateral points on the zygomatic bones (Moore-Jansen et al., 1994). See Figure 2.1.
- 11. Mastoid Height (MDH)** – distance between the most superior point of the auditory meatus to the most inferior aspect of the mastoid process (Moore-Jansen et al., 1994). See Figure 2.4.
- 12. Mastoid Breadth (MaWd)** – mastoid breadth at the level of the cranial base (Patil and Mody, 2005). See Figure 2.4.
- 13. Mastoid Flare (MF)** – average distance between the most inferiorly protruding point on the mastoid process (**13.1**) to the most laterally protruding point on the mastoid process (**13.2**). Calculated as:  $[(\text{“13.2”} - \text{“13.1”}) / 2]$ . See Figure 2.5.

### **Mandibular Measurements**

- 14. Bigonial Breadth (Go-Go)** – distance between both gonion (point of intersection between inferior mandibular body and ramus) (Moore-Jansen et al., 1994). See Figure 2.6.

**15. Bicondylar Breadth (Cdl-Cdl)** – distance between the lateral most points on the two condyles (Moore-Jansen et al., 1994). See Figure 2.6.

**16. Minimum Ramus Breadth (MinRam)** – least breadth of the mandibular ramus (Moore-Jansen et al., 1994). Figure 2.7.

**17. Maximum Ramus Breadth (MaxRam)** – distance between the most anterior point on the mandibular ramus to the most posterior point on the mandibular ramus (Moore-Jansen et al., 1994). See Figure 2.7.

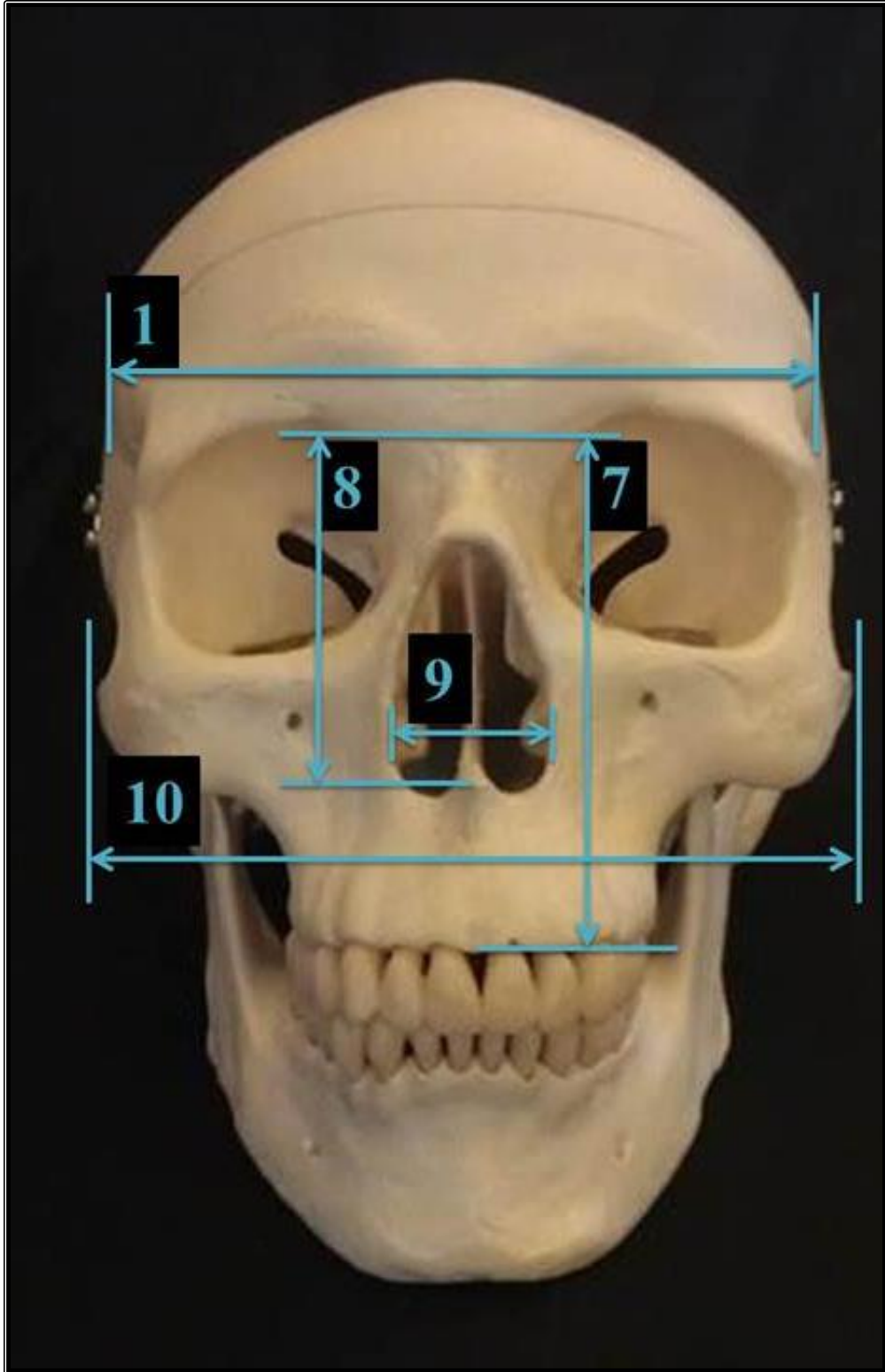
**18. Mandibular Angle (GoAng)** – angle formed by the inferior border of the mandibular body and posterior border of the ramus (Moore-Jansen et al., 1994). In this study, the mandibular angle was measured by placing the protractor perpendicular to the line connecting the two gonias and aligning the straight edge of the angle determiner parallel to the central lines of the ramus. See Figure 2.8.

**19. Mandibular Length (MaxLen)** – distance from the anterior margin of the mental eminence to a center point on perpendicular line projected between the two mandibular angles (Moore-Jansen et al., 1994). In this study, maximum length of the mandible was measured by aligning the two gonias along a straight line on a sheet of graph paper. One mark was made at the most projecting point on the mental eminence, and another at the line connecting the two gonias. The length between the two marks was measured using a sliding caliper. See Figure 2.9.

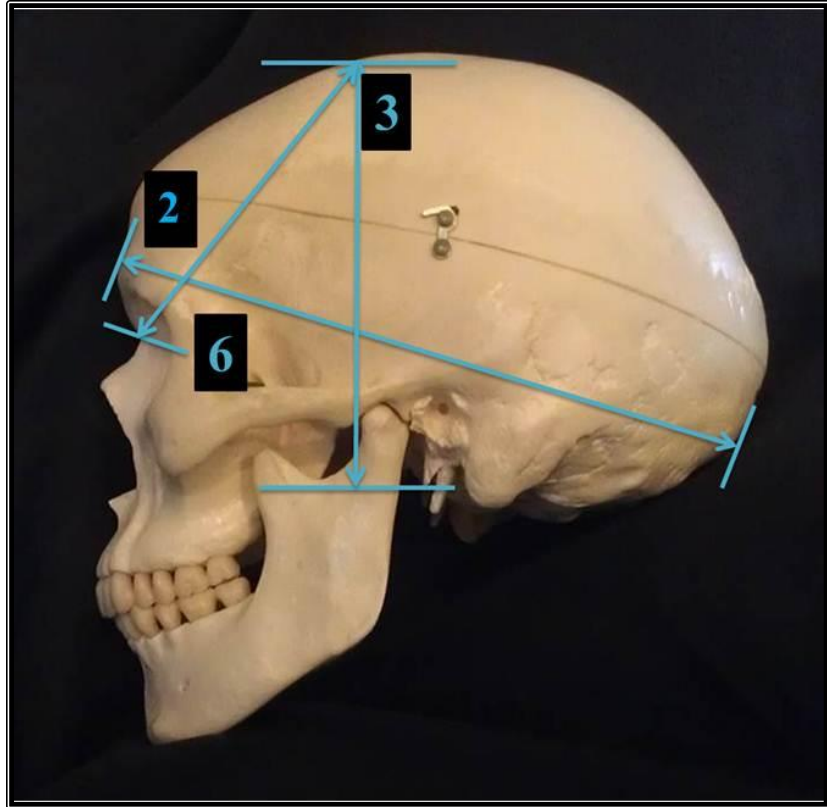
**Table 2.1** Summary of Measurement Abbreviation, Definition and Description

<b>Abbreviation</b>	<b>Name</b>	<b>Osteometric Distance</b>
1. Eu-Eu	Maximum Cranial Breadth	<i>euryon-euryon</i>
2. G-Op	Maximum Cranial Length	<i>glabella-opisthocranium</i>
3. Ba-B	Basion-Bregma Height ("cranial height")	<i>basion-bregma</i>
4. Ba-N	Cranial Base Length	<i>basion-nasion</i>
5. Ba-Pr	Basion-Prosthion Length	<i>basion-prosthion</i>
6. B-N	Bregma-Nasion ("front chord")	<i>bregma-nasion</i>
7. N-Pr	Upper Facial Height	<i>nasion-prosthion</i>
8. N-Ns	Nasal Height	<i>nasion-nasospinale</i>
9. Al-Al	Nasal Breadth	<i>allare-allare</i>
10. Zy-Zy	Bizygomatic Breadth	<i>zygomatica-zygomatica</i>
11. MDH	Mastoid Height	<i>mastoid height</i>
12. MaWd	Mastoid Breadth	<i>mastoid breadth</i>
13. MF	Mastoid Flare	<i>mastoid flare</i>
14. Go-Go	Bigonial Breadth	<i>gonion-gonion</i>
15. Cdl-Cdl	Bicondylar Breadth	<i>condylon-condylon</i>
16. MinRam	Minimum Ramus Breadth	<i>minimum ramus breadth</i>
17. MaxRam	Maximum Ramus Breadth	<i>maximum ramus breadth</i>
18. GoAng	Mandibular Angle	<i>mandibular angle</i>
19. MaxLen	Mandibular Length	<i>maximum mandibular length</i>

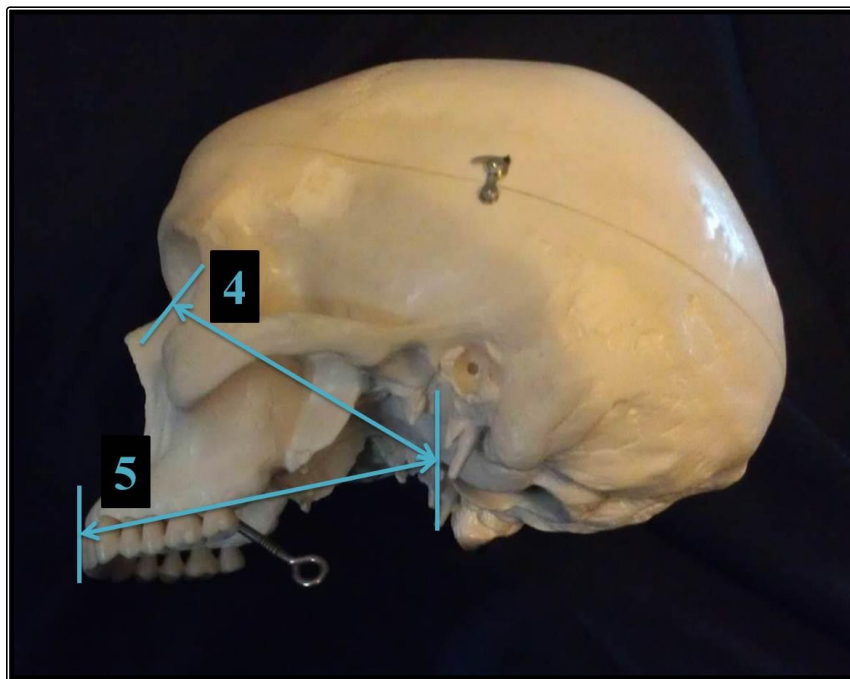




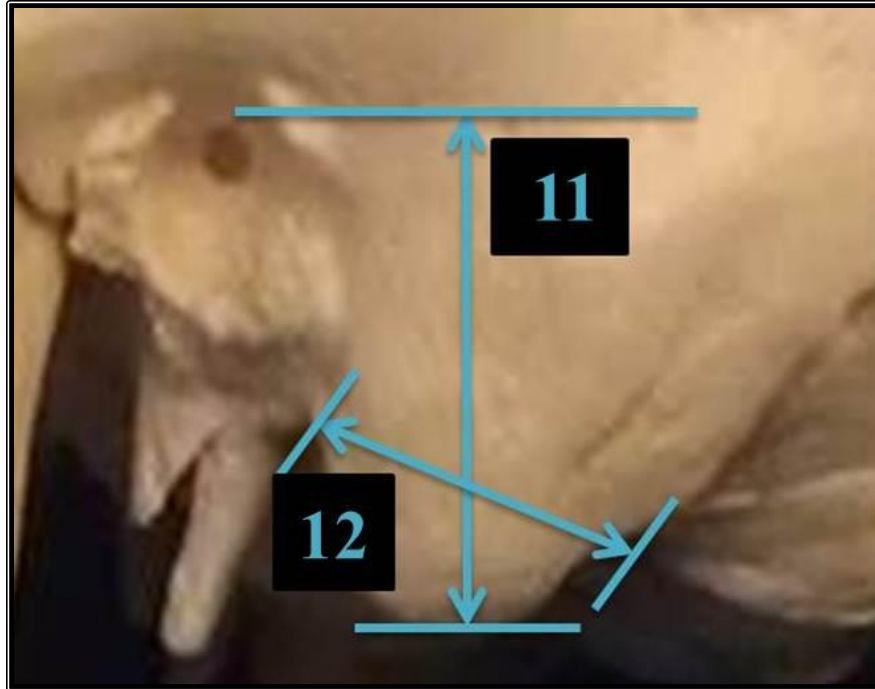
**Figure 2.1** Measurements of the Face (Nos. 1, 7, 8, 9, 10)



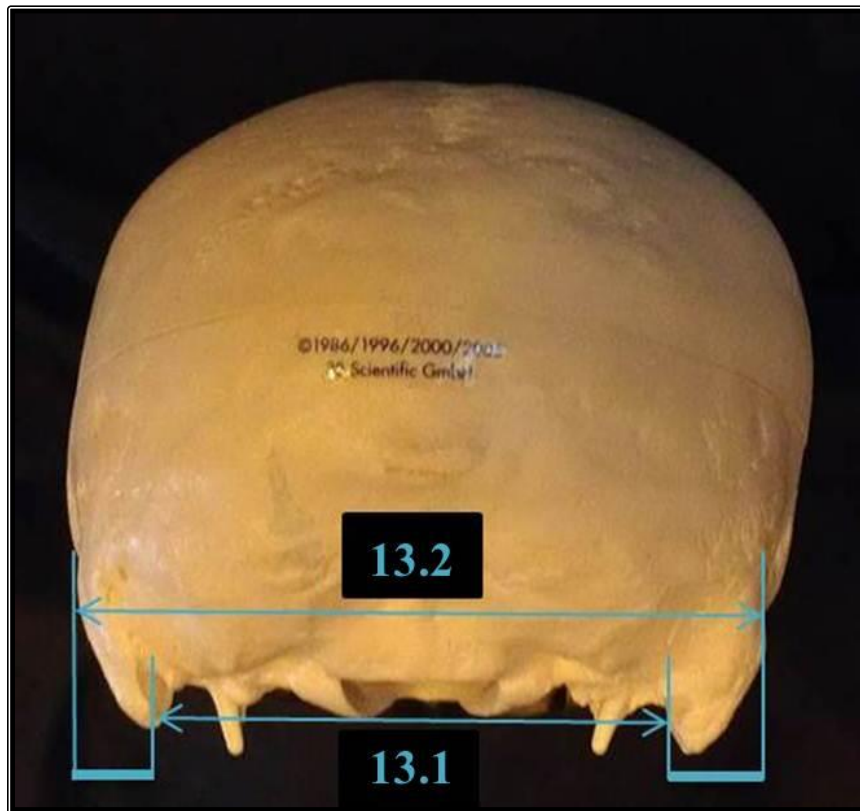
**Figure 2.2** Selected Measurements of the Lateral Cranium 1 (Nos. 2, 3, 6)



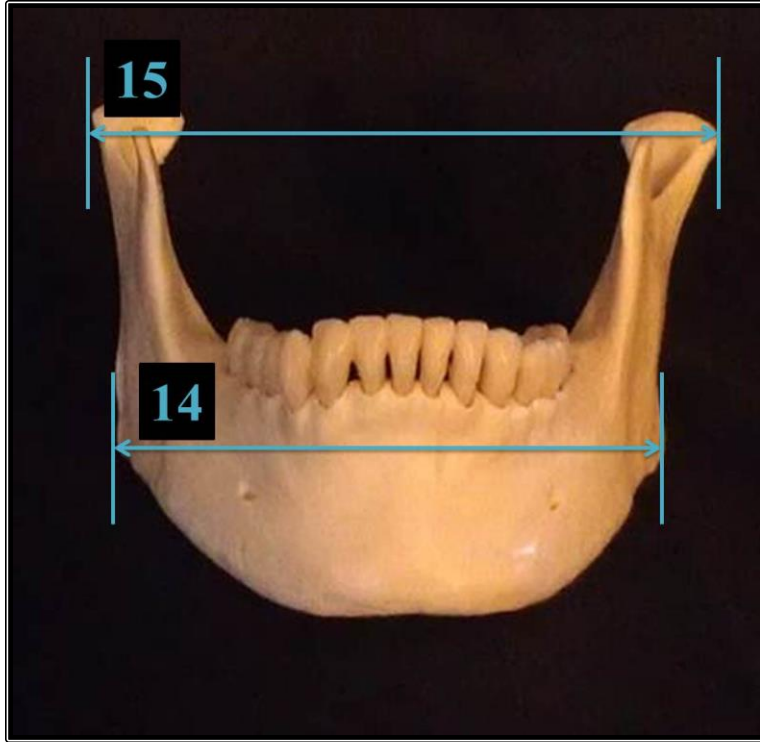
**Figure 2.3** Selected Measurements of the Lateral Cranium 2 (Nos. 4-5)



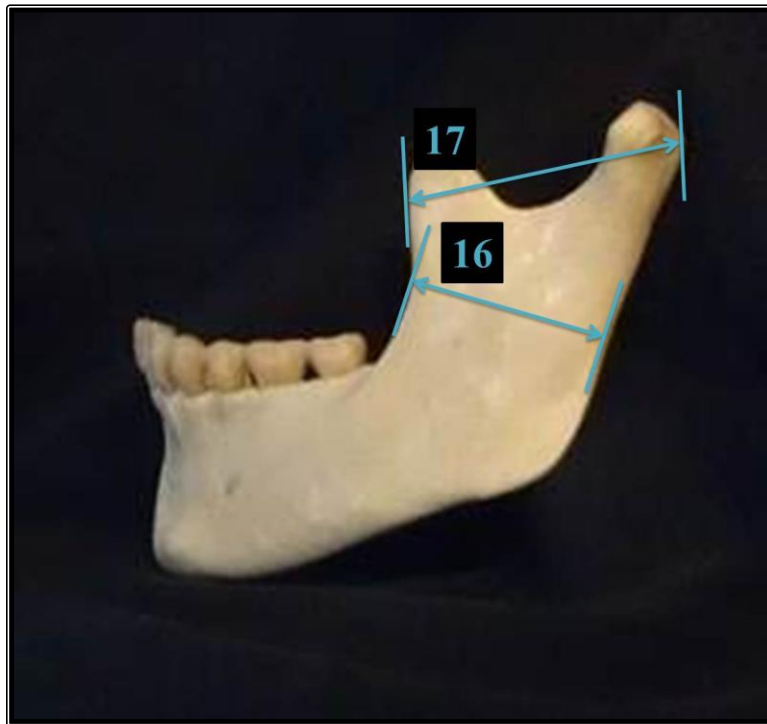
**Figure 2.4** Measurements of the Lateral Mastoid (Nos. 11-12)



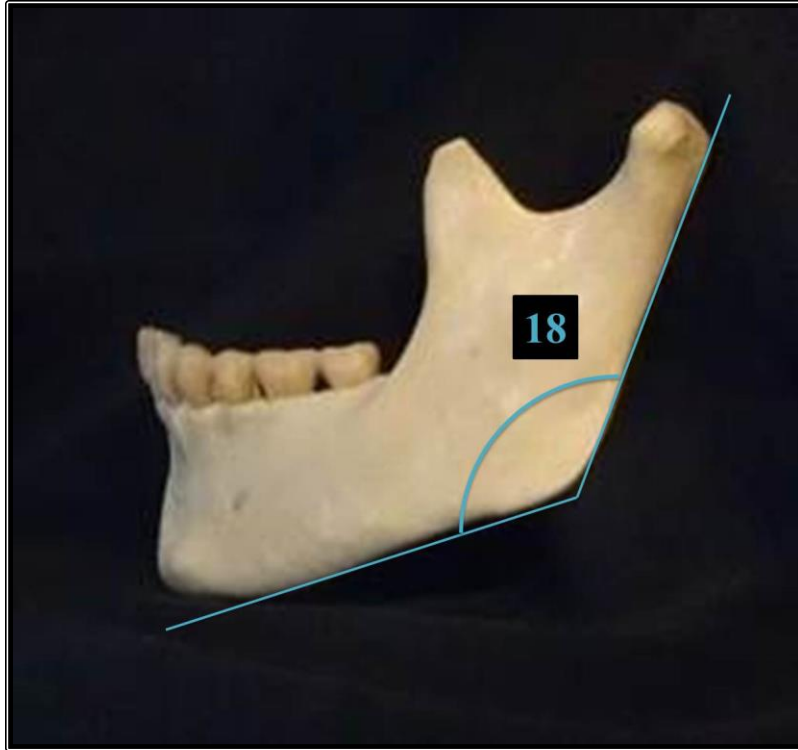
**Figure 2.5** Mastoid Flare (No. 13, calculated as half the distance between 13.1 and 13.2)



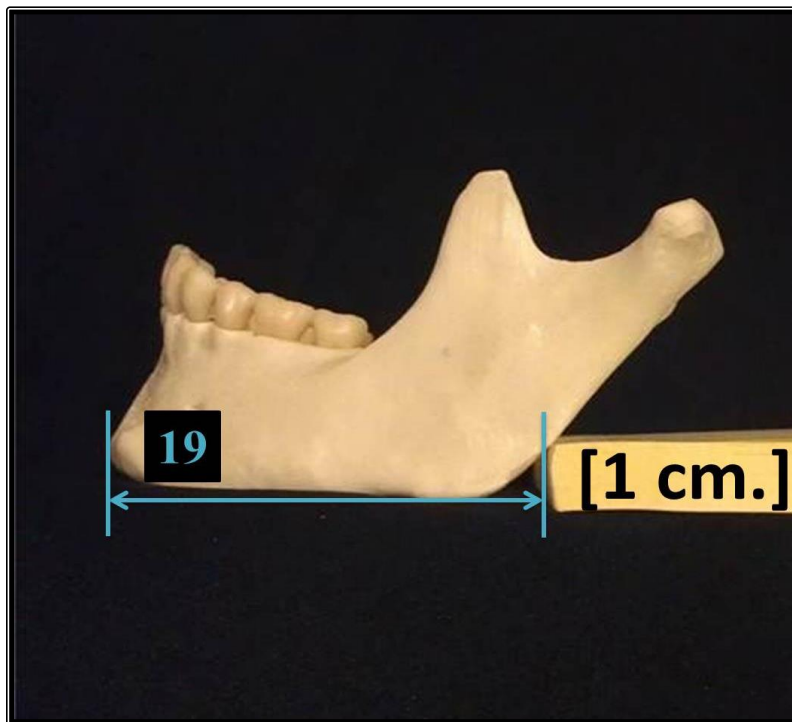
**Figure 2.6** Measurements of Mandibular Breadth (Nos. 14-15)



**Figure 2.7** Measurements of the Mandibular Ramus (Nos. 16-17)



**Figure 2.8** Mandibular Angle (No. 18)



**Figure 2.9** Mandibular Length (No. 19)

### **2.2.2 Measurement Precision**

Each variable was re-measured among 10 skulls to calculate measurement precision, for which the formula is  $1 - \frac{|\text{original measurement} - \text{second measurement}|}{\text{original measurement}} \times 100$ .

### **2.2.3 Statistical Analysis**

All statistical analyses were computed using SAS ® software. Principal components analysis was used to simplify the data and avoid any redundancies among inter-correlating variables. Analysis of Variance (ANOVA) was used to compare differences between males and females within each ancestral category. Each ancestry was tested separately in order to isolate each variable's presence of sexual dimorphism. ANOVA was also used to compare differences between African-Americans and European-Americans within each sex. Multivariate analysis of variance (MANOVA) was used to determine the presence of significant interactions between the categories of sex and race for each variable. A significant interaction indicates that there is a discrepancy in the relationship between the two categories (i.e. sex and ancestry) for that variable in relation to the other variables, which means that sexual dimorphism is expressed inconsistently between ancestries for any variable showing interaction. MANOVA, hence, tests for differences in the expression of sexual dimorphism between ancestral populations. For each variable showing interaction, the means of each sub-category were plotted to observe relationships of sexual dimorphism between ancestries. Alpha was set at 0.05.

## CHAPTER 3: RESULTS

### 3.1 Measurement and Intraobserver Precision

Measurement precision ranged from 92%-100% among the 19 variables (Table 3.1).

**Table 3.1** Measurement Precision for Twenty Measurements

Variable	Measurement Precision %
Ba-N	100
Zy-Zy	100
Go-Go	100
Cdl-Cdl	100
G-Op	99
Ba-B	99
B-N	99
N-Ns	99
MasTip	99
MasFlare	99
MinRam	99
MaxRam	99
Eu-Eu	98
Ba-Pr	98
Al-Al	98
N-Pr	97
GoAng	97
MaxLen	96
MDH	95
MaWd	92

### 3.2 Descriptive Statistics

The means and standard deviations for each variable by sub-group are reported in Table 3.2.

Mandibular angle (GoAng) is reported in degrees; all other variables are reported in millimeters.

**Table 3.2** Descriptive Statistics Organized by Sex and Ancestry

		Females			Males			
	Variable	N	Mean	Std. Dev.	Variable	N	Mean	Std. Dev.
		African-Americans	Eu-Eu	55	134.6	5.9	Eu-Eu	50
G-Op	55		182.6	6.1	G-Op	50	190.1	7.1
Ba-B	55		128.1	5.3	Ba-B	50	134.7	6.4
Ba-N	55		98.8	4.8	Ba-N	50	102.9	4.2
Ba-Pr	52		99.6	5.3	Ba-Pr	50	103.8	5.4
B-N	55		107.3	4.5	B-N	50	113	6.0
N-Pr	53		61.5	8.1	N-Pr	50	68.6	4.9
N-Ns	55		48.3	3.2	N-Ns	50	50.8	2.9
Al-Al	55		24.9	3.8	Al-Al	49	25	2.7
Zy-Zy	55		123.5	4.9	Zy-Zy	50	131.1	4.7
MDH	54		29	3.4	MDH	50	32.8	3.3
MaWd	55		19.9	3.6	MaWd	50	23.2	5.3
MF	55		9.3	1.8	MF	50	10.2	1.5
Go-Go	54		89.3	4.7	Go-Go	50	96.9	7.6
Cdl-Cdl	54		111.7	6.3	Cdl-Cdl	50	118.2	5.8
MinRam	55		30.6	2.9	MinRam	50	32.6	3.0
MaxRam	54		39.8	3.3	MaxRam	50	42.5	3.6
GoAng	54		126.4	6.3	GoAng	50	118.6	7.1
MaxLen	54		77.9	5.7	MaxLen	50	81.1	5.5
European-Americans	Variable	N	Mean	Std. Dev.	Variable	N	Mean	Std. Dev.
	Eu-Eu	49	138.6	6.4	Eu-Eu	49	139.2	7.4
	G-Op	49	173.6	6.6	G-Op	49	186.6	7.8
	Ba-B	49	130.5	4.3	Ba-B	49	140.7	4.9
	Ba-N	49	97.2	4.0	Ba-N	49	105.4	4.7
	Ba-Pr	47	92	5.3	Ba-Pr	47	96.5	6.8
	B-N	49	107	4.4	B-N	49	114.8	5.2
	N-Pr	47	61.9	3.3	N-Pr	48	67.4	5.0
	N-Ns	49	48.2	2.3	N-Ns	48	51.3	5.9
	Al-Al	49	21.4	2.4	Al-Al	48	21.7	2.8
	Zy-Zy	49	121.6	5.0	Zy-Zy	49	129.4	6.2
	MDH	49	27.8	2.9	MDH	49	32.7	3.6
	MaWd	49	16.3	3.5	MaWd	49	21.3	4.4
	MF	49	10.1	1.6	MF	49	10.5	2.7
	Go-Go	48	91.6	5.5	Go-Go	49	97.6	7.1
	Cdl-Cdl	47	110.3	6.5	Cdl-Cdl	47	116.3	5.7
	MinRam	46	27.7	3.3	MinRam	49	30.4	2.7
	MaxRam	46	38.1	3.3	MaxRam	49	41.6	3.4
	GoAng	48	123.8	5.6	GoAng	49	122.2	5.9
MaxLen	48	74.1	3.4	MaxLen	49	78	5.5	



### 3.3 Principal Components Analysis

Principal components analysis shows that five principal components have eigenvalues  $\geq 1.0$ . Table 3.3 displays each variable with its corresponding weighted coefficient within each principal component. Variables with weighted coefficients  $\geq |0.5|$  are highlighted. Three variables have coefficients  $\geq |0.5|$  for two principal components indicating multiple associations for these variables: G-Op, MinRam, and MaxRam. PC<sub>1</sub> shows overall positive association between general measures of length and breadth. PC<sub>2</sub> characterizes positive associations between measures of cranial length and height. PC<sub>3</sub> characterizes positive associations in overall breadth of the skull. PC<sub>4</sub> characterizes positive associations among upper facial height (N-Pr), nasal height (N-Ns), mastoid height (MDH) and mastoid flare (MF). PC<sub>5</sub> shows an inverse relationship between mandibular angle (GoAng) and measures of ramus breadth.

**Table 3.3** Principal Components with Weighted Coefficients of All Variables on a Varimax Rotated Matrix, (PC=Principal Component)

Variable	PC <sub>1</sub>	PC <sub>2</sub>	PC <sub>3</sub>	PC <sub>4</sub>	PC <sub>5</sub>
Eu-Eu	-0.16	0.27	0.64	-0.18	0.09
G-Op	0.66	0.51	0.18	0.10	-0.03
Ba-B	-0.02	0.84	0.27	0.16	-0.14
Ba-N	0.40	0.59	0.13	0.22	-0.21
Ba-Pr	0.78	0.02	0.06	0.06	-0.26
B-N	0.19	0.79	0.30	0.07	0.01
N-Pr	0.30	0.37	-0.07	0.54	-0.09
N-Ns	0.17	0.18	0.04	0.79	0.02
Al-Al	0.56	-0.33	0.28	-0.38	0.13
Zy-Zy	0.33	0.13	0.72	0.37	-0.23
MDH	0.40	0.23	0.27	0.50	0.01
MaWd	0.58	0.09	0.11	0.35	0.11
MF	-0.10	-0.06	0.19	0.63	-0.07
Go-Go	0.02	0.24	0.72	0.20	-0.12
Cdl-Cdl	0.28	0.08	0.75	0.16	-0.23
MinRam	0.63	0.11	0.14	0.00	-0.61
MaxRam	0.51	0.21	0.16	0.00	-0.53
GoAng	0.00	-0.06	-0.13	-0.06	0.85
MaxLen	0.69	0.21	-0.10	0.15	-0.09

### **3.4 ANOVA and MANOVA**

#### **3.4.1 Sexual Dimorphism within each Ancestry**

Table 3.4 displays the results of ANOVA for sexual dimorphism within each ancestry. The variables which show significance are highlighted; the larger sex and percent of sexual dimorphism are included in separate columns. Percent sexual dimorphism is calculated as  $(|\text{male mean} - \text{female mean}|) / \text{male mean} \times 100$ . Only one variable, nasal breadth (Al-Al), shows no significant difference within either ancestry. Each of the other 18 variables shows significant difference between the sexes among African-Americans, where males are larger than females except for the mandibular angle. Fifteen variables show significant difference among European-Americans, where males are larger than females. The variables which do not show significant difference among European-Americans but are not significant among African-Americans are: maximum cranial breadth (Eu-Eu), mastoid flare (MF) and the mandibular angle (GoAng).

#### **3.4.2 Ancestral Variation within each Sex**

Table 3.5 displays the results of ANOVA for ancestral variation within each sex. The variables showing significance are highlighted. The larger ancestry for each variable is included in a separate column, along with the absolute difference between means (i.e. delta). Thirteen variables show significant differences between African-Americans and European-Americans among females; African-American females are larger than European-American females for each variable except maximum cranial breadth, cranial height and bigonial breadth. Eight variables show significant difference among males; African-American males are larger than European-

**Table 3.4** ANOVA p-values for Sexual Dimorphism within Each Ancestry  
(M=Males,F=Females)

Variable	African-Americans			European-Americans		
	p-value	Larger	% SD	p-value	Larger	% SD
Eu-Eu	<0.05	M	2	0.67	-	0 <sup>1</sup>
G-Op	<0.0001	M	4	<0.0001	M	7
Ba-B	<0.0001	M	5	<0.0001	M	7
Ba-N	<0.0001	M	4	<0.0001	M	8
Ba-Pr	0.0002	M	4	0.0005	M	5
B-N	<0.0001	M	5	<0.0001	M	7
N-Pr	<0.0001	M	10	<0.0001	M	8
N-Ns	0.0001	M	5	0.001	M	6
Al-Al	0.9	-	0 <sup>1</sup>	0.56	-	0 <sup>1</sup>
Zy-Zy	<0.0001	M	6	<0.0001	M	6
MDH	<0.0001	M	12	<0.0001	M	15
MaWd	0.0003	M	14	<0.0001	M	23
MF	0.01	M	9	0.38	-	0 <sup>1</sup>
Go-Go	<0.0001	M	8	<0.0001	M	6
Cdl-Cdl	<0.0001	M	5	<0.0001	M	5
MinRam	0.0009	M	6	<0.0001	M	9
MaxRam	<0.0001	M	6	<0.0001	M	8
GoAng	<0.0001	M	7	0.18	-	0 <sup>1</sup>
MaxLen	<0.05	F	4	<0.0001	M	5

<sup>1</sup>The calculated percent sexual dimorphism from the raw data for Al-Al, MF and GoAng are 1%, 4% and 1% respectively; however, because ANOVA does not detect significant difference for these variables among European-Americans, the percent differences are reported as 0%. The percent sexual dimorphism for Eu-Eu among European-Americans is 0%.

American males for each variable except cranial height, cranial base length and the mandibular angle.

Seven variables show significant differences between African-Americans and European-Americans within each sex: maximum cranial length (G-Op), cranial height (Ba-B), basion-prosthion length (Ba-Pr), nasal breadth (Al-Al), minimum ramus breadth (MinRam), mandibular angle (GoAng), and maximum length of the mandible (MaxLen). Six variables show significant differences exclusively among females: maximum cranial breadth (Eu-Eu), bizygomatic breadth (Zy-Zy), mastoid flare (MF), mastoid breadth (MaWd), bigonial breadth (Go-Go), and maximum

ramus breadth (MaxRam). Cranial base length (Ba-N) is the only variable which shows significant difference exclusively among males.

**Table 3.5** ANOVA p-values for Ancestral Variation within Each Sex (AA=African-Americans, EA=European-Americans)

Variable	Females			Males		
	p-value	Larger	Delta	p-value	Larger	Delta
Eu-Eu	0.00	EA	4.0	0.40	-	0.0
G-Op	<.0001	AA	9.0	0.02	AA	3.5
Ba-B	0.01	EA	2.4	<.0001	EA	6
Ba-N	0.08	-	0.0	0.01	EA	2.5
Ba-Pr	<.0001	AA	7.6	<.0001	AA	7.3
B-N	0.69	-	0.0	0.11	-	0.0
N-Pr	0.76	-	0.0	0.24	-	0.0
N-Ns	0.83	-	0.0	0.56	-	0.0
Al-Al	<.0001	AA	3.5	<.0001	AA	3.3
Zy-Zy	0.05	AA	1.9	0.15	-	0.0
MDH	0.06	-	0.0	0.93	-	0.0
MaWd	<.0001	AA	3.6	0.06	-	0.0
MF	0.03	AA	0.8	0.51	-	0.0
Go-Go	0.03	EA	2.3	0.61	-	0.0
Cdl-Cdl	0.25	-	0.0	0.10	-	0.0
MinRam	<.0001	AA	2.9	0.00	AA	2.2
MaxRam	0.01	AA	1.7	0.21	-	0.0
GoAng	0.03	AA	2.6	0.01	EA	3.6
MaxLen	<.0001	AA	3.8	0.01	AA	3.1

### 3.4.3 Interactions between Categories of Sex and Ancestry

Four variables show significant interaction between sex and ancestry: maximum cranial length (G-Op), cranial height (Ba-B), cranial base length (Ba-N) and mandibular angle (GoAng) (Table 3.6). A significant interaction suggests that the additive effect of ancestry alters the expression of sex; hence, there is ancestral variation in sexual dimorphism for that particular variable. As follows, the expression of sexual dimorphism among African-Americans significantly differs from that among European-Americans for these four variables.

Nasal breadth (Al-Al) is the only variable which does not show overall sexual dimorphism. Maximum cranial length (G-Op) and cranial height (Ba-B) show significant difference for both sex and ancestry, whereas cranial base length and mandibular angle (GoAng) show significant difference for sex but not ancestry. In addition to cranial base length and mandibular angle, frontal cord (B-N), upper facial height (N-Pr), nasal height (N-Ns) and mastoid height (MDH) show significant difference for ancestry but not sex. Table 3.7 displays a comparison between the results from each ANOVA and the interactions of MANOVA.

**Table 3.6** MANOVA p-values for Overall Sex, Dim., Ancestral Variation and Sex\*Ancestry Interaction

Variable	Sex	Ancestry	Sex * Ancestry
Eu-Eu	0.02	0.02	0.31
G-Op	<0.0001	<0.0001	0.01
Ba-B	<0.0001	<0.0001	0.05
Ba-N	<0.0001	0.19	<0.01
Ba-Pr	<0.0001	<0.0001	0.93
B-N	<0.0001	0.23	0.17
N-Pr	<0.0001	0.79	0.30
N-Ns	<0.0001	0.85	0.49
Al-Al	0.76	<0.0001	0.61
Zy-Zy	<0.0001	0.01	0.50
MDH	<0.0001	0.34	0.18
MaWd	<0.0001	<0.0001	0.26
MF	0.03	0.04	0.32
Go-Go	<0.0001	0.04	0.79
Cdl-Cdl	<0.0001	0.05	0.94
MinRam	<0.0001	<0.0001	0.37
MaxRam	<0.0001	0.01	0.68
GoAng	<0.0001	0.57	<0.01
MaxLen	<0.0001	<0.0001	0.34

### 3.4.4 Plots of Sub-Group Means for Interactive Variables

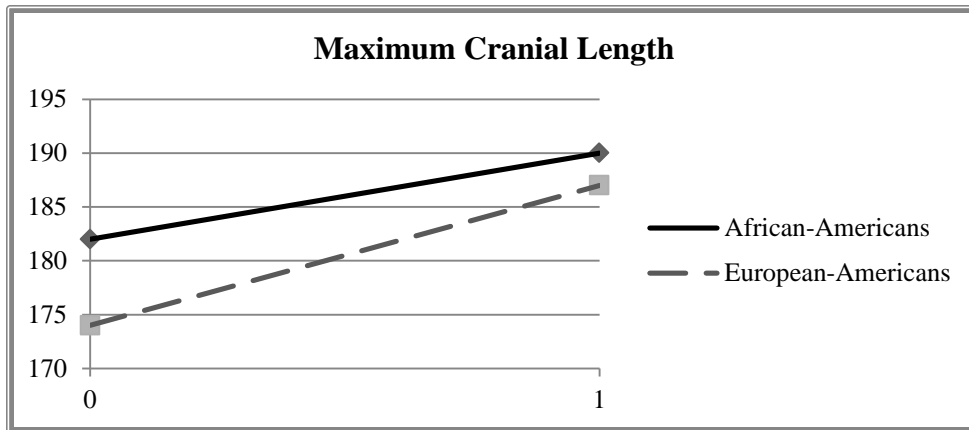
Plots for the means of each interactive variable within each sub-group are displayed in Figures 3.1-4. The plots provide a visual representation of the results described in Sections 3.4.1-3; they also provide a way to compare the patterns of sexual dimorphism of each variable.

**Table 3.7** Comparison of Results between each ANOVA and Interactions of MANOVA

Variable	ANOVA Sex. Dim. (p-value)		ANOVA Ancestry (p-value)		MANOVA p-value
	Afro-Am.	Euro-Am.	Females	Males	Sex*Ancestry
Eu-Eu	<0.05	0.67	0.00	0.40	0.31
G-Op	<0.0001	<0.0001	<0.0001	0.02	0.01
Ba-B	<0.0001	<0.0001	0.01	<0.0001	0.05
Ba-N	<0.0001	<0.0001	0.08	0.01	<0.01
Ba-Pr	0.0002	0.0005	<0.0001	<0.0001	0.93
B-N	<0.0001	<0.0001	0.69	0.11	0.17
N-Pr	<0.0001	<0.0001	0.76	0.24	0.30
N-Ns	0.0001	0.001	0.83	0.56	0.49
Al-Al	0.9	0.56	<0.0001	<0.0001	0.61
Zy-Zy	<0.0001	<0.0001	0.05	0.15	0.50
MDH	<0.0001	<0.0001	0.06	0.93	0.18
MaWd	0.0003	<0.0001	<0.0001	0.06	0.26
MF	0.01	0.38	0.03	0.51	0.32
Go-Go	<0.0001	<0.0001	0.03	0.61	0.79
Cdl-Cdl	<0.0001	<0.0001	0.25	0.10	0.94
MinRam	0.0009	<0.0001	<0.0001	0.00	0.37
MaxRam	<0.0001	<0.0001	0.01	0.21	0.68
GoAng	<0.0001	0.18	0.03	0.01	<0.01
MaxLen	<0.05	<0.0001	<0.0001	0.01	0.34

### Maximum Cranial Length

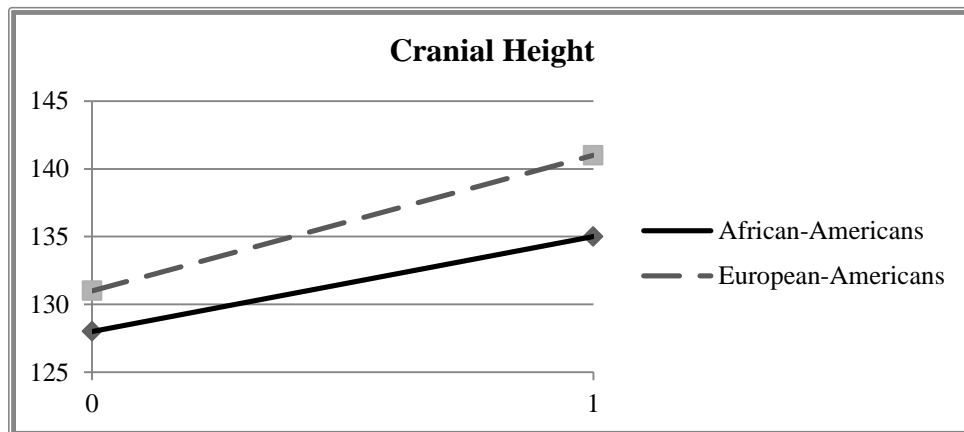
The trend line for maximum cranial length for African-Americans is above that of European-Americans, demonstrating that African-Americans have longer crania than European-Americans (Figure 3.1). The trend lines for each ancestry do not cross, illustrating overall ancestral variation. Within each ancestral group, males are larger than females. The slope of the trend line for European-Americans is steeper than that of African-Americans, indicating that there is a greater magnitude of sexual dimorphism of maximum cranial length among European-Americans; this difference is reported in Table 3.4 (7% > 4%). The magnitude of ancestral variation is greater among females than males (9.0 mm > 3.5 mm) (see Table 3.5).



**Figure 3.1** Plots of Means for each Sub-Group, Maximum Cranial Length (0=F; 1=M)

### Cranial Height

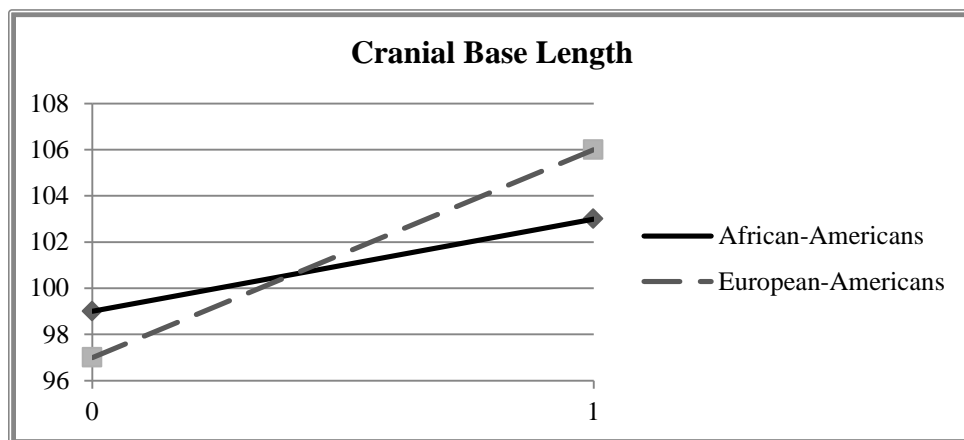
Figure 3.2 illustrates that European-Americans have higher cranial vaults and a greater degree of sexual dimorphism of cranial height (7% > 5%) than African-Americans (see Table 3.4). The trend lines for each ancestry do not cross, illustrating overall ancestral variation. In both ancestral groups, males are larger than females, and ancestral variation is greater among males than females (6 mm > 2.4 mm) (see Table 3.5).



**Figure 3.2** Plots of Means for each Sub-Group, Cranial Height (0=F; 1=M)

## Cranial Base Length

Figure 3.3 illustrates that European-Americans have a greater magnitude of sexual dimorphism of cranial base length than African-Americans (8% > 4%) (see Table 3.4). In both groups, males are larger than females. The trend lines for each ancestry cross, illustrating a lack of overall ancestral variation; however, the magnitude of ancestral variation is slightly larger among males than females (2.5 mm > 0.0 mm) (see Table 3.5). The magnitude is too small to contribute to an overall difference when the sexes are grouped together.

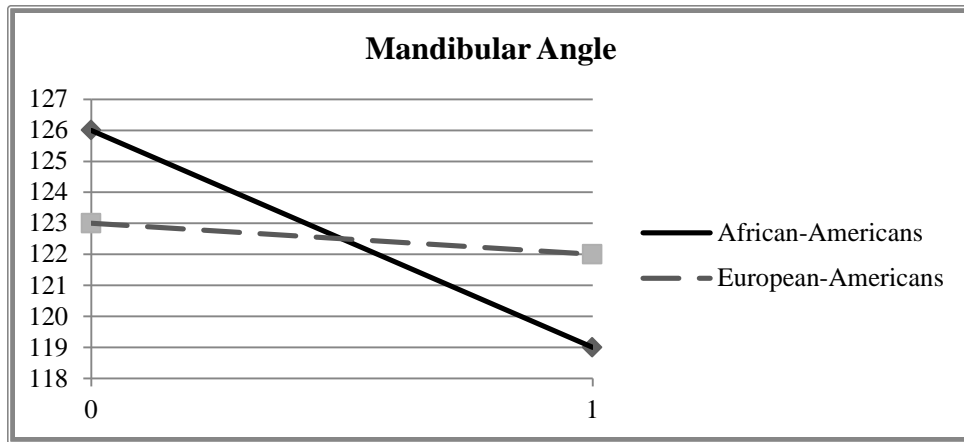


**Figure 3.3** Plots of Means for each Sub-Group, Cranial Base Length (0=F; 1=M)

## Mandibular Angle

Figure 3.4 illustrates that African-Americans have a greater magnitude of sexual dimorphism than European-Americans (7% > 0%) (see Table 3.4). In both groups, females are larger than males; however, the difference is nonsignificant among European-Americans (Table 3.4). The trend lines for each ancestry cross, illustrating an overall lack of ancestral variation; however the magnitude of ancestral variation is slightly larger among males (3.6 mm > 2.6 mm) (see Table 3.5). The magnitude is too small to contribute to an overall difference when the sexes are grouped together.





**Figure 3.4** Plots of Means for each Sub-Group, Mandibular Angle (0=F; 1=M)

## **CHAPTER 4: DISCUSSION**

By using MANOVA, this study provides an alternative approach to understanding variation in sexual dimorphism. Many previous conclusions regarding variation in sexual dimorphism have been based on studies using discriminant function analysis as well as principal components analysis. These two statistical tests measure predictability of certain variables for correctly classifying skulls into appropriate sex and ancestry categories. The conclusions from these studies concerning variation in sexual dimorphism between ancestral groups were made on the basis that predictive formulas lose accuracy when applied to individuals of a different ancestry from which the formulae were developed. Alternatively, MANOVA provides specific information regarding the significance of interaction between sex and ancestry within each variable. While discriminant function analysis and principal components analysis indicate general variation in the pattern of sexual dimorphism between two ancestral groups, MANOVA provides specific information in respect to the pattern of variation within each variable.

### **4.1 Explanation of the Significance of Interactions**

A side by side comparison of two independently performed ANOVAs for differences between the sexes within each ancestry provides an initial overview of variation in sexual dimorphism between African-Americans and European-Americans (Table 3.4). The group of variables which only show sexual dimorphism within one ancestry differs slightly from the group of variables which show interaction (Table 3.7). Two of the significantly interactive variables, maximum cranial length (G-Op) and cranial height (Ba-B), show overall sexual dimorphism and ancestral variation (Table 3.7); these two variables also show sexual dimorphism within each ancestral group as well as ancestral variation within each sex (Table 3.7). The umbrella of significance within maximum cranial length and cranial height suggests

that sexual dimorphism is expressed differently between African-Americans and European-Americans for these traits. Figures 3.1 and 3.2 illustrate that European-Americans have a greater magnitude of sexual dimorphism than African-Americans for each of these two variables.

Cranial base length (Ba-N) shows significant interaction as well as overall sexual dimorphism; however, this variable does not show overall ancestral variation (Tables 3.7). Figure 3.3 illustrates that European-Americans have a greater magnitude of sexual dimorphism than African-Americans for cranial base length.

Lastly, the mandibular angle (GoAng) shows overall sexual dimorphism but not ancestral variation, as well as a significant interaction between sex and ancestry (Table 3.7). Figure 3.4 illustrates that African-Americans have a greater magnitude of sexual dimorphism than European-Americans for mandibular angle.

Mandibular angle is unique from the other three variables showing significant interaction in that it does not show sexual dimorphism within each ancestry (Table 3.4). The reason may be that mandibular angle is not a measure of skull size like the linear measurements; instead, the mandibular angle measures the space between two bony elements (i.e., mandibular body and ramus). Furthermore, the various bones which contribute to each linear measurement are separate at birth and fuse into a cohesive unit later in the life, whereas mandibular angle develops as one unit in utero.

## **4.2 Possible Reasons for the Variation in Sexual Dimorphism**

### **4.2.1 Nutritional Hypothesis of Sexual Dimorphism**

The variation in sexual dimorphism between African-Americans and European-Americans could be attributed to each population having had unequal levels of nutrition, which Mielke et al. (2011:279-80) refer to as the “nutritional hypothesis.” The authors explain that

throughout human evolution, females have become less affected by nutritional fluctuations due to selection for hormonal mechanisms which support the nutritional demands of pregnancy and breast feeding. On the other hand, males are not under the same reproductive demands and have more allowance to respond to fluctuations in nutrition. Reason follows that any deficit in nutritional status of a population would affect the growth of males more than the growth of females. Furthermore, in populations where there are lower levels of adequate nutrition, there is less sexual dimorphism because males have not had the environmental support to reach their maximum growth potential.

Evidence which supports the nutritional hypothesis has traditionally been found in studies on sexual dimorphism of stature (Wolfe and Gray, 1982). The theory has also been used to describe variation in sexual dimorphism of the pelvis (Meindl et al., 1985; Rosenberg, 1988; Walker, 2005) as well as the cranium (İşcan et al., 1995). Dahinten and Pucciarelli (1986) found that nutritional deprivation in rats decreases testosterone levels, and the effect of this deprivation is greater on males than females. Pucciarelli (1981) further found that nutritional deprivation in rats differentially affects various elements of the skull. Four of the traits Pucciarelli (1981) classified as “nutritionally unstable” (i.e. neurocranial length, height, width and masseteric length) are analogous to measurements taken in the current study: maximum cranial length (G-Op), cranial height (Ba-B), maximum cranial breadth (Eu-Eu), and mandibular length (MaxLen), respectively. Accordingly, these four variables can serve as a proxy for inferring nutritional status among African-Americans and European-Americans. The lack of variation in sexual dimorphism of maximum cranial breadth and mandibular length between the two ancestries suggests that nutritional status was comparable for these two populations; therefore, the variation in sexual dimorphism of maximum cranial length, cranial height, and possibly cranial base

length could be explained by reasons other than nutritional inequality between African-Americans and European-Americans.

Because mandibular angle (GoAng) is a measure of shape (i.e. degree angle) rather than size (i.e. linear distance), it may not be affected by nutritional deprivation in the same way as maximum cranial length, cranial height and cranial base length. However, size can be measured on the mandibular ramus which directly outlines the perimeter of the mandibular angle. As the condyles grow more vertically, as opposed to horizontally, the angle becomes more acute (Lee et al., 2001); this pattern towards acuteness continues until the individual reaches adulthood (Gungor et al., 2007). The results of principal components analysis show that the mandibular angle is associated with both measures of the mandibular ramus: minimum ramus breadth (MinRam) and maximum ramus breadth (MaxRam) (Table 3.3); as the breadth of the ramus decreases, the mandibular angle increases. This association further suggests that the size of the mandibular angle is strongly affected by the growth of the mandibular ramus.

Pucciarelli (1981) found that measurements of the ramus are affected by nutritional deprivation in rats. Loth and Henneberg (1996) also found that flexure of the ramus (measure of indentation on the posterior ramus) develops only among males due to their longer growth period. Therefore, sexual variation in the mandibular ramus is directly affected by nutritional status, which would consequently affect sexual dimorphism of the mandibular angle.

The results of MANOVA indicate that minimum and maximum ramus breadths do not have a significant interaction between sex and ancestry (Table 3.6), which suggests that there are comparable levels of sexual dimorphism in the mandibular angle between African-Americans and European-Americans. Presumably, the variation in sexual dimorphism of the mandibular angle is likely caused by factors other than differential nutritional status.

#### **4.2.2 Secular Change and Sample Bias among European-American Males**

The European-American males in the current study are principally from a later historical period than the other three sub-groups, and secular changes which may have occurred in the skull must be considered when analyzing variation among the samples. Jantz and Meadows Jantz (2000) found that maximum cranial length (G-Op) and cranial height (Ba-B) have both increased among European-American males between the mid-19<sup>th</sup> century and 1970s, with change in length being to a lesser degree than that of height. Wescott and Jantz (2005) found that the increase in cranial height is mostly attributed to changes in the inferior and posterior vault, particularly influenced by the downward movement of basion (located at the base of the cranium) and relative stability of bregma (located on the top of the cranium). The greater sexual dimorphism in cranial height and cranial base length (Ba-N) among European-Americans in this study could, therefore, be explained by sample bias associated with secular changes in the cranium at the base of the skull. The greater distance between the means of European-American males and females could be a ramification of the greater increase in length and height among the European-American males. Because maximum cranial length has undergone weaker, and sometimes nonsignificant (Jantz and Meadows Jantz, 2000) secular change, the greater dimorphism among European-Americans in maximum cranial length could be explained by factors other than sample bias.

Jantz and Meadows Jantz (2000), Wescott and Jantz (2005) and Martin and Danforth (2009) suggest that changes in diet and medical care, including advances in orthodontic procedures, most likely contribute to secular changes. One of the changes in medical care includes increased dental care. While Martin and Danforth (2009) did not measure mandibular angle (GoAng), they did measure the mandibular ramus, which directly affects the size of the

angle. The authors found no secular change in minimum ramus breadth (MinRam) or maximum ramus breadth (MaxRam), which suggests that factors other than the growth of the mandibular ramus explain the variation in sexual dimorphism of the mandibular angle found in this study.

Numerous studies have found a significant increase in the size of the mandibular angle with excessive tooth loss (Balci et al., 2005; Oettlé et al., 2009; Ohm and Silness, 1999). Likewise, Meindl et al. (1985:82) suggest that the adult mandible is “the most environmentally modified of all bones” and that “remodeling accelerates after tooth loss.” Oettlé et al. (2009) further found that individuals with an even distribution of molars on both sides showed greater symmetry between left and right angles. The variation in sexual dimorphism of the mandibular angle could, therefore, be explained by increased tooth loss among the European-American males in this study due to increases in orthodontic treatment in more recent history. The current study, however, did not record observations on tooth loss.

#### **4.2.3 Genetic Contributions to Ancestral Variation**

One of the factors which contributes to the variation in sexual dimorphism of maximum cranial length between African-Americans and European-Americans could be genetic, resulting from different biological adaptations to disparate ecological environments throughout the evolutionary history of *Homo sapiens*. Relethford (2009) found a correlation between variation in cranial phenotypes and geographical distance; others have also found a relationship between climate and cranial index (Beals, 1972; Beals et al., 1984). Human populations native to cold climates have larger and broader skulls in order to preserve heat; in contrast, human populations native to hot climates have smaller and narrower skulls in order to dissipate heat (see Mielke et al., 2011). Variations in the size of the nasal aperture have also been found to be associated with variations in climates. Populations which are native to cold, dry climates have relatively high and

narrow nasal apertures, whereas populations native to warm, moist climates have relatively short and broad nasal apertures (Mielke et al., 2011). As with adaptations in cranial morphology, adaptations in the nasal aperture are associated with varying levels of heat retention (Hennessy and Stringer, 2002). Relethford (2004:261) states that “some aspects of cranial shape [may] have been subject to interregionally differing selection pressures.” Furthermore, Relethford (1994) concludes that Europe was genetically isolated from Africa for much of human history, suggesting that the ancestral variation between populations native to Africa and Europe is genetic, and that the variation derives from differential selective pressures between the disparate climates of African and Europe.

Additional research shows that cranial traits are moderately to strongly heritable (Devor, 1987; Sparks and Jantz, 2002) and variation between populations persists through time. Mielke et al. (2011) provide evidence that even though American descendants of immigrants show significant changes in cranial size and shape throughout generations, the differences between ethnic groups remain the same (see also Gravlee et al., 2003), which suggests that environmental factors do not obliterate genetic factors in cranial variation. Therefore, the ancestral variation between African-Americans and European-Americans may retain a strong genetic component. Ousley et al. (2009) found that morphological differences persist between African-Americans and European-Americans even though both ancestral groups have undergone secular change (also see Wescott and Jantz, 2005). Additionally, von Cramon-Taubadel (2011) presents evidence which supports the idea that the cranial vault especially retains ancestral variation. Therefore, the variation in sexual dimorphism of maximum cranial length between African-Americans and European-Americans could be explained by genetic variation in addition to sample bias among European-American males.



Viðarsdóttir et al. (2002) present evidence which suggests that Europeans in particular, among geographically disparate populations, have a unique craniofacial ontogeny with the most significant differences from any other group in their study. Sardi and Ramirez Rozzi (2012) offer further evidence in support of a strong genetic influence in the pattern of cranial development, and that patterns of development vary between populations. When comparing Europeans to South Africans, the authors found that morphological variation in the neurocranium is present at birth, and they concluded that this variation is due to divergent prenatal growth patterns between the two ancestral groups. The authors also found variation in postnatal rates of development, where the frontal region of the cranium develops more quickly among South Africans, which suggests that Europeans undergo a longer period of growth in the frontal region. This suggests that as humans migrated to Europe, they developed a genetic mutation altering the developmental pattern of the face and cranium. Natural selection could have favored individuals with decelerated growth in order to develop the cranial morphology necessary to survive in the colder climate of Europe.

Differential growth patterns have also been found between the sexes. Joffe et al. (2005) found that male head circumference increases from 1.9% to 2.4% that of female size within the first year of life, indicating a more accelerated growth pattern. Bulygina et al. (2006) found that the facial skeleton grows for a longer period of time in males than in females. Consequently, the increased sexual dimorphism in maximum cranial length among European-Americans is probably a ramification of prolonged growth of the cranium, specifically the frontal region, among Europeans. European-Americans, therefore, express exaggerated sexual dimorphism of maximum cranial length as a result of a twofold effect of prolonged growth.

Principal components analysis of this study shows that maximum cranial length (G-Op) is associated with two principal components: PC<sub>1</sub> and PC<sub>2</sub> (Table 3.3). While PC<sub>2</sub> includes cranial height (Ba-B) and cranial base length (Ba-N), both of which are subject to sample bias, PC 1 does not include these variables; however, each variable in PC<sub>1</sub> does show ancestral variation (Table 3.6). Therefore, while the variation in sexual dimorphism of maximum cranial length may partly be explained by sample bias, it is also explained by ancestral variation.

While genetic variation contributes to the variation in sexual dimorphism of maximum cranial length, it does not contribute to that of the mandibular angle. Oettlé et al. (2009) found no significant difference in the mandibular angle between South African blacks and whites when mandibles contained all molars. The authors also found no difference between the sexes. Therefore, the variation in sexual dimorphism of the mandibular angle between African-Americans and European-Americans in the current study is best explained by variation in the degree of tooth loss.

## CHAPTER 5: CONCLUSIONS

The results of this study show that there are differences in sexual dimorphism between African-Americans and European-Americans, which fails to support the null hypothesis. The greater dimorphism among European-Americans in cranial height and cranial base length may be explained by sample bias due to secular change among the European-American males in this study. Most of the European-American males sampled in this study lived during a more recent time period than the other three sub-groups, and they may express secular changes which have occurred in the cranium since the mid-19<sup>th</sup> century. Further research using the same methods should control for secular change by sampling all individuals from the same time period.

Concerning the nutritional hypothesis, any significant effect that non-comparable levels of nutrition would have on the variation in sexual dimorphism between ancestries would be nested in the effects of secular change. The current study is not a reliable test of the nutritional hypothesis because the sample of European-American males did not represent the same historical period as that of European-American females; thus, this study did not control for nutritional status within each sex. However, maximum cranial breadth can be used to neutralize the effects of sample bias because it has undergone only a weak amount of secular change. By inference, the similarities in sexual dimorphism between African-Americans and European-Americans suggest that the two ancestries had comparable levels of nutrition, and factors other than nutrition must explain the variation in sexual dimorphism.

The variation in sexual dimorphism of the mandibular angle could also be explained by sampling error due to secular change. Part of increased access to dental care includes more frequent surgical tooth extraction. The European-American males in the current study may have had greater access to dental care and surgical removal of the third molars, which would increase

the mandibular angle making this trait resemble the female type. Therefore, the European-Americans in this study show less sexual dimorphism for this trait than African-Americans.

While only sample bias explains the variation in sexual dimorphism between African-Americans and European-Americans in cranial height, cranial base length and mandibular angle, it only partially explains the variation in maximum cranial length. Even though secular changes in maximum cranial length have occurred in European-American males, the changes are relatively small. The variation is, therefore, also explained by genetic variation, which reflects evolutionary change among Europeans for elongated periods of cranial growth. In addition to this possible adaptation, males also experience an accelerated and prolonged period of growth. The combination of the possible European adaptation and sexually differentiated development enhances the sexual dimorphism among European-Americans in relation to African-Americans.

Genetic differences between African-Americans and European-Americans influence variation in their dimorphism. Natural selection related to sexual differences in response to nutritional variation contributes to sexual dimorphism. Females are under greater selective pressure than males to make metabolic processes available for reproductive purposes such as pregnancy and breastfeeding. Males are subject to less intense selective pressure and, correspondingly, they are more responsive than females in their growth to nutritional variation. For example, selective pressure for heat retention among prehistoric Europeans may be associated with increased cranial growth. The variation in sexual dimorphism between African-Americans and European-Americans seen in this study is a result of the twofold interplay between the selection between the sexes and the selection among Europeans. Despite considerable genetic overlap between African-Americans and European-Americans, there remains significant morphological variation in the cranium. This conclusion should be tested by

further studies which control for secular change and nutritional equality while using the same statistical methods.

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## VITA

Amanda Grace Kittoe grew up in Alliance, Ohio where she attended Marlinton High School. After being graduated in 2003, she spent one year as a foreign exchange student in Dreux, France through the Rotary International Student Exchange Program. Following her year abroad, she enrolled in Case Western Reserve University in Cleveland, Ohio where she earned her Bachelor of Arts in anthropology and psychology. In 2006, she spent a semester studying at the University of Hyderabad in Hyderabad, India. Upon being graduated in 2009, she wrote her senior thesis, "Covariation in limb-limb and limb-trunk proportions in whites and blacks and males and females using the Hamann-Todd Collection, Cleveland Museum of Natural History" under the direction of Dr. Scott Simpson, which was published in the undergraduate student research journal, *Discussions* (Fall 2008, Volume 5). Later that year, she enrolled in the Master of Arts program in the Department of Geography and Anthropology at Louisiana State University where she studied under the supervision of Dr. Robert Tague. She has presented her work entitled "Reliability of forensic stature estimation: Co-variation in limb proportions in American Whites and Blacks" at the 2010 Annual Meeting for the Southern Anthropological Society. She has also presented posters at the 2011 and 2012 Annual Meeting for the American Association of Physical Anthropologists entitled "Population-based effects on limb proportions and implications for stature estimation" and "Sex estimation using the mastoid process: Variation in sexual dimorphism between populations." She plans to continue her studies on human biological variation by earning a doctorate and pursuing a career in academia.