2020

Exploring sexual dimorphism of ancestral cranial nonmetric traits in modern European Americans

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https://hdl.handle.net/2144/41305

BOSTON UNIVERSITY

SCHOOL OF MEDICINE

Thesis

EXPLORING SEXUAL DIMORPHISM OF ANCESTRAL CRANIAL NONMETRIC TRAITS IN MODERN EUROPEAN AMERICANS

by

SAVANNAH RAE MILLS

B.A., University of Florida, 2018

Submitted in partial fulfillment of the
requirements for the degree of
Master of Science

2020

Approved by

First Reader ______________________________

Sean D. Tallman, Ph.D., RPA
Assistant Professor of Anatomy and Neurobiology

Second Reader ______________________________

Tara L. Moore, Ph.D.
Associate Professor of Anatomy and Neurobiology

ACKNOWLEDGMENTS

I would first, and foremost, like to thank my advisor Dr. Sean D. Tallman who assisted me, time and again, with the process of developing my thesis; and who was a wonderful professor. Secondly, I would like to thank Dr. Tara L. Moore, my program director and second reader, who was so supportive of all the students, and who developed this program in order for young professionals to continue their education within their dream field. This thank you also extends to the rest of the faculty who are a part of the Forensic Anthropology program at Boston University School of Medicine. They have created a wonderful program that has ultimately prepared me for the professional working environment within our field.

I would also like to thank Dr. Daniel J Wescott and the rest of the faculty at Texas State University, who welcomed me at their facility when I visited to collect my data. I would like to thank Dr. Allen Gregg Harbaugh, who assisted me with the development of my statistical analyses; and my friend Joeli McKee, who sat with me for extended periods of time running and processing the analyses. I would of course like to thank my supportive friends whom I have made since moving to Boston. They are an amazing group of people, who have time and again offered their support throughout these past two years. Finally, I would like to thank my parents, who no matter what, always supported me and my endeavors, even when they’ve taken me across the country.

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ABSTRACT

The present study analyzes cranial nonmetric traits used in forensic ancestry estimation on contemporary skeletal remains of modern European Americans in order to determine if there are statistically significant differences between males and females in trait expression. Research on cranial nonmetric traits for ancestry estimation has largely ignored the effects of sexual dimorphism on trait expression; however, there is growing evidence that some traits may be impacted by sex, among other variables. The 17 macromorphoscopic traits described in Hefner and Linde (2018) and the six mandibular morphoscopic traits described in Berg (2008) were scored on 97 females and 113 males from the Texas State University Donated Skeletal Collection in San Marcos, Texas. Chi-square tests were used to analyze if there are statistically significant cranial nonmetric trait expressions between males and females. From these tests, the results indicate that 14 out of the 23 cranial and mandibular nonmetric traits are statistically significantly different between the sexes, with a *p*-value less than 0.05. Gonial angle flare is the most significant feature, while the zygomaticomaxillary suture is the least significant feature. Additionally, correspondence analyses (CA) show the relationship between each cranial nonmetric trait score, that demonstrated significance, and both sexes. Ultimately, this research demonstrates that several nonmetric traits used in ancestry estimation are affected by sex; thus, it may be beneficial to develop sex-specific ancestry models for nonmetric traits.

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LIST OF ABBREVIATIONS

ANS	Anterior Nasal Spine
ARS	Ascending Ramus Shape
CS	Chin Shape
GAF	Gonial Angle Flare
INA	Inferior Nasal Aperture
IOB	Interorbital Breadth
LBM	Lower Border of the Mandible
MTb	Mandibular Torus
MTh	Malar Tubercle
NAS	Nasal Aperture Shape
NAW	Nasal Aperture Width
NBC	Nasal Bone Contour
NBS	Nasal Bone Shape
NFS	Nasofrontal Suture
NO	Nasal Overgrowth
OBS	Orbital Shape
PD	Postbregmatic Depression
PREI	Posterior Ramus Edge Inversion
PS	Palate Shape
PZT	Posterior Zygomatic Tubercle

SPS	Supranasal Suture
TPS	Transverse Palatine Suture
ZS	Zygomaticomaxillary Suture

CHAPTER 1: INTRODUCTION

When the field of physical anthropology was first emerging, anthropologists were concerned with classifying human groups into categories in order to understand human variation (DiGangi and Hefner, 2013). Physical anthropologists assumed that groups of humans conformed to distinct types, and thus they placed them into a hierarchy of races (DiGangi and Hefner, 2013:120). Two of the most influential physical anthropologists who helped develop the field, Aleš Hrdlička and Earnest Hooton, explained human variation as, “a result of separate evolutionary pathways leading to different races.” (DiGangi and Hefner, 2013, p. 120). This was the belief of Aleš Hrdlička and Earnest Hooton. Their viewpoint was based on physical characteristics such as skin color and facial features. This belief led Earnest Hooton to develop the Harvard Blanks, which is a standard for recording nonmetric traits, cranial measurements, and general cranial observations (DiGangi and Hefner, 2013). These were then used to answer questions regarding body form. Earnest Hooton was very interested in the use of cranial nonmetric traits in order to classify individuals into types, since he believed races were typological (DiGangi and Hefner, 2013). Despite his beliefs regarding race, he was actually antiracist and was a great influencer in the field of physical anthropology. Many biological anthropologists today can actually trace their “educational pedigree” back to Hooton through dissertation committee members (DiGangi and Hefner, 2013).

Another highly influential physical anthropologist in the early twentieth century was Franz Boas. Similar to Hooton and Hrdlicka, Boas had a significant influence on the perspective of race. However, unlike Hooton and Hrdlicka, he rejected types and embraced culture and environment as the answers to human variation (DiGangi and Hefner, 2013). His belief and position on the importance of culture and the environment in regard to human variation subsequently became the foundation for research questions today (DiGangi and Hefner, 2013). He also stressed the importance of metric traits in order to understand secular change in humans. Boas believed that metric traits could reveal the changes in biology, which are due to changing variables in the environment (DiGangi and Hefner, 2013). This was opposed to Hooton, who preferred the use of cranial nonmetric traits when studying human variation.

Eventually, due to the foundation Boas established within the field, the belief of typologies in regard to human races began to slowly fade. Today, biological anthropologists no longer study human variation in terms of hierarchies similar to the way in which Hrdlicka and Hooton did. Due to the influence Boas had on the understanding of human variation in the field, ancestry is viewed differently today. Thus, the estimation of ancestry in forensic anthropology focuses on the emphasis of environmental variables that effect variation such as culture, nutrition, stress, and climate (DiGangi and Hefner, 2013).

Within the field of forensic anthropology, anthropologists routinely establish a biological profile which is an important aspect for identifying unknown individuals from their skeletal remains. These profiles, which estimate sex, age, ancestry, and stature are created to give law enforcement and medical examiner/coroner offices a better description of the individual when trying to match them to missing persons reports (Klales and Kenyhercz, 2015). One of the most important components of the biological profile is ancestry. In order to estimate ancestry, forensic anthropologists can utilize two approaches: metric and nonmetric methods. Metric data is collected by using sliding or spreading calipers, mandibulometers, osteometric boards, and cranifor (DiGangi, 2012). Metric data is subsequently input into FORDISC, which then classifies the unknown individual into one of 13 ancestral groups (Jantz and Ousley, 2005). When this method is implemented in a forensic case, the forensic anthropologist is not required to have years of observer experience to measure these traits. For the nonmetric method, the forensic anthropologist completes a visual assessment of traits that are then measured using an ordinal scoring scale or scored as present/absent (Birkby *et al.*, 2008). It is normally utilized by those with years of experience in identifying individuals and understanding human variation. Thus, the traits used in this method are quite subjective (Hefner, 2009). However, researchers have developed better definitions and training methods, which help with identifying what ancestral group an individual may be from when found in a forensic context.

Hefner has written numerous papers on the subject, specifically examining the statistical analyses of nonmetric traits compared to that of metric traits (Hefner, 2007; Hefner, 2009; Hefner and Ousley, 2014; Hefner *et al.,* 2014; Hefner and Linde, 2018). Hefner and Linde (2018), outline and describe in detail 17 cranial nonmetric traits and their use in estimating ancestry. Berg has also conducted research examining the use of morphometric and morphoscopic variables on estimating ancestry and sex, examining the human mandible compared to that of the cranium (Berg, 2008). Research on sexual dimorphism of cranial and mandibular nonmetric traits, however, is lacking. Hefner has consistently pooled males and females together when researching the use of ancestral cranial nonmetric traits (Hefner, 2007; Hefner, 2009; Hefner and Ousley, 2014; Hefner *et al.,* 2014). However, recent research has suggested that factors, such as sex, do affect cranial nonmetric traits used to assess ancestry (Tallman, 2016; Kilroy et al. in review). It is through such research that anthropologists are better able to understand the variability of these traits, and the potential research that is needed in order developed a more standardized approach to the estimation of ancestry within a forensic context.

Rationale and Hypothesis

The relevance of the present study is based not only on the crucial importance of ancestry estimation for the biological profile, but also on the lack of research in regard to the variability of ancestral macromorphoscopic traits between males and females. These traits are variables of the cranium reflected as soft-tissue differences in living individuals, typically considered a subtaxon to traditional cranial nonmetric traits (Hefner and Linde, 2018). They are subdivided into five classes which are bone shape, bony feature morphology, suture shape, trait presence/absence, and feature prominence/protrusion (Hefner and Linde, 2018). In terms of research conducted to determine specific traits that are best used to identify the ancestry of individuals from the European American ancestral group, metric traits have typically been utilized given that nonmetric traits alone have little discriminatory value (Carpenter, 1976; Maddux *et al.*, 2015; Meeusen *et al.*, 2015; Spradley, 2015; Spradley and Jantz, 2016). However, greater standardization of nonmetric traits will assist in a more accurate estimation of ancestry in a forensic context, in addition to metric traits.

The improvement of ancestry assessment for the biological profile is crucial given the increasing diversity within the United States. Having a better understanding of the variation of not only between ancestral groups, but also within them is crucial in forensic contexts. Thus, by observing potential differences in nonmetric traits between males and females of various populations, a more accurate estimation of ancestry could be developed.

Further research is needed in order to have a better understanding of the effects of sex on the frequency of ancestral cranial nonmetric traits. Thus, the present study examines the frequency of nonmetric traits used to estimate ancestry between European American males and females in order to determine if they are sexually dimorphic. It is hypothesized that statistically significant differences are present between European American males and females, ultimately assisting in the further standardization of nonmetric traits when utilized in a forensic context in addition to cranial metric traits.

Organization of Chapters

The organization of the following chapters is divided as such: Chapter 2 discusses the history of cranial nonmetric traits, followed by their application within the field of forensic anthropology. This will further include the controversial use of these traits when applied to the biological profile in forensic contexts. Furthermore, Chapter 2 will close with the discussion of sexual dimorphism of cranial nonmetric traits, and the research that has been conducted on this topic. Chapter 3 will detail the materials and methods utilized in this study. This will include the skeletal sample that was used in order to conduct the analysis, a list of the nonmetric traits that were scored on the skeletal sample, and finally the statistical analyses used to test the hypothesis. Chapter 4 presents the results of the statistical analyses including tables and figures illustrating the nonmetric traits that are found to be sexually dimorphic, as well as intraobserver error. Chapter 5 will then discuss in further detail the results presented in chapter four, specifically discussing the statistically significant differences between males and females and what this presents for future ancestry estimation. The final chapter, Chapter 6, concludes with a summary of the study, its purpose, and ultimately future research that is needed in order to better understand sexual dimorphism of these traits. This includes not just European American males and females, but also males and females of other ancestral populations.

CHAPTER 2: PREVIOUS RESEARCH

The estimation of ancestry in a forensic anthropological context is a pivotal part of the biological profile. When estimating the ancestry of an unknown individual, two methods are utilized: nonmetric and metric approaches, where metric traits are typically preferred (Hefner, 2007). Cranial nonmetric traits are described as features on the skull that are reflected as soft-tissue differences in living individuals (Hefner and Linde, 2018). It is a different approach to use craniometric traits, which require the use of multiple instruments. However, the forensic anthropologist estimating the ancestry of an unknown individual needs to have years of experience and understand human variation in order to accurately estimate ancestry when observing the nonmetric traits. Overall, the use of cranial nonmetric traits has been studied and used in the field of forensic anthropology as a means to estimate ancestry for over fifty years. They have been modified and improved by numerous biological anthropologists within the field who have made it easier to estimate ancestry in forensic anthropological contexts, thus making the methods more preferable in the long run.

The History of Cranial Nonmetric Traits

In the early days of physical anthropology, the study of modern human crania was oriented toward establishing distinct traits that were indicative of certain “geographic races” (Gill 1998). The Harvard List, developed by E.A. Hooton, was a list of such cranial nonmetric traits compiled in order to assist early physical anthropologists distinguish between groups of people. Hooton (1931) applied these traits to 560 individuals from the North Pacific Coast, as well as craniometry. In this study, the Easter Eskimo was distinguished from the Western Eskimo by utilizing the nasal aperture, the development of the sagittal crest, and the frontal orientation of the orbits (Hooton, 1931). From these traits, Hooton (1931) found that they illustrated similarities to the “Mongol stock.” Although this early study within the field of physical anthropology is quite outdated, the use of cranial nonmetric traits to estimate ancestry was one of the first of its kind to do so.

Following Hooton, research testing cranial nonmetric traits diversified, and in the second half of the twentieth century researchers began utilizing the traits in accordance with other factors. Carpenter (1976) compared nonmetric variables to metric variables in order to determine how well they predict age, race and sex. A total of 317 crania were scored from the Terry Collection at the U.S. National Museum, which consists of American “blacks” and “whites” (Carpenter, 1976). Carpenter (1976) scored 12 metric variables and 15 nonmetric variables, scoring the latter as present or absent. In order to see what predictive power there are between the variables, Carpenter (1976) used a three-way MANOVA analysis. From this research, they found that metric variables are significant indicators of sex and “race”, but not for age (Carpenter, 1976). Nonmetric variables, on the other hand, are a significant indicator of age, but not sex and race (Carpenter, 1976). Finally, they found that nonmetric traits alone have little discriminatory value, and that researchers should continue to compile a list of nonmetric traits that are significant indicators of sex, race, and age (Carpenter, 1976).

Moving away from facial features, Napoli and Birkby (1990) studied the visibility of the oval window in the middle ear between “Mongoloid” (e.g., “American Indian”) and “non-Mongoloid” individuals. It is found that observing the oval window through the external auditory meatus is easier in “Caucasoid” and “Caucasoid/Mongoloid” admixed individuals compared to that of prehistoric “American Indian” crania (Napoli and Birkby, 1990). The sample representing the former was derived from forensic cases, and the sample representing the prehistoric “American Indian” was derived from a site in Arizona dated between 1280 and 1400 AD (Napoli and Birkby, 1990). It was found that there was complete visibility of the oval window in 94% of the “Caucasoid” sample compared to 69% of the admixed sample (Napoli and Birkby, 1990). Only 13% of the “American Indian” sample had complete visibility of the oval window, indicating that this trait may assist ancestry estimation when attempting to distinguish between the groups studied.

Following this study, Rhine (1990) conducted research to determine if anthropologists could assess “race” from nonmetric and metric cranial analyses in the late twentieth century (Rhine, 1990). They focused on four groups that accounted for the major “population strains” including Caucasoids, Mongoloids (Amerinds), Hispanics, and Blacks (Rhine’s terms). They utilized the traits found on the “Harvard List,” which was developed by E.A. Hooton (Rhine, 1990). Brues (1990) notes the issue with the subjective nature when collecting observational data. Utilizing the traits that are dichotomous by nature helps mitigate the subjectivity it is discussed in Brues (1990). Hooton, on the other hand, avoided this categorization, ultimately leaving out observation information. Most of these traits are nonmetric cranial traits and are “bipolar,” meaning they can differentiate between two of the groups. However, they cannot be used to distinguish among all of the groups (Rhine, 1990). From this research, they observed that there are certain nonmetric traits that are expressed in each “population strain.” The “Caucasoid” nasal aperture is supposedly narrow and has a deep sill with a long spine. “Mongoloids,” on the other hand, reportedly have a nasal aperture that is medium in width, a nasal sill that is burred, and a short spine (Rhine, 1990). It was also found that Hispanics show a combination of “Caucasoid” and “Mongoloid” cranial nonmetric traits (Rhine, 1990). Although these findings were a step in the area of estimating ancestry at the time, the use of the term “race” and the designated names for the “population strains” has changed over time. Furthermore, more research has been conducted on the variation of cranial nonmetric and metric analyses that have expanded upon Rhine’s (1990) research.

Bass (2005) pairs the descriptions of the cranial nonmetric traits with illustrations in order to aid in the development of techniques for estimating what they term “racial origin.” The groups are separated as “Caucasoid (White),” “Negroid (Black),” and “Mongoloid (American Indian)” (Bass, 2005). Each group is listed with a variation of the cranial nonmetric trait, such as nasal sill for “Caucasoid” and nasal guttering for “Negroid” (Bass, 2005). This form of nomenclature has, of course, been discontinued in all most all recently published biological anthropology publication. However, it is important to note the year in which this article occurred, and the time which had passed between then and the publication of Hooton’s Harvard List in the 1930s.

Following this study, Hefner (2009) observed nonmetric traits within a large sample of modern human skulls, focusing on 11 common traits from Rhine (1990) to illustrate that it is an experience-based approach. Each population was grouped according to geographic ancestry, which included African, Asian, European, and Native American. Hefner (2009) found that no single individual displayed all 11 expected traits following Rhine (1990), and that current trait lists for ancestry ignore variation within these populations. It was concluded that due to this trait expression within group variation, the use of nonmetric traits to estimate ancestry are not reliable on its own (Hefner, 2009). Furthermore, nonmetric traits should be analyzed within a statistical framework, including logistic regression, naïve Bayesian, and *k*-Nearest Neighbor (Hefner, 2009). Overall, Hefner (2009) re-examined the list of nonmetric traits used to assess ancestry at the time and emphasizes that each trait's growth and development must be understood in order to score it. This allows the observer to understand how and why these traits are expressed differently between populations (Hefner, 2009).

Hefner and Ousley (2014) were concerned with the lack of methods for objectively scoring morphoscopic, or nonmetric, traits. The objective was to examine the use of morphoscopic traits and explore eleven methods for classifying an unknown cranium into a reference group (Hefner and Ousley, 2014). A total of 718 adults from the National Museum of Natural History at the Smithsonian, the William M. Bass Donated Skeletal Collection, and the Pima County Office of the Medical Examiner were observed to document the morphoscopic traits (Hefner and Ousley, 2014). These individuals were selected due to the range of casework seen in forensic anthropology labs in the U.S., and to also document morphoscopic traits in a sample of Hispanic individuals. There has been little research conducted observing these traits in Hispanic individuals, which makes it all the more difficult to estimate ancestry. An important part of this study is that males and females were pooled for analysis (Hefner and Ousley, 2014). Hefner (2009) noted no differences in morphoscopic trait expression, with the exception of postbregmatic depression. Given this, most studies centered around the observation of morphoscopic trait analysis following Hefner (2009) have pooled males and females instead of separating them. Ultimately, Hefner and Ousley (2014) found that morphoscopic traits can be used successfully to assess ancestry without relying on just the experience of the observer. This can be done by utilizing various methods for classification, such as artificial neural networks (aNN), optimized summed scored attributes method (OSSA), support vector machines (SVM), and random forest models (RFM) (Hefner and Ousley, 2014).

Application in Forensic Anthropology

The biological profile is a crucial part of forensic anthropology when trying to identify an unknown individual. When working on a case, forensic anthropologists create these profiles to provide law enforcement with a description of the individual that could be used to match them to missing persons reports (Klales and Kenyhercz, 2015). One part of this profile is ancestry, and the goal of determining ancestry is simply to provide a prediction of the ancestry of the individual from either metric or nonmetric traits of the cranial and postcranial skeleton (Hefner, 2007). The two methods for determining ancestry differ in several factors. First, cranial nonmetric traits require the forensic anthropologist to have years of observer experience, and for them to fully understand human variation. This understanding can be accomplished by observing skeletal remains from various collections and from participating in numerous forensic cases. Due to the subjectivity of cranial nonmetric traits, however, some forensic anthropologists prefer the use of metric traits. These traits are measured using spreading and sliding calipers as compared to being measured with an ordinal scoring system, like nonmetric traits (DiGangi and Hefner, 2013). Also, the data is collected using sliding or spreading calipers, mandibulometers, or cranifor for a more precise estimation (DiGangi and Hefner, 2013). Furthermore, there are some advantages to using metric traits when estimating the ancestry of skeletal remains. This includes the use of FORDISC, which is a software that allows researchers to input their measurements into a database that will classify the unknown individual into an ancestral group (DiGangi and Hefner, 2013). With this software and database, forensic anthropologists do not need years of experience to take measurements on a skeleton.

Although there are many advantages to using metric traits, cranial nonmetric traits are still used by forensic anthropologists (Hefner, 2007). Cranial nonmetric traits are typically used more often for three reasons: they have a long-standing tradition in anthropological studies, they can still be observed on fragmented skeletal remains, and they can be scored with minimal difficulty as opposed to metric traits which require various instruments (Hefner, 2007). Even though they are the preferred traits when estimating ancestry, they were not standardized like metric traits for many years. Angel and Kelley (1990) studied the use of the inversion of the posterior edge of the ramus given that the mandible is a dense bone, it will most likely be present in a forensic case. This trait was scored as “absent,” “slight,” +, and ++ (Angel and Kelley, 1990). It was found that the posterior edge of the ramus differed between “Black” and “White” males, however, there was less difference between the females (Angel and Kelley, 1990).

Following this, Gill (1995) reported on newly developed methods for distinguishing “Whites” from “American Indians,” listing and describing the new traits. At the time, the quantification of the new traits (palate shape, transverse palatine suture, zygomaticomaxillary suture, and nasal bone shape) by population had not been done (Gill, 1995). It was found that the effectiveness of the new approaches for ancestry estimation during the skeletal identification process varies, however, they are useful in forensic contexts (Gill, 1995). Gill (1998) further addresses forensic anthropologists by noting the need to be aware of the advances in skeletal anatomy and the changing social meanings of “race.” A list of commonly used cranial nonmetric traits was compiled in order to attempt a standardization of the traits (Gill, 1998); however, the traits are still grouped by “geographic race.”

It was not until Hefner developed the Osteoware program, Nonmetrics, that biological anthropologists could score the traits on an ordinal scale instead of just as absent or present (Hefner, 2009). Hefner has been an important contributor to the use of cranial nonmetric traits with his development of the Nonmetrics Module, which describes 16 cranial nonmetric traits and their scoring system (Smithsonian Institution, 2011). Hefner and Linde (2018) published a book, *Atlas of Human Cranial Nonmetric Traits*, which describes 17 cranial nonmetric traits and details their use in the field of biological and forensic anthropology. Hefner has greatly improved the methodology of cranial nonmetric traits, and subsequently has improved the estimation of ancestry in forensic anthropology cases.

Although estimating ancestry is a crucial component when developing the biological profile for a forensic case, there is contention surrounding this application in legal contexts. Ancestry is said to be the most controversial of the biological profile, due to the dichotomy in the field of forensic anthropology with the use of the term "race" or ancestry (Klales and Kenyhercz, 2015). Most biological anthropologists consider race to be an arbitrary line of research and do not study human variation in a typological manner similar to that of physical anthropologists in the early twentieth century (Hefner, 2007). Although many biological anthropologists share this viewpoint, ancestry is still estimated in a forensic context. It is the duty of the forensic anthropologist to serve the medico-legal communities to which they have an obligation (Smay and Armelagos, 2000). To do this, the forensic anthropologist will estimate the "social race" of the individual. Social race is self-prescribed or socially determined by an individual in their lifetime and can be found on one's driver's license (Hefner, 2007). Essentially, it is the race in which the individual, whose remains are being analyzed, identified as when they were living. This is the "race" that will assist law enforcement officers in their investigation and help with identifying what individual the skeletal remains belong to. When using the term ancestry, on the other hand, the forensic anthropologist is describing the ethnic group in which the individual would have belonged to (Hefner, 2007). This is estimated through the observation of metric and nonmetric traits on the skeletal remains.

Many forensic anthropologists explicitly state that the skeletal identification of race does not have to do with whether or not races exit (Smay and Armelagos, 2000). Further, forensic anthropologists have a duty to the lay public and their students to educate them on human variation and its application to the estimation of ancestry in the biological profile (Smay and Armelagos, 2000). If people are not properly educated on the use of cranial nonmetric traits and why they vary between populations, then they will not understand how these traits assist in determining the potential ancestry of an unknown individual in a forensic context.

Sexual Dimorphism of Cranial Nonmetric Traits

Observing sexual dimorphism within nonmetric traits has only been conducted within the last ten years. One such study was conducted by Klales and Kenyhercz (2015) who examined the utility of the 16 nonmetric traits, which were presented by Hefner (2009) and Osteoware for assessing ancestry. They state that researchers, such as Hefner and Ousley (2014), note that skeletal nonmetric traits that are used to estimate ancestry are not unique to specific groups, but occur in all groups with different frequencies (Klales and Kenyhercz, 2015). Using the cranial nonmetric traits Hefner collected data on, Klales and Kenyhercz (2015) put them into a statistical framework for classification purposes. Scoring a total of 208 crania from the Hamann-Todd Osteological Collection, the authors separated the crania into four groups based on sex and ancestry: white females and white males; black females and black males (Klales and Kenyhercz, 2014). Three observers were used to score the 16 traits on the crania, each with various background knowledge of the traits and educations regarding osteology. In order to calculate the classification accuracies, a two-way analysis was used for the pooled sex groups, while a four-way analysis was used for the separate male and female groups (Klales and Kenyhercz, 2014). These analyses were done for each statistical method that was used in order to determine if there is a difference in classification based on the grouping of males and females. Ultimately, Klales and Kenyhercz (2014) found that there is a range of variation seen in trait expression, which supports Hefner's statement that trait lists for ancestry ignore variation within groups. Furthermore, the classification accuracies for the two-way analyses ranged from 73.3% to 88.6%, while the four-way analyses ranged from 46.7% to 60.4% (Klales and Kenyhercz, 2014). This suggests that pooling males and females together could result in a more accurate ancestry assessment.

Brasili (1999) examined cranial nonmetric traits and their use in order to understand variation in human populations. Several problems were addressed with this method, one being that there is a lack of agreement between authors on the importance of sex differences (Brasili, 1999). It is stated that many researchers believe that when studying cranial nonmetric traits, the sexes must be kept separate instead of pooling (Brasili, 1999). The other problems that are addressed is that of age and whether asymmetries of expression of bilateral traits should be considered. The authors examined the skulls of three samples of Sardinian adults exhumed in the early 1900s, and scored 18 cranial nonmetric traits (Brasili, 1999). The sexes were analyzed separately, individuals older than 70 years were excluded, and both sides of the skull were scored for bilateral traits (Brasili, 1999). The authors found that, overall, age does not influence the frequency of the cranial nonmetric traits, and that side differences in the skull could provide important information about environmental influences (Brasili, 1999). Furthermore, the authors found that there were differences in frequency of cranial nonmetric traits between the sexes in two of the Sardinian samples. Overall, the research conducted by Brasili (1999) supplies further knowledge about variations in cranial nonmetric traits in relation to that of sex, age and laterality.

Tallman (2016) observed nonmetric sexual dimorphism along with cranial nonmetric variation in over one thousand Japanese and Thai individuals. One objective established 37 cranial and mandibular trait frequencies in order to discern if the Japanese and Thai populations differ from one another, and from the Native American populations (Tallman, 2016). Through this research, it was found that various factors affect nonmetric traits and the way they are utilized when assessing ancestry. One of these factors is sex, which has not been expanded upon in other studies. However, when sex was included in binary logistic regression equations, it failed to contribute to classification accuracies. This implies that sex does not significantly impact nonmetric trait expression in Japanese and Thai individuals, specifically. On the other hand, it also does not suggest that sex would not impact nonmetric trait expression in individuals from other groups, such as European Americans.

Overall, the studies referenced have demonstrated that further research is needed in order to have a better understanding of the effects of sex on ancestral cranial nonmetric traits. The authors have explained that although nonmetric traits by themselves may not be as effective when estimating ancestry in a forensic context, developing a better method to observe them could potentially increase the accuracy in the long run. Thus, observing factors, such as sex, that could affect the expression of cranial and mandibular nonmetric traits, is one area to begin this research. Given the findings in Tallman (2016) on how sex, along with other factors, affect nonmetric traits in Japanese and Thai individuals, it leads to the question on whether a difference can be found in ancestral cranial nonmetric traits between European American males and females.

CHAPTER 3: MATERIALS AND METHODS

This chapter presents the materials and methods that were utilized in the present study. First, the skeletal sample that was observed for the purpose of the study will be discussed in further detail, specifically explaining the demographics and where the sample originates. Following this, the nonmetric traits that were scored using the skeletal sample will be discussed. These traits, which are based on Hefner and Linde's (2018) cranial morphoscopic traits and Berg's (2008) mandibular morphoscopic traits, were scored utilizing an ordinal scoring method. Finally, the statistical analyses, which were used to analyze the data obtained from the research will be discussed. The statistical analyses utilized were chi-square test of independence, contingency table plots, and Cohen's Kappa to test for intraobserver error. Chi-square tests were used in order to determine significant relationships between each of the nonmetric traits and sex. One-dimensional Principal Component Analysis (PCA) plots, which are the underlying rationale behind correspondence analysis, were generated in order to illustrate the variation between the ordinal scores, and males and females for the traits that were found to have a significant relationship with sex. The results of these analyses will be presented in Chapter 4 and discussed in further detail in Chapter 5.

Skeletal Sample

The data were collected at Texas State University in San Marcos, Texas using the donated skeletal collection at the Grady Early Building. This collection consists of more than 200 modern European Americans who were donated to the collection for research purposes and are represented both cranially and postcranially. Demographic histories of the individuals are known; thus, researchers can access antemortem information during and subsequent to data collection. Each individual was initially processed at the Osteology Research and Processing Laboratory (ORPL) and then at the Forensic Anthropology Research Facility (FARF) in San Marcos, Texas, which is a 26-acre outdoor human decomposition research laboratory at Texas State's Freeman Ranch. There, research is conducted in relation to time since death, the postmortem interval, and decomposition processes for human remains under various climate conditions. In total, 210 individuals (M=113; F=97) were observed using Hefner and Linde's (2018) method for scoring cranial nonmetric traits, and Berg's (2008) method for scoring mandibular nonmetric traits.

Morphoscopic Traits

Morphoscopic traits are variables of the cranium, sometimes reflected as soft-tissue differences, that are subsequently divided into five different classes: bone shape, bony feature morphology, suture shape, trait presence or absence, and feature prominence or protrusion (Hefner and Linde, 2018). These traits are occasionally used to estimate ancestry, or population affiliation, in order to identify an individual in a forensic context; however, limited methods for utilizing nonmetric traits exist.

This study examines 17 morphoscopic traits of the cranium and six morphoscopic traits of the mandible following Hefner and Linde (2018) and Berg (2008). Both the left and right sides were scored for traits that are observed on both sides of the cranium and mandible. Each trait is given an ordinal score that correlates to the observer's observation of said trait. The morphoscopic traits and their scoring categories are described in Table 3.1.

Table 3.1: Nonmetric traits used for forensic ancestry assessment following Hefner and Linde (2018); mandibular morphoscopic traits following Berg (2008).

TRAIT	ORDINAL SCORING SYSTEM	SOURCE
Inferior Nasal Aperture (INA)	1 – marked slope; 2 – moderate slope; 3 – abrupt; 4 – weak sill; 5 – pronounced sill	Hefner and Linde (2018)
Interorbital Breadth (IOB)	1 – narrow; 2 – medium; 3 – broad	Hefner and Linde (2018)
Malar Tubercle (MTh)	0 – no projection; 1 – trace; 2 – medium; 3 – pronounced	Hefner and Linde (2018)
Nasal Aperture Shape (NAS)	1 – teardrop; 2 – bell; 3 – bowed	Hefner and Linde (2018)
Nasal Aperture Width (NAW)	1 – narrow; 2 – intermediate; 3 – broad	Hefner and Linde (2018)
Nasal Bone Contour (NBC)	0 – low & rounded; 1 – oval; 2 – broad plateau; 3 – narrow plateau; 4 – triangular	Hefner and Linde (2018)
Nasal Bone Shape (NBS)	1 – straight; 2 – superior pinch; 3 – lateral bulge; 4 – triangular	Hefner and Linde (2018)
Posterior Zygomatic Tubercle (PZT)	0 – absent; 1 – weak; 2 – moderate; 3 –marked	Hefner and Linde (2018)
Nasofrontal Suture	1 – round; 2 – square; 3 – triangular; 4 – irregular	Hefner and Linde (2018)
Orbital Shape (OBS)	1 – rectangular; 2 – circular; 3 – rhombic	Hefner and Linde (2018)
Supranasal Suture (SPS)	0 – obliterated; 1 – unfused; 2 – closed but visible	Hefner and Linde (2018)

Zygomaticomaxillary Suture (ZS)	0 – no angles; 1 – one angle; 2 – two or more angles	Hefner and Linde (2018)
Anterior Nasal Spine (ANS)	1 – slight; 2 – intermediate; 3 – marked	Hefner and Linde (2018)
Nasal Overgrowth	0 – absent; 1 – present	Hefner and Linde (2018)
Postbregmatic Depression	0 – absent; 1 – present	Hefner and Linde (2018)
Palate Shape (PS)	1 – elliptical; 2 – parabolic A; 3 – parabolic B; 4 – hyperbolic	Hefner and Linde (2018)
Transverse Palatine Suture (TPS)	1 – straight; 2 – anterior bulging; 3 – M-shaped; 4 – posterior bulging	Hefner and Linde (2018)
Chin Shape (CS)	1 – blunt; 2 – pointed; 3 – square; 4 – bilobate	Berg (2008)
Lower Border of the Mandible (LBM)	1 – straight; 2 – undulating; 3 – partial rocker; 4 – rocker	Berg (2008)
Ascending Ramus Shape (ARS)	1 – pinched; 2 – wide	Berg (2008)
Gonial Angle Flare (GAF)	0 – absent; 1 – inverted; 2 – slight; 3 – medium; 4 – everted;	Berg (2008)
Mandibular Torus (MTb)	0 – absent; 1 – present	Berg (2008)
Posterior Ramus Edge Inversion (PREI)	0 – absent; 1 – slight; 2 – medium; 3 – turned	Berg (2008)

Data Collection

The observed skeletons were chosen based on the state of the mandible and overall structure of the facial bones. Those with highly resorbed alveoli on either the mandible or maxilla were subsequently not used. This would not allow for the scoring of several traits including mandibular tori and palate shape, and therefore were scored as

"NA." Furthermore, the skeletons varied in age where males ranged age 21-95 years and females ranged age 21-102 years. However, age was not accounted for in this study.

The 97 females were scored first, because the first individual in the collection is female. Each trait was scored visually using the associated ordinal scoring system and associated diagrams, while the nasal bone contour trait was scored using a contour gauge to better asses the shape of the nasal bones. Following this, the 113 males were scored. Similar to the female individuals, the traits were scored visually by the observer, while the nasal bone contour trait was scored using a contour gauge.

Lastly, the data were entered into Excel spreadsheets, one for female European Americans and one for male European Americans. On two occasions separated by a two-week period, intraobserver data was collected on 10% of the crania and mandibles for both males (n=11) and females (n=10), as documented in Hefner (2009). These skeletons were randomly selected from the list of donated skeletons originally observed.

Statistical Analysis

Excel spreadsheets were subsequently combined into one file and imported into the statistical software package RStudio (version 1.1.463), which is an integrated developer environment (IDR) for R that combines R and other programming languages (Gandrud, 2016). Each of the 23 numeric variables, or morphoscopic traits, were changed to integer variables in order to indicate the levels within each variable. These levels are the ordinal scores that were given to each trait initially when data was collected from the 210 individuals. Given that the morphoscopic mandibular traits from Berg (2008) were not given ordinal scores similar to Hefner and Linde (2018), they had to be changed. These six variables were subsequently made into categorical variables that would take on numeric values (Table 3.2). This allowed for all of the data to be comparable.

Chi-Square Analyses

Chi-square tests were used to determine if there were statistically significant morphoscopic trait expression differences between the European American male and female skeletons analyzed in this study. A Chi-square test of independence, or the Pearson Chi-square test, is a common statistic used when testing hypotheses that involve nominal variables (McHugh, 2013). What is unique about the Chi-square is that it can provide information on the significance of any observed differences as well as information on exactly which categories account for said differences (McHugh, 2013). For this study, a Chi-square test of independence was conducted in RStudio for each morphoscopic trait in order to identify the significance it has with sex, the null hypothesis being that there is no relationship between the morphoscopic traits and sex while the alternative hypothesis is that there is a relationship between the morphoscopic traits and sex. From this, a mosaic plot was created for each morphoscopic trait in order to better illustrate the variation in ordinal scores per males and females.

Correspondence Analyses

Subsequently, correspondence analyses (CA) was used to analyze the relationship between each morphoscopic trait that is found to have a significant relationship (p-value < 0.05), and both sexes. A correspondence analysis was used as a method of data visualization that is applicable to data where values are relative to one another

(Greencare, 2010). This analysis was visualized in correspondence analyses plots for both European American males and females. To utilize a correspondence analysis, the data must be on the same scale, such as tables of counts (Greencare, 2010). The plots generated are a multidimensional graphic display of points illustrating the spatial distance between the categorical variables from the original dataset (Greencare, 2010). These points represent vectors that are of relative values in rows or in columns, which are relative to their margins (Greencare, 2010). However, given that there are only two variables (males and females) for one of the axes, a multidimensional plot could not be generated. Instead, a one-dimensional PCA plot was generated for each of the significant traits with a diagonal line reaching from 100% males to 100% females. These are the underlying rational behind correspondence analysis, which occurs in higher dimensions. The variables to be displayed for each morphoscopic trait, found to have a significant relationship with sex, will be males and females as well as each ordinal score for a specific morphoscopic trait. The plots will visualize, by the location of the scores on the male/female spectrum, which ordinal score for each morphoscopic trait European American males and females are more likely to be associated with.

Each PCA plot will display the *p*-value, chi-square value, and the Cramer's V correlation for the trait. Cramer's V correlation is an alternative to Phi, which is a measure for the strength of an association between two categorical variables in a 2x2 contingency table (Akoglu, 2018). Cramer's V is used for tables that are bigger than 2x2 tabulation, and the interpretation ranges from very weak (> 0) to very strong (> 0.25) (Akoglu, 2018). With these variables, and the location of the ordinal scores in relation to males and females, the plots illustrate, in detail, the traits that are found to be sexually dimorphic.

Intraobserver Error

Finally, intraobserver error was examined with Cohen's Kappa in RStudio, which is a form of an observer agreement for categorical data that expresses the quantities which reflect the extent to which the observers agree among themselves (Landis and Koch, 1977). This was conducted in a two-week period, for both males (n=11) and females (n=10), while data was initially being collected in order to test for the reliability of the researcher's observations. The strength of the agreement is categorized into six groups: poor, when the estimate is less than 0; slight, when the estimate is 0-0.20; fair, when the estimate is 0.21-0.40; moderate, when the estimate is 0.41-0.60; substantial, when the estimate is 0.61-0.80; and almost perfect, when the estimate is 0.81-1.00 (Landis and Koch, 1977). The strength of the agreement will ultimately determine the reliability of the morphoscopic trait when used to estimate ancestry.

CHAPTER 4: RESULTS

This chapter presents the results of the statistical analyses that were conducted on the cranial and mandibular morphoscopic traits for European American males and females. The chi-square analyses and correspondence analyses indicate that 14 of the 23 nonmetric traits observed are statistically significant, and thus are affected by the sex of the individual. One-dimensional Principal Component Analysis (PCA) plots were subsequently generated for these 14 traits to better illustrate the variation between the ordinal scores per trait and sex. The interpretation for each of the trait's Cramer's V correlation ranges from strong to very strong indicating that the strength of association between the trait and sex is quite high, thus illustrating sexual dimorphism. The intraobserver error indicates that 13 of the 23 nonmetric traits were found to have "substantial" or "almost perfect" agreement when rescored, while the remaining 10 nonmetric traits were found to have "fair" to "moderate" agreement (Landis and Koch, 1977). The results from the chi-square analyses, contingency table plots, and intraobserver error will be discussed in further detail in the following chapter.

Chi-Square Analysis

Chi-square tests for independence were conducted for the traits. Each trait was tested to determine if it has a significant relationship with sex within the skeletal sample. After each chi-square test was conducted, the expected and observed values were also calculated. If there were less than five individuals for both males and females for an ordinal score within a trait for the observed values, those individuals were absorbed into the following ordinal score in order to give a better representation of the overall relationship between that trait and sex, if applicable. Following this, mosaic plots were created in order to better illustrate the observed values. Figures A.1 – A.23, which illustrate the frequency of each ordinal score per male and female per trait in a mosaic plot, are found in the Appendix.

After the chi-square tests for independence were conducted, it was found that 14 out of the 23 nonmetric traits have a significant relationship with sex, with a *p*-value less than 0.05. These traits are ANS, INA, NAS, NBC, NBS, OBS, PS, PZT, SPS, CS, LBM, ARS, GAF, and PREI. Tables 4.1 – 4.23 include the *p*-values as well as the expected values per ordinal score per trait for both males and females.

Table 4.1: ANS frequencies for males and females.

	Males			**Females**	
Score	**n**	**%**		**n**	**%**
1	4	3.77		3	3.23
2	38	45.73		47	39.26
3	71	63.50		47	54.50
$X^2 = 4.3834$		df = 2	p = 0.03629		

Table 4.2: INA frequencies for males and females.

	Males			Females	
Score	**n**	**%**		**n**	**%**
1	2	1.08		0	0.92
2	7	9.69		11	8.31
3	29	35.51		37	30.49
4	32	33.9		31	29.1
5	43	32.82		18	28.18
X^2 = 10.272		df = 4	p = 0.01639		

Table 4.3: IOB frequencies for males and females.

	Males			Females	
Score	**n**	**%**		**n**	**%**
1	103	100.62		84	86.38
2	10	12.38		13	10.62
X^2 = 0.6915		df = 1	p = 0.4057		

* ordinal score 3 was not scored within this sample

Table 4.4: MTh frequencies for males and females.

	Males			Females	
Score	**n**	**%**		**n**	**%**
0	48	46.81		39	40.19
1	56	60.80		57	52.20
2	9	5.38		1	4.62
X^2 = 0.11101		df = 2	p = 0.739		

* ordinal score 3 was not scored within this sample

Table 4.5: NAS frequencies for males and females.

	Males		**Females**	
Score	**n**	**%**	**n**	**%**
1	64	73.72	73	63.28
2	40	30.67	17	26.33
3	9	8.61	7	7.39
$X^2 = 8.9549$		df = 2	p = 0.01136	

Table 4.6: NAW frequencies for males and females.

	Males		**Females**	
Score	**n**	**%**	**n**	**%**
1	109	107.62	91	92.38
2	4	5.38	6	4.62
$X^2 = 0.32786$		df = 1	p = 0.5669	

* ordinal score 3 was not scored within this sample

Table 4.7: NBC frequencies for males and females.

	Males		**Females**	
Score	**n**	**%**	**n**	**%**
0	0	1.61	3	1.39
1	37	43.05	43	36.95
2	14	9.69	4	8.31
3	49	43.05	31	36.95
4	13	15.60	16	13.40
$X^2 = 9.7292$		df = 4	p = 0.02101	

Table 4.8: NBS frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
1	6	11.30	15	9.70
2	56	65.11	65	55.89
3	43	30.13	13	25.87
4	8	6.46	4	5.43
$X^2 = 20.833$		df = 3	p = 0.000114	

Table 4.9: NO frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
0	47	53.53	52	45.47
1	66	59.47	44	50.53
$X^2 = 2.8065$		df = 1	p = 0.09388	

Table 4.10: NFS frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
1	77	68.88	51	59.12
2	10	12.91	14	11.09
3	12	14.53	15	12.47
4	14	16.68	17	14.32
$X^2 = 5.3838$		df = 3	p = 0.1458	

Table 4.11: OBS frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
1	44	55.42	59	47.58
2	1	1.08	1	0.92
3	68	56.50	37	48.50
$X^2 = 9.2986$		df = 2	p = 0.002293	

Table 4.12: PS frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
1	19	31.21	39	26.79
2	57	49.50	35	42.50
3	23	20.99	16	18.01
4	14	11.30	7	9.70
$X^2 = 14.613$		df = 3	p = 0.002179	

Table 4.13: PBD frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
0	89	84.48	68	72.52
1	24	28.52	29	24.48
$X^2 = 1.6401$		df = 1	p = 0.2003	

Table 4.14: PZT frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
0	12	16.68	19	14.32
1	36	45.20	48	38.80
2	40	36.59	28	31.41
3	24	13.99	2	12.01

$X^2 = 23.925$ df = 4 p = 0.0000259

Table 4.15: SPS frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
0	5	10.76	15	9.24
1	27	22.06	14	18.94
2	80	79.64	68	63.36

$X^2 = 9.0899$ df = 3 p = 0.01062

Table 4.16: TPS frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
1	41	45.63	43	38.37
2	51	46.72	35	39.28
3	14	12.50	9	10.50
4	7	8.15	8	6.85

$X^2 = 2.6401$ df = 3 p = 0.4505

Table 4.17: ZS frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
0	37	36.05	30	30.95
1	67	66.72	57	57.28
2	9	10.22	10	8.78
$X^2 = 0.37355$		df = 2	p = 0.8296	

Table 4.18: CS frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
1	43	58.11	65	49.89
2	0	3.23	6	2.77
3	58	43.59	23	37.41
4	12	8.07	3	6.93
$X^2 = 22.899$		df = 3	p = 0.00001066	

Table 4.19: LBM frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
1	21	25.29	26	21.71
2	79	68.34	48	58.66
3	13	19.37	23	16.63
$X^2 = 9.714$		df = 2	p = 0.007774	

*ordinal score 4 was not scored within this sample

Table 4.20: ARS frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
1	82	68.34	45	58.66
2	31	44.66	52	38.34
$X^2 = 13.886$		df = 1	p = 0.0001943	

Table 4.21: GAF frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
0	7	14.53	20	12.47
1	14	26.37	35	22.63
2	29	34.44	35	29.56
3	31	20.45	7	17.55
4	32	17.22	0	14.78
$X^2 = 62.121$		df = 4	p = 1.039e-12	

Table 4.22: MTb frequencies for males and females.

	Males		Females	
Score	**n**	**%**	**n**	**%**
0	59	63.66	58	53.34
1	52	47.34	35	39.66
$X^2 = 1.3994$		df = 1	p = 0.2368	

Table 4.23: PREI frequencies for males and females.

	Males			Females	
Score	**n**	**%**		**n**	**%**
0	99	87.17		63	74.83
1	11	20.99		28	18.01
2	3	4.30		5	3.70
3	0	0.54		1	0.46
X^2 = 15.28		df = 3	p = 0.0004809		

Correspondence Analysis

One-dimensional PCA plots were generated in order to visualize which ordinal scores for the statistically significant traits were more closely linked with males and females. Along each spectrum within the plots, the ordinal score's location is determined by the number of times it was scored on a male or female. The location will thus be either closer to 1.0 for the male percentage or closer to 1.0 for the female percentage. Some of the following traits had ordinal scores that were only scored a few times (< 5) throughout the sample, resulting in those scores being absorbed into the next in order to give a better representation of the overall relationship. However, the original *p*-value will be displayed on the plots, but the only trait whose *p*-value changed drastically from insignificant to significant was ANS. Each morphoscopic trait's ordinal scores will be discussed along with their *p*-value and Cramer's V correlation (Akoglu, 2018), followed by each of their corresponding plots below (Figures 4.1 – 4.14).

One-Dimensional Principle Component Analysis Plots

Morphoscopic trait ANS has a *p*-value of 0.03629 after the individuals who were scored as a 1 were absorbed into the next score in order to give a better representation of the overall relationship. This indicates that this trait is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 3 (“marked”) is more closely associated with males, and a score of 2 (“intermediate”) is more closely associated with females. A score of 1 was not recorded as often within the sample, and thus there was little difference between sexes. Furthermore, the Cramer’s V correlation is 0.151, which is indicative of a strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait INA has a *p*-value of 0.01639, indicating that it is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 5 (“pronounced sill”) and 1 (“marked slope”) are more closely associated with males, and a score of 4 (“weak sill”), 3 (“abrupt”), and 2 (“moderate slope”) are more closely associated with females. Furthermore, the Cramer’s V correlation is 0.2486, which indicative of a strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait NAS has a *p*-value of 0.01136, indicating that it is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 3 (“bowed”) and 2 (“bell”) are more closely associated with males, while a score of 1 (“teardrop”) is more closely associated with females.

Furthermore, the Cramer's V correlation is 0.2065, which is indicative of a strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait NBC has a *p*-value of 0.02101, after the individuals who were scored as a 0 were absorbed into the next score in order to give a better representation of the overall relationship. This indicates that this trait is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 3 ("narrow plateau") and 2 ("broad plateau") are more closely associated with males, while a score of 4 ("triangular"), 1 ("oval") and 0 ("low and rounded") are more closely associated with females. Furthermore, the Cramer's V correlation is 0.2412, which is indicative of a strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait NBS has a *p*-value of 0.00011, indicating that it is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 4 ("triangular") and 3 ("lateral bulge") are more closely associated with males, while a score of 2 ("superior pinch") and 1 ("straight") are more closely associated with females. Furthermore, the Cramer's V correlation is 0.3369, which is indicative of a very strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait OBS has a *p*-value of 0.00229 after the individuals who were scored as a 2 were absorbed into the next score in order to give a better representation of the overall relationship. This indicates that this trait is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 3 ("rhombic") is more closely associated with males, while a score of 2 ("circular") and 1 ("rectangular") are more closely associated with females. Furthermore, the Cramer's V correlation is 0.2201, which is indicative of a strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait PS has a *p*-value of 0.00217, indicating that it is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 4 ("posterior bulging"), 3 ("parabolic B"), and 2 ("parabolic A") are more closely associated with males, while a score of 1 ("elliptical") is more closely associated with females. Furthermore, the Cramer's V correlation is 0.2638, which is indicative of a very strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait PZT has a *p*-value of 0.00002, after the individuals who were scored as a 4 were absorbed into the next score in order to give a better representation of the overall relationship. This indicates that this trait is found to have a statistically significant relationship with sex. With the ordinal score broken down, it was found that a score of 3 ("marked") and 2 ("moderate") are closely associated with males, while a score of 1 ("weak") and 0 ("absent") are more closely associated with females. Furthermore, the Cramer's V correlation is 0.3377, which is indicative of a very strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait SPS has a *p*-value of 0.01062, after the individuals who were scored as a 3 were absorbed into the next score in order to give a better representation of the overall relationship. This indicates that this trait is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 2 ("closed but visible") and 1 ("unfused") are more closely associated with males, while a score of 0 ("obliterated") is more closely associated with females.

Furthermore, the Cramer’s V correlation is 0.2175, which is indicative of a strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait CS has a *p*-value 0.00001, indicating that it is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 4 (“bilobate”), and 3(“square”) are more closely associated with males, while a score of 2 (“pointed”), and 1 (“blunt”) are more closely associated with females. Furthermore, the Cramer’s V correlation is 0.3777, which is indicative of a very strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait LBM has a *p*-value of 0.00777, indicating that it is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 2 (“undulating”) is more closely associated with males, while a score of 3 (“partial rocker”) and 1 (“straight”) are more closely associated with females. Furthermore, the Cramer’s V correlation is 0.2151, which is indicative of a strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait ARS has a *p*-value of 0.00019, indicating that it is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 1 (“pinched”) is more closely associated with males, while a score of 2 (“wide”) is more closely associated with females. Furthermore, the Cramer’s V correlation is a 0.2668, which is indicative of a very strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait GAF has a *p*-value of 1.039e-12, indicating that it is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 4 (“everted”) and 3 (“medium”) are more closely associated with males, while a score of 2 (“slight”), 1 (“inverted”), and 0 (“absent”) are more closely associated with females. Furthermore, the Cramer’s V correlation is 0.5439, which is indicative of a very strong association (Akoglu, 2018) between this trait and sex.

Morphoscopic trait PREI has a *p*-value of 0.00048, after the individuals who were scored as a 3 were absorbed into the next score in order to give a better representation of the overall relationship. This indicates that this trait is found to have a statistically significant relationship with sex. With the ordinal scores broken down, it was found that a score of 0 (“absent”) is more closely associated with males, while a score of 1 (“slight”), 2 (“medium”), and 3 (“turned”) are more closely associated with females. Furthermore, the Cramer’s V correlation is 0.2741, which is indicative of a very strong association (Akoglu, 2018) between this trait and sex.

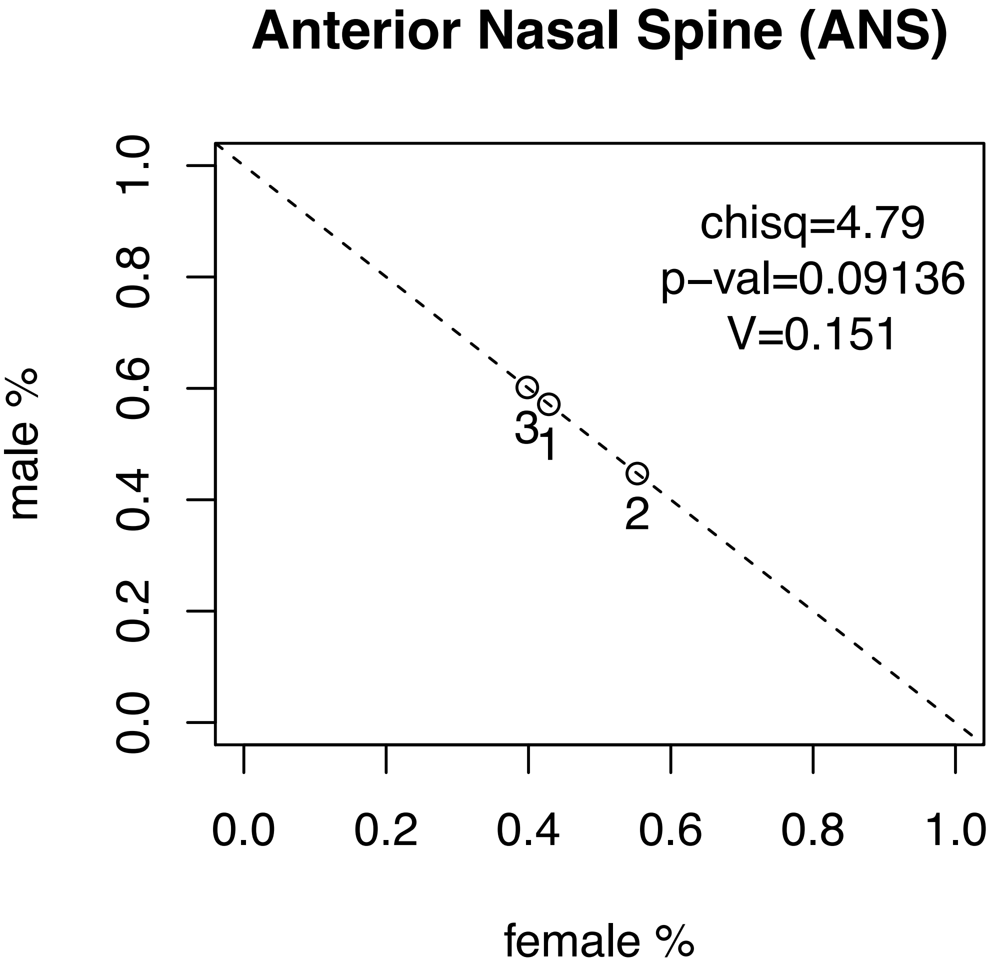

Figure 4.1. One-dimensional plot for ANS and sex.

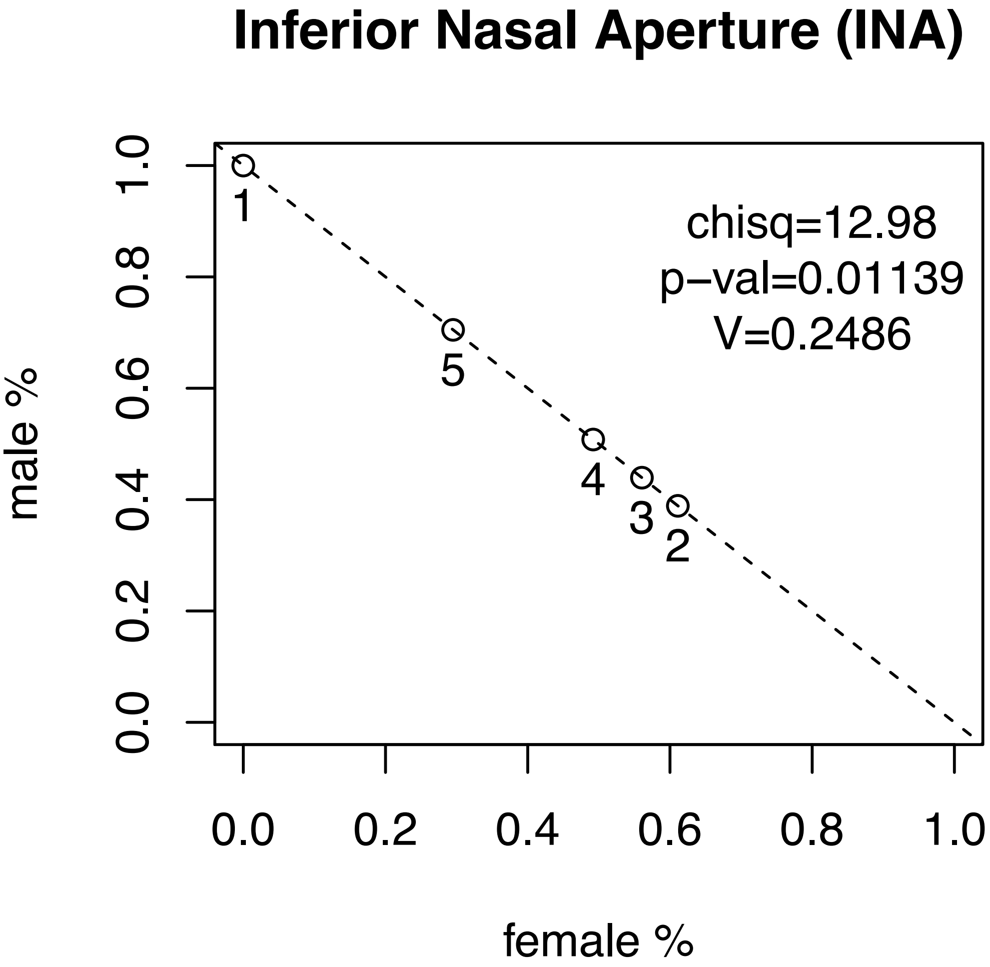

Figure 4.2. One-dimensional plot for INA and sex.

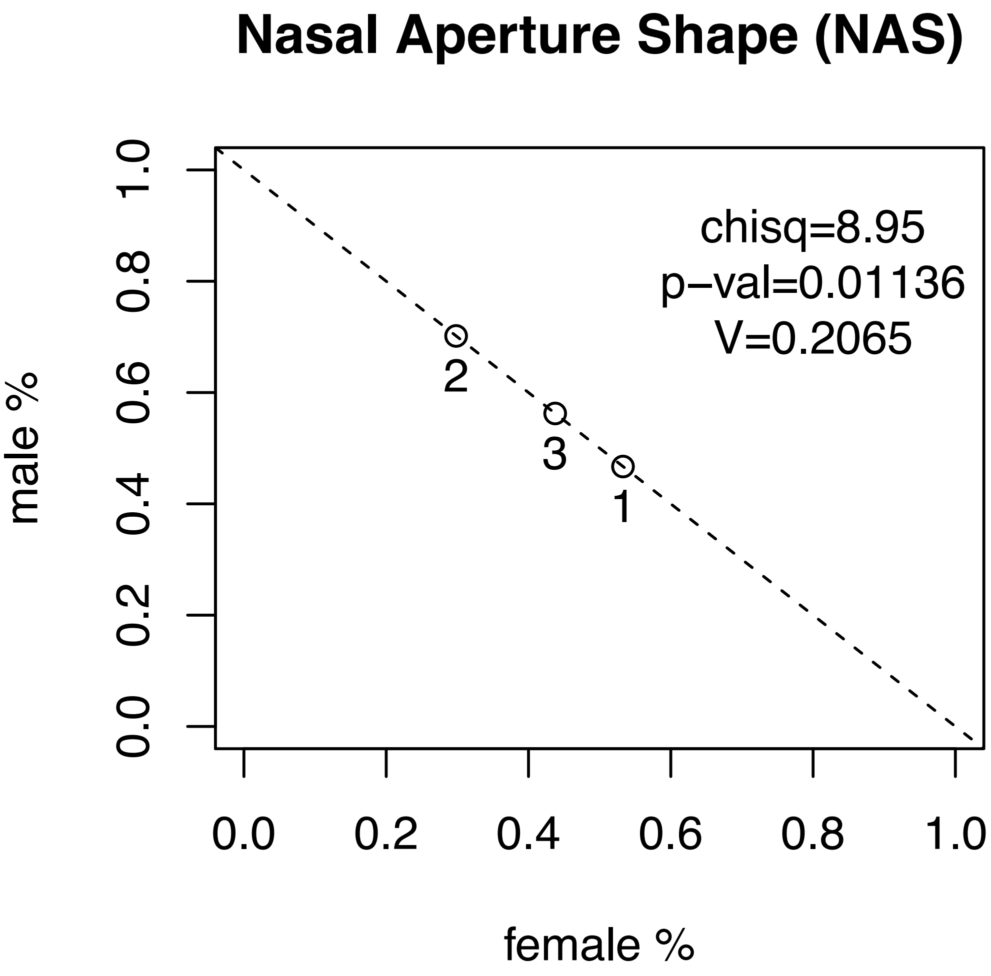

Figure 4.3. One-dimensional plot for NAS and sex.

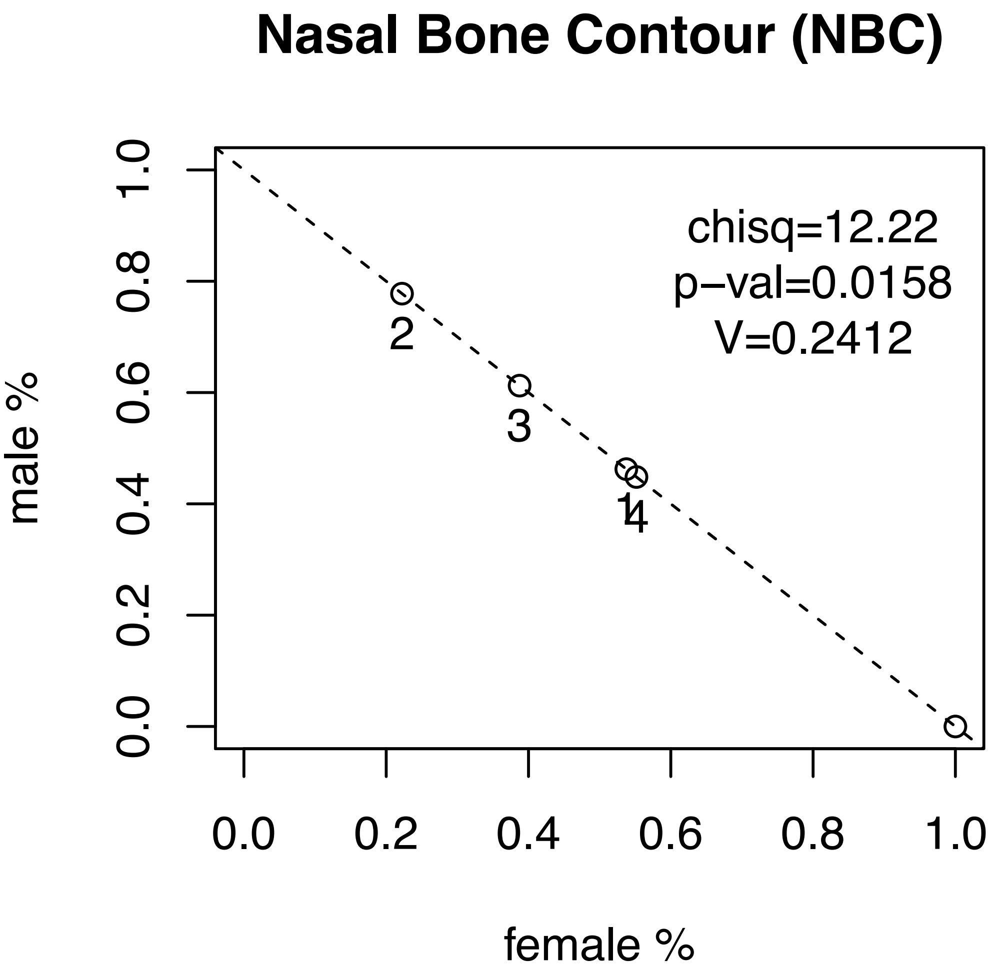

Figure 4.4. One-dimensional plot for NBC and sex.

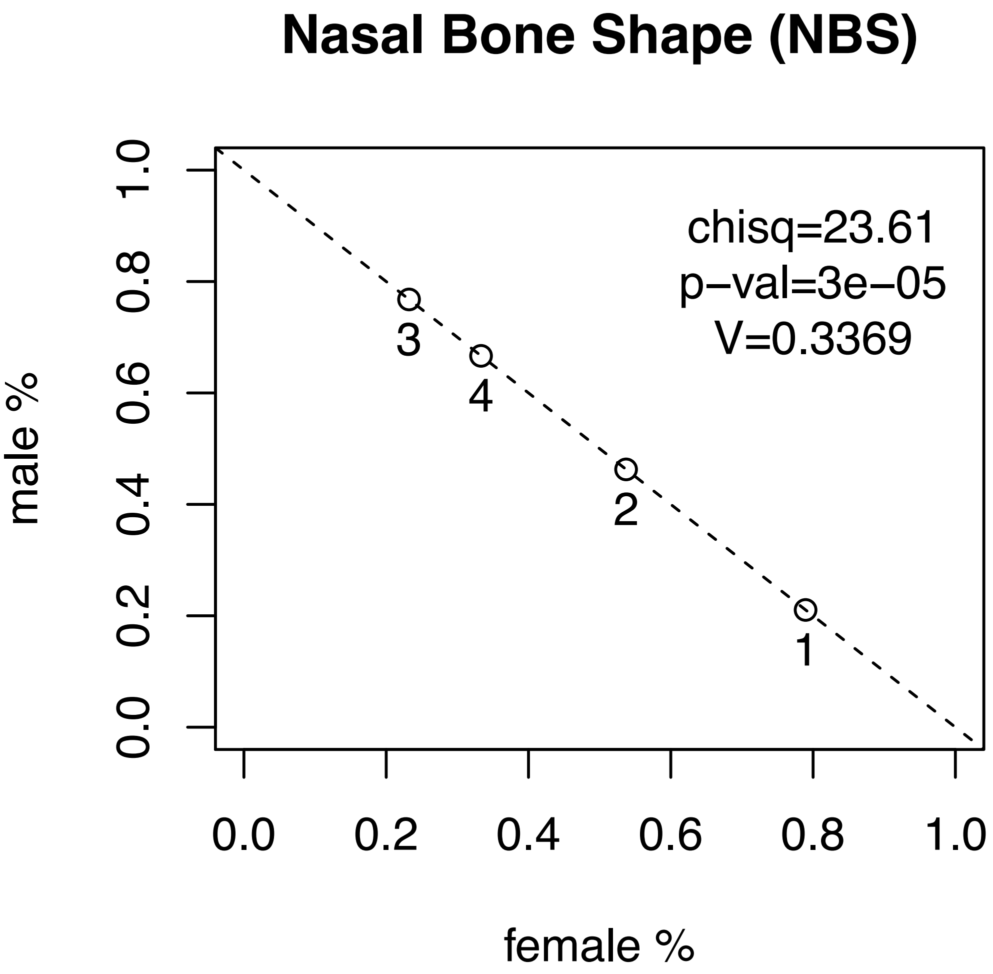

Figure 4.5. One-dimensional plot for NBS and sex.

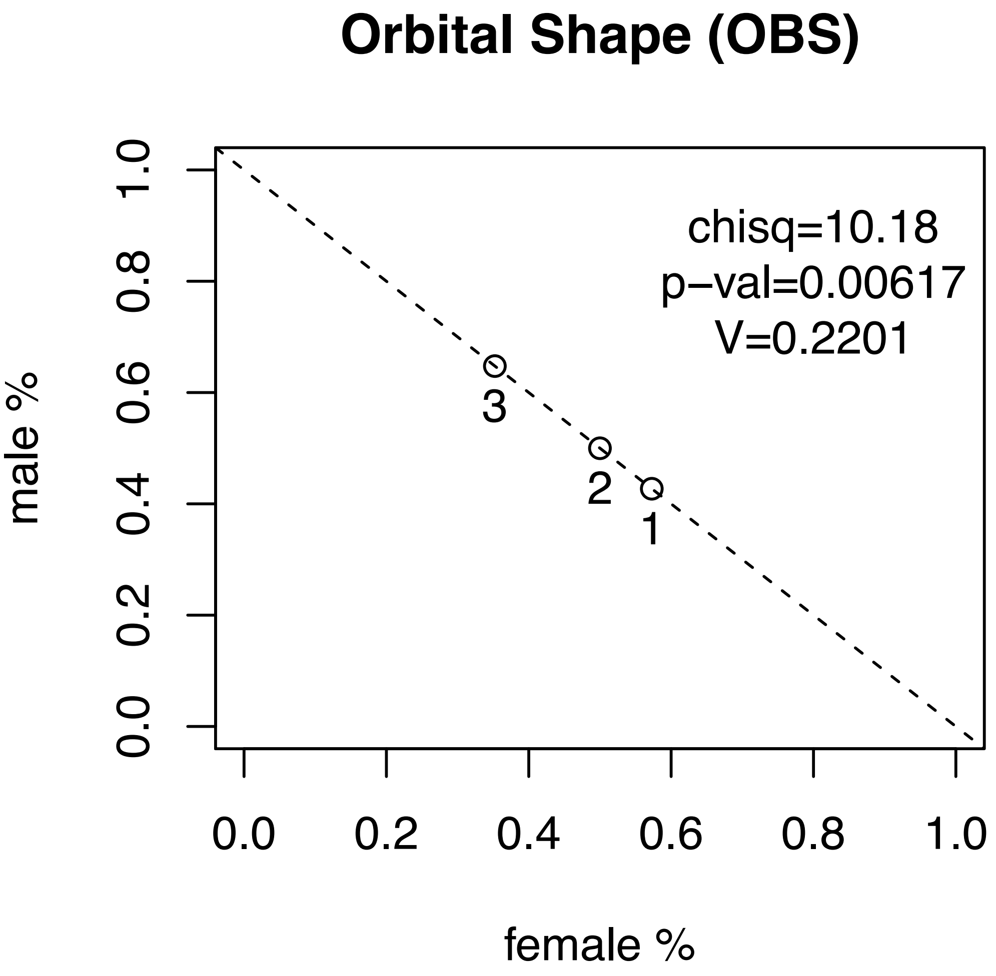

Figure 4.6. One-dimensional plot for OBS and sex.

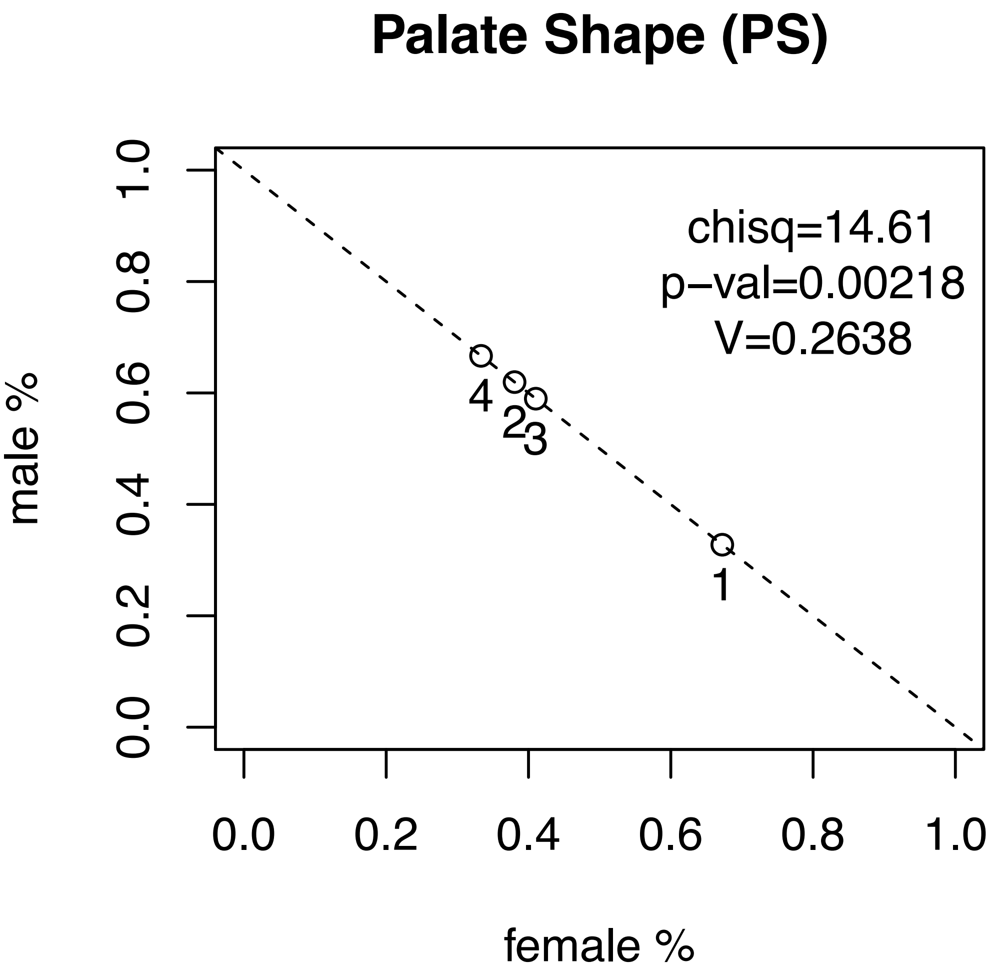

Figure 4.7. One-dimensional plot for PS and sex.

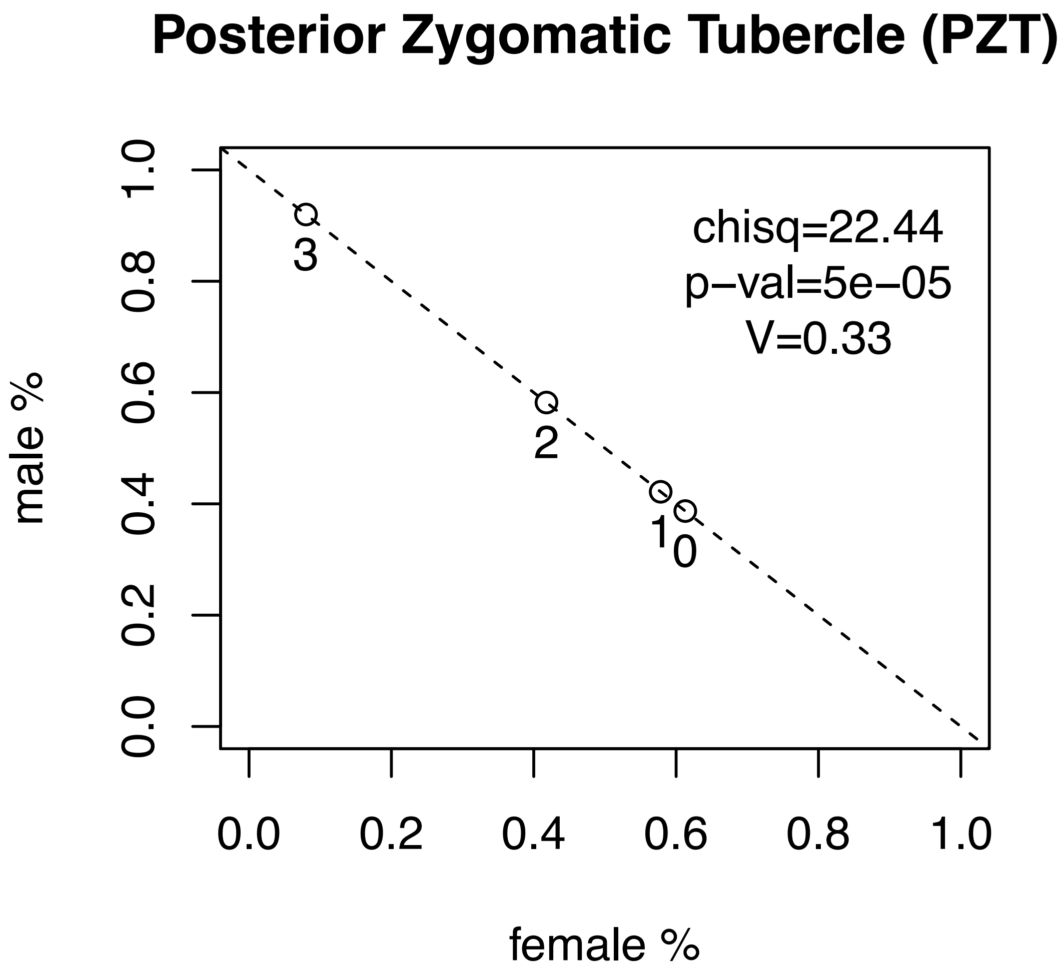

Figure 4.8. One-dimensional plot for PZT and sex.

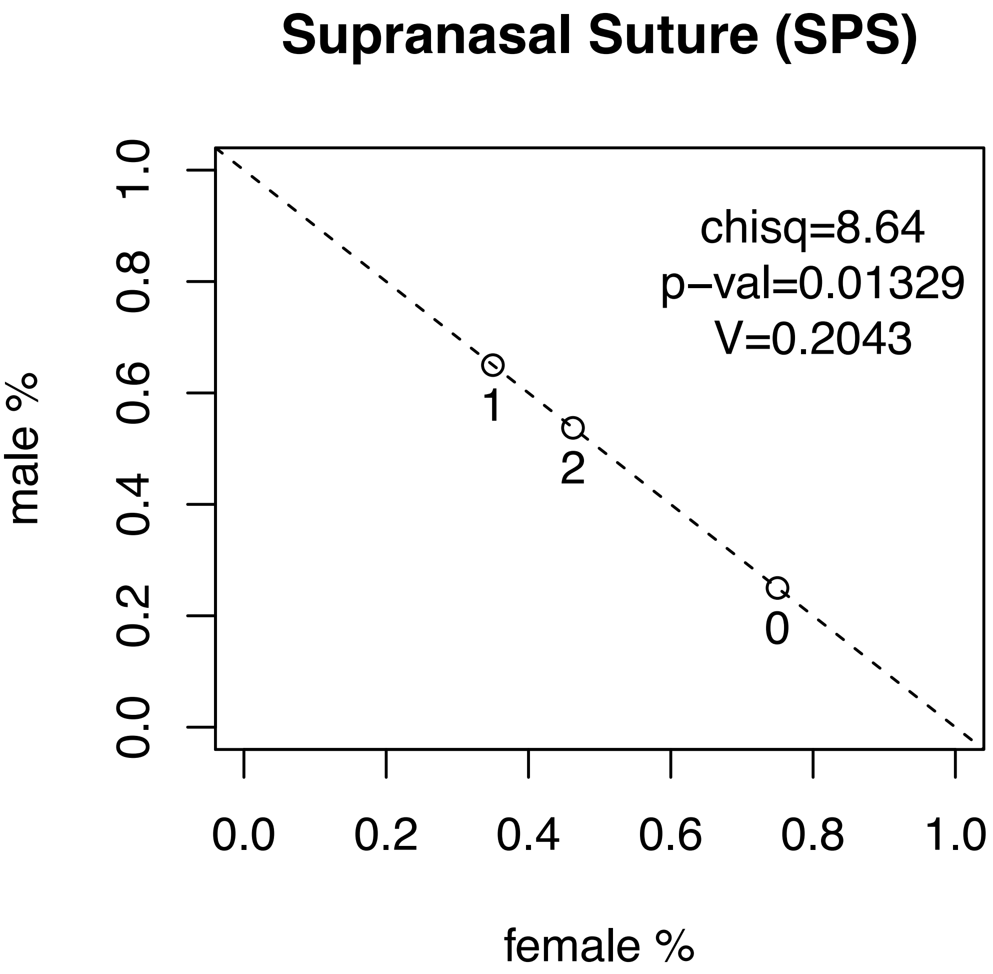

Figure 4.9. One-dimensional plot for SPS and sex.

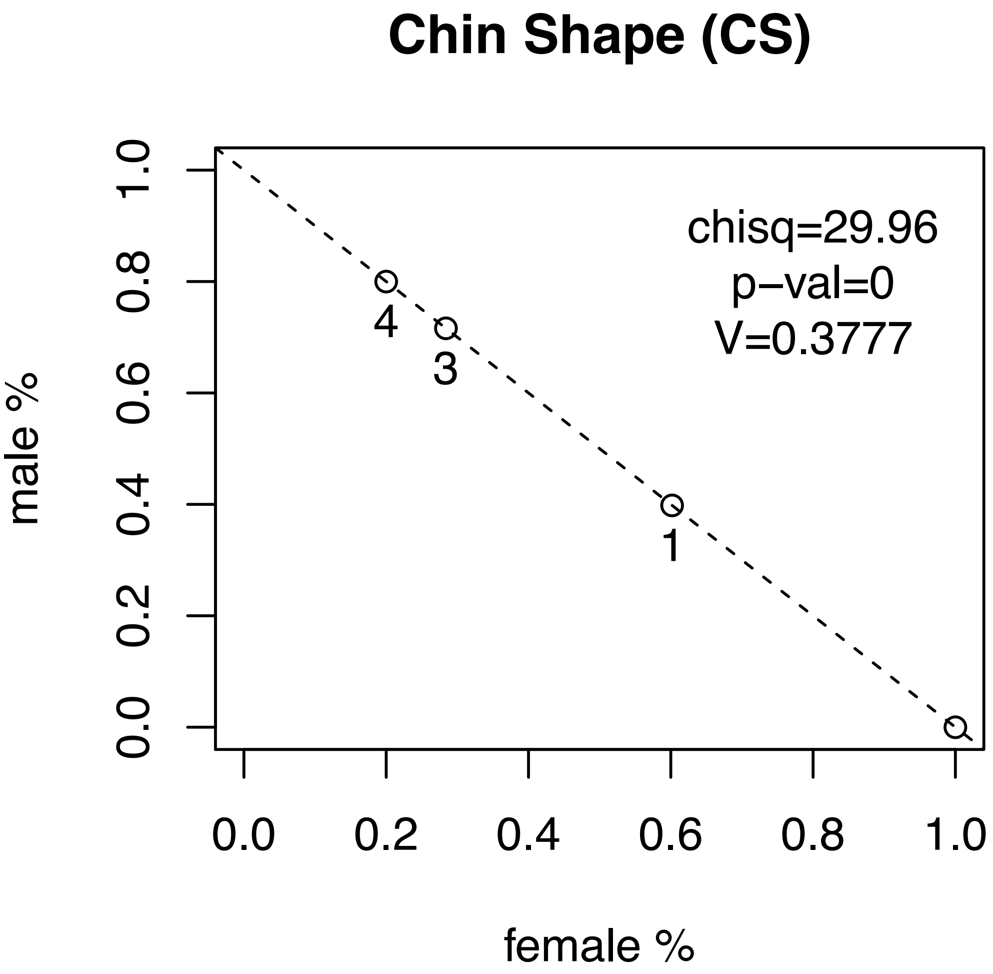

Figure 4.10. One-dimensional plot for CS and sex.

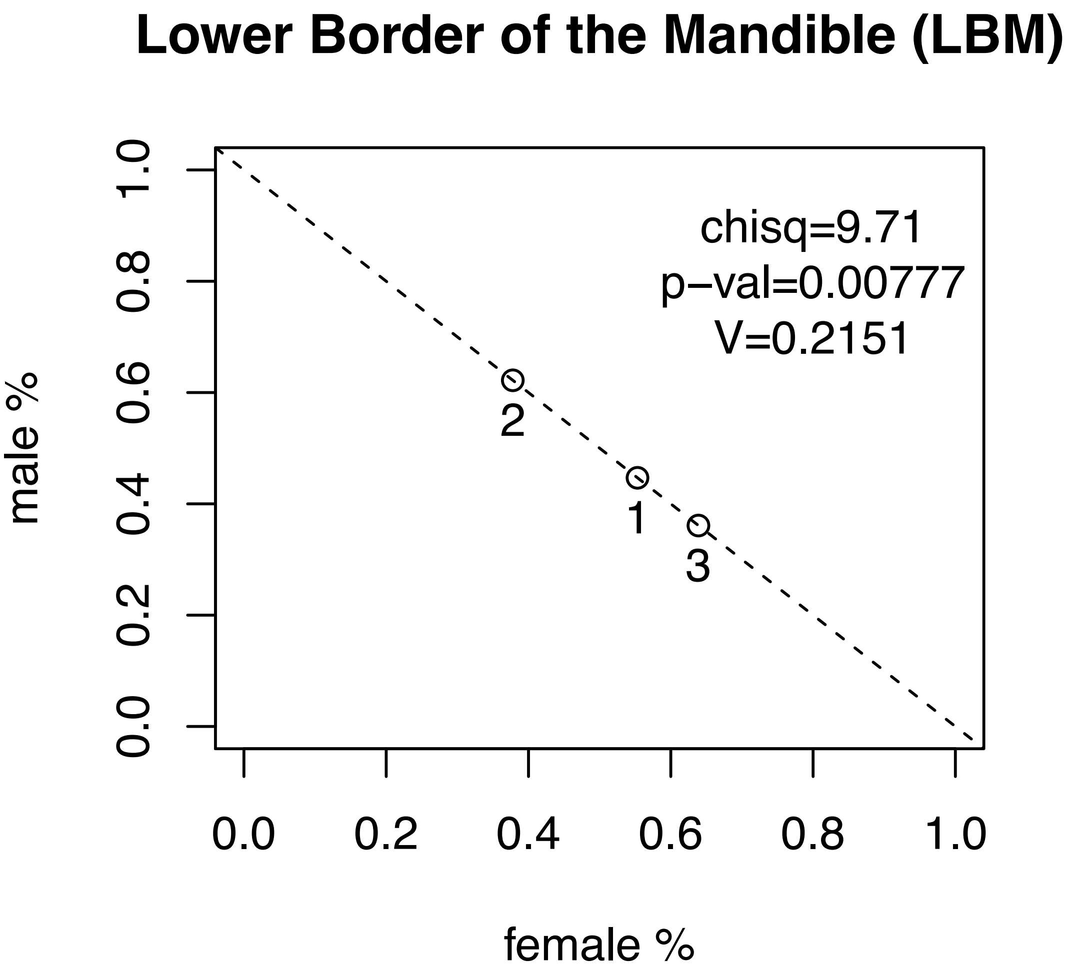

Figure 4.11. One-dimensional plot for LBM and sex.

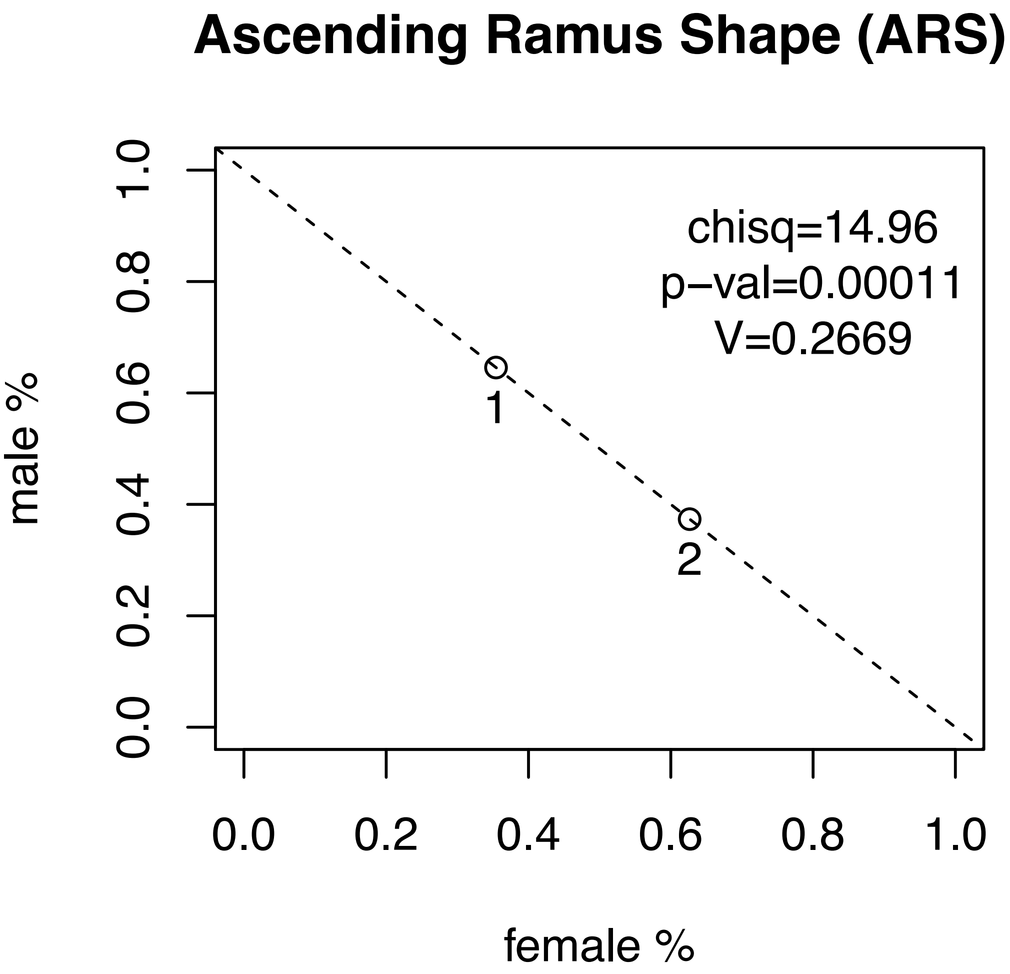

Figure 4.12. One-dimensional plot for ARS and sex.

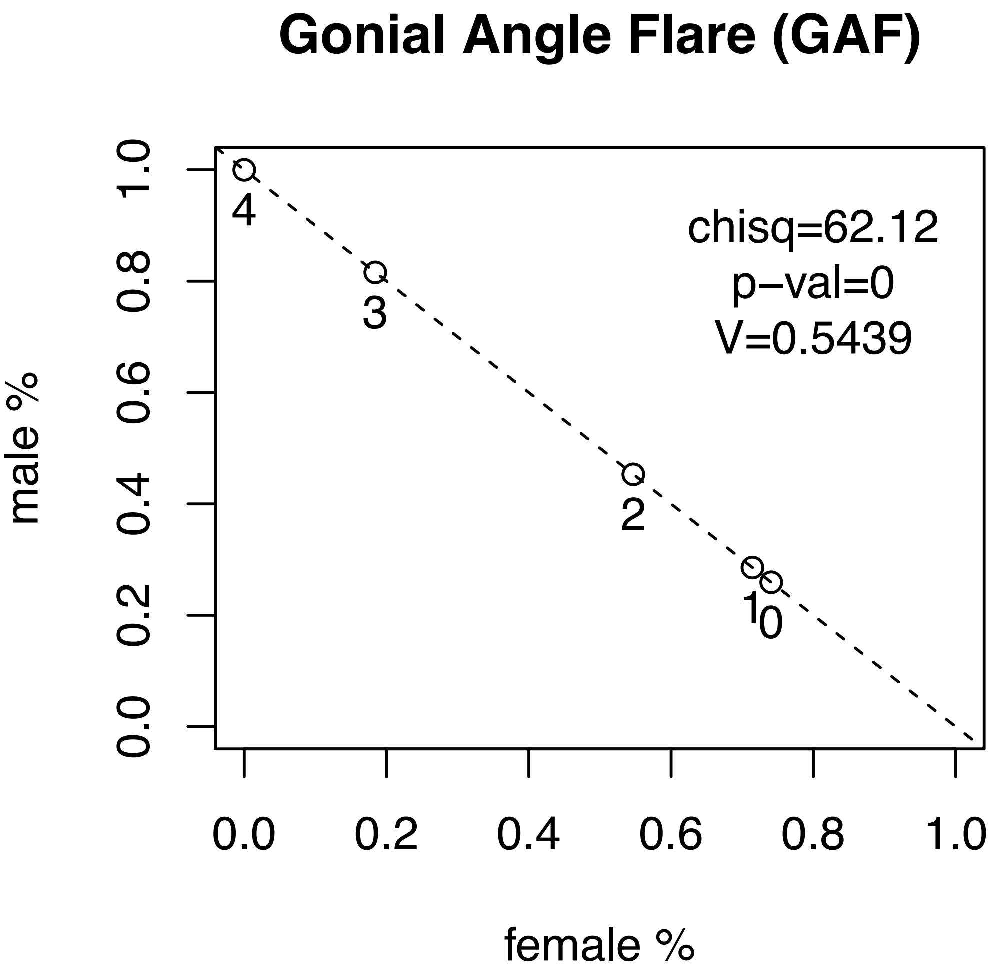

Figure 4.13. One-dimensional plot for GAF and sex.

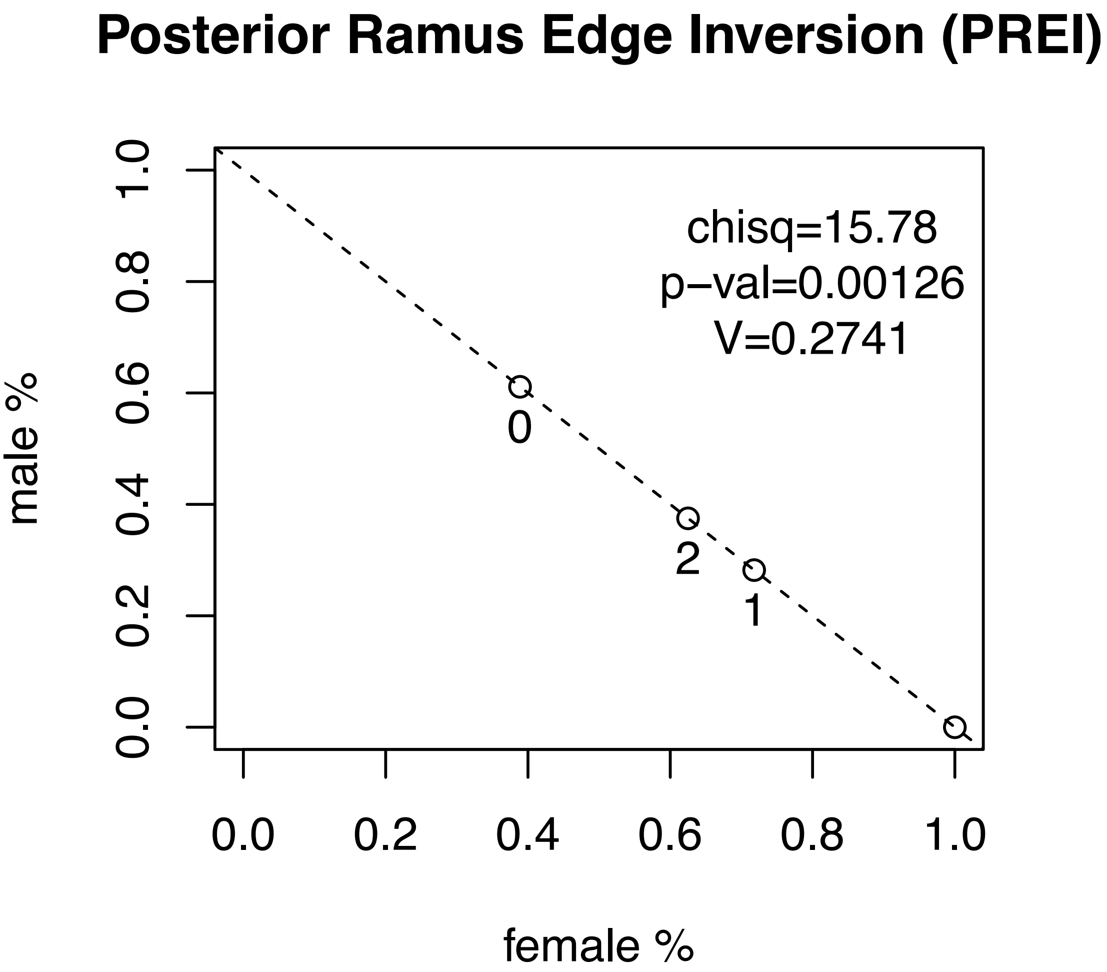

Figure 4.14. One-dimensional plot for PREI and sex.

Intraobserver Error

Intraobserver error was conducted by rescoring 10% of both the male (n=11) and female (n=10) portion of the sample over a two-week period. Using Cohen's Kappa to analyze the intraobserver error in RStudio, it was found that 13 of the 23 morphoscopic traits had "substantial" to "almost perfect" agreement when rescored (Landis and Koch, 1977). These include ANS, INA, IOB, MTh, NAS, NAW, NBC, NBS, NFS, PS, PZT, TPS, ZS, CS, LBM, ARS, GAF, MTb, and PREI. The remaining 10 morphoscopic traits were found to have "fair" to "moderate" agreement (Landis and Koch, 1977).

Table 4.24 includes all 23 morphoscopic traits, their Cohen's Kappa weighted estimate, and the strength of their agreement.

Table 4.24: Intraobserver error.

Trait	Cohen's Kappa	Agreement (Landis and Koch, 1977)
ANS	0.73	Substantial
ARS	0.63	Substantial
CS	0.83	Almost perfect
GAF	0.77	Substantial
INA	0.80	Substantial
IOB	0.64	Substantial
LBM	0.43	Moderate
MTh	0.72	Substantial
MTb	0.90	Almost perfect
NFS	0.75	Substantial
NAS	0.56	Moderate
NAW	1.00	Perfect
NBC	0.50	Moderate
NBS	0.53	Moderate
NO	0.39	Fair
OBS	0.29	Fair
PS	0.55	Moderate
PBD	0.39	Moderate
PREI	0.78	Substantial
PZT	0.71	Substantial
SPS	0.34	Fair
TPS	0.57	Moderate
ZS	0.71	Substantial

CHAPTER 5: DISCUSSION

This chapter discusses the results presented in the previous chapter in further detail. Specifically, which cranial and mandibular morphoscopic traits statistically differ between European American males and females within the sample. The results included the chi-square tests of independence, one-dimensional Principal Component Analysis (PCA) plots, and Cohen's Kappa test for intraobserver error. In sum, these results will illustrate the morphoscopic traits that are most sexually dimorphic within European Americans, the reliability of each of these traits, and ultimately what this means for the estimation of ancestry within a forensic context.

Chi-Square Analysis

The Chi-square tests of independence indicated that 14 of the 23 total morphoscopic traits observed within the sample of European American males and females have a significant relationship with sex (p-value < 0.05). This was illustrated in Tables 4.1-4.23, which detailed the frequencies for each of the 23 traits between males and females, and their overall p-value. From this, it can be concluded that there are ancestral cranial and mandibular morphoscopic traits that are sexually dimorphic within this European American sample. This means that the use of these traits could ultimately affect the estimation of ancestry within this population, given that they exhibit sexual dimorphism.

Although such research as Klales and Kenyhercz (2015) found that separating males and females by ancestry resulted in a less accurate classification compared to pooling them, it was only conducted on two populations: “Black” and “White.” In some populations, such as Japanese and Thai individuals, sex does not significantly impact nonmetric trait expression (Tallman 2016); however, it is important to consider that other populations may appear more sexually dimorphic than others. Angel and Kelley (1990) found that such traits as the GAF has a small difference between the “Black,” “White,” and Native American populations, but a large sex difference. Such findings indicate that, although not all morphoscopic traits will be sexually dimorphic, some may be, which could potentially affect the outcome of ancestry estimation within certain populations.

The current study found that 14 morphoscopic traits exhibit sexual dimorphism, specifically 9 of the 17 cranial nonmetric traits and 5 of the 6 mandibular nonmetric traits. This emphasizes that the mandible is highly sexually dimorphic and could potentially affect ancestry estimation if used within this population.

Overall, given that past research has typically pooled males and females within a sample, since little difference in the ancestral nonmetric traits was perceived, these are significant results. Ultimately, this indicates the need for a more standardized approach to the estimation of ancestry, especially within a forensic context given the gravity of the cases. If certain morphoscopic traits used in the estimation of ancestry when developing a biological profile are exhibiting sexual dimorphism, the result could potentially be skewed and thus not reflect the accurate ancestry of the individual.

Correspondence Analysis

The correspondence analysis generated 14 one-dimensional PCA plots illustrating the degree of sexual dimorphism per morphoscopic trait and each of their ordinal scores. From these plots it can be inferred that these traits exhibit some form of sexual dimorphism within European Americans, which could ultimately result in an incorrect ancestry estimation.

The current study found that of the 14 morphoscopic traits that exhibit sexual dimorphism, females are given lower scores than males for most of the traits, similar to the findings in Tallman (2016). For the trait CS, for example, females were scored as a 1 or 2 while males were scored as a 3 or 4. Similarly, for the trait GAF, females were scored as a 0, 1, or 2 while males were scored as a 3 or 4. Not all of these traits exhibited this pattern, however. For trait PREI, males were scored as a 0 and females were scored as a 1, 2 or 3. Overall, this only occurred for a few of the 14 traits, so the pattern is fairly consistent throughout the sample.

Furthermore, the study found that the Cramer's V correlation for 14 traits range from strong (> 0.15) to very strong (> 0.25) (Akoglu, 2018), illustrating that there is a strong association between sex and these morphoscopic traits. The trait with the highest Cramer's V correlation is GAF, which has a value of 0.5439, while the trait with the lowest correlation is ANS, with a value of 0.151. Given these values, it can be concluded that there is a high degree of correlation between sex and these traits, illustrating that they are sexually dimorphic.

Sexual Dimorphism

Similar to the findings in Tallman (2016), several cranial and mandibular traits were found to be affected by sex; however, these traits varied between Tallman (2016) and the current study. For the Japanese and/or Thai samples, it was found that the CS, PZT, PREI, GAF, ARS, and PS were similarly scored between males and females within this study's sample. However, the traits INA, NAS, NBC, SPS, and OBS differed in scoring between males and females. Although when sex was included in binary logistic regression equations it failed to contribute to classification accuracies, the findings still illustrate that these nonmetric traits are being affected by various factors; and it is notable that different traits are being affected within different samples from various populations.

Atkinson and Tallman (2019) similarly found that the effects of sex on the degree of nonmetric traits are minimal within the tested modern Japanese, Thai, and precontact Southwest Native American samples. Of the 35 nonmetric cranial and mandibular traits scored, 31 were found to differ significantly when sex was pooled (Atkinson and Tallman, 2019). When males and females were separated, 28 traits differed significantly within the male sample, and 25 traits differed significantly within the female sample

(Atkinson and Tallman, 2019). Overall, this study illustrates that sex does not contribute to statistical models when attempting to distinguish between ancestry groups.

For this sample in the current study, the degree of sexual dimorphism per the 14 morphoscopic traits found to be statistically significant is formed for several reasons; some traits are related to muscle attachment sites, while others are related to shape and size differences. Each of the 14 traits will be discussed below as to the possible reason for sexual dimorphism. It is important to note that, although the degree of sexual dimorphism per the 14 morphoscopic traits is notable within this sample, this study did not test how sex factors into ancestry estimation methods.

Anterior Nasal Spine (ANS)

The ANS is the thin projection of bone at the inferior margin of the nasal aperture located on the maxillae (White *et al.,* 2011). This bony projection is the attachment site of the facial expression muscle, the dilator naris posterior (Hefner and Linde, 2018), which allows the nostrils to be flared. As the anchor for the nasal tip, the ANS influences the degree of projection for the nose and the upper lip (Hefner and Linde, 2018). During the process of facial growth, the cartilaginous nasal septum is seen as the primary force in shaping the maxilla (Enlow and Bang, 1965). The ANS moves in a downward direction through bone deposition as the process of bone resorption and deposition is occurring throughout the premaxilla (Enlow and Bang, 1965). Given the growth and development of the area in which the ANS is located, the degree to which the trait varies between males and females within this sample is most likely based on the size of the trait. Even though it is a muscle attachment site, the muscle is used for facial expression only, never growing in size due to use.

Inferior Nasal Aperture (INA)

The INA is the shape of the inferior border of the nasal aperture, where the nasal floor transitions into the vertical portion of the maxilla (Hefner and Linde, 2018). The INA joins together at the ANS, and this region forms part of the upper lip. This is not an attachment site for any particular muscle; however, it is lined with the membrane mucosa nasi (Hefner and Linde, 2018), which extends to the external upper lip. Similar to the ANS, the INA is affected by the growth of the nasal septum (Enlow and Bang, 1965). Previous research has found that the shape and size of this region is due to the resorption of the anterior nasal floor during growth and development (McCollum and Ward, 1997; Nicholas and Franciscus, 2014). Given that INA is not a muscle attachment site, and that the trait is affected mainly by the resorption of the nasal floor, the degree to which INA varies between males and females within this sample is most likely based on the size and shape of the trait.

Nasal Aperture Shape (NAS)

The NAS is the greatest lateral projection of the nasal aperture regardless of the overall width of the nasal opening; the region is divided into two compartments that are separated by the nasal septum (Hefner and Linde). This region is outlined by the nostrils and is comprised of several muscles key to facial expression. The nasalis, which compresses the nasal aperture; the depressor septi, which draws the nose inferiorly; and the levator labii superioris alaeque nasi, which opens the nostrils and elevates the upper lip (Sobiesk and Munakomi, 2019). Similar to the ANS and INA, the NAS is influenced by the growth and development of the nasal septum (Enlow and Bang, 1965), as well as responses to physiological demands in terms of respiratory needs (Hefner and Linde, 2018). In terms of the degree to which NAS varies between males and females within this sample, it is most likely influenced by the size of the nasal aperture during growth and development, as well as the environment in which the individual grew up in.

Nasal Bone Contour (NBC)

The NBC is the contour of the nasal bone structure, which are covered by the procerus and nasalis muscles (Hefner and Linde, 2018). The procerus muscles originate on the nasal bone inserting on the glabella, where it functions to wrinkle the skin over the bridge of the nose (Sobiesk and Munakomi, 2019). Throughout puberty, the size of the nasal bones increase, and are affected by growth and developmental responses to olfaction and respiration (Hefner and Linde, 2018). Unlike the previously discussed traits (ANS, INA, and NAS), the NBC is not part of the maxillae; however, the nasal bones are directly influenced by growth of development of the maxillae (Enlow and Bang, 1965). Thus, the degree to which the NBC varies between males and females within this sample, is most likely influenced by the size of the nasal bones and the growth of the surrounding bone, as compared to any muscle attachment site.

Nasal Bone Shape (NBS)

The NBS is the contour of the lateral borders of the nasal bones, compared to the NBC, which is the contour of the overall structure of the nasal bones (Hefner and Linde, 2018). The NBS is affected by the growth and development of the maxillary frontal processes (Enlow and Bang, 1965), as they fuse to the nasal bones during this period. The NBS, like the NBC, is further influenced by the developmental response to olfaction and respiration (Hefner and Linde, 2018). The degree to which the NBS varies between males and females within this sample, is most likely influenced by the size and overall shape of the nasal bones, compared to any muscle attachment site.

Orbital Shape (OBS)

The OBS is defined as the shape of the bony sockets (Hefner and Linde, 2018), which consist of several bones including the frontal, the maxillae, the ethmoid, the zygomatics, and the lacrimals. Each of these bones define the shape of the orbital margins, ultimately creating the OBS. The growth of the orbit is influenced by the growth of the human eye as well as the growth and development of the surrounding bones. The orbital margins also act as attachment sites for various muscles, including the orbicularis oculi, located underneath the skin of the eyelid (Tong and Patel, 2019). The frontalis muscle, originating from the frontal bone, inserts onto the orbicularis oculi. This is a large muscle that contributes to various facial expressions. The degree to which the OBS varies between males and females within this sample, is most likely influenced by the growth and development of the surrounding bones, as well as the muscle attachments sites.

Palate Shape (PS)

The PS is the contour of the dental arcade (Hefner and Linde, 2018), which is defined by the palatine processes of the maxillae and the horizontal portions of the palatine bones (White *et al.,* 2011). It is affected by the overall shape of the anterior and posterior dentition within the alveolar processes of the maxillae. The palate grows inferiorly during bone deposition (Enlow and Bang, 1965), and together the maxillae and the palatines fuse along two sutures. The morphology of the palate is influenced by the actions of mastication as well. Although no muscles of mastication attach to or originate from the palate, the process of mastication greatly affects its growth and development. For individuals with larger muscles of mastication, the shape of the palate will be affected differently during the period of development. Thus, the degree to which the PS varies between males and females within this sample is most likely influenced by the surrounding muscle attachment sites.

Posterior Zygomatic Tubercle (PZT)

The PZT is the posterior projection of the zygomatic bone located on the frontal process (Hefner and Linde, 2018). The trait stabilizes between the ages of 15 and 20 years, following puberty, as the surrounding temporalis muscle has strengthened (Hefner and Linde, 2018). The temporalis muscle is a muscle of mastication, and the PZT is the origin for fibers of the temporal fascia, or the superficial layer of the muscle (Hefner and Linde, 2018). This muscle spans from the temporal fossa to the inferior temporal line, ultimately passing underneath the zygomatic arch and inserting onto the coronoid process of the mandible (Basit *et al.,* 2019). Given the size of the muscle that is attaching to the PZT, it can be concluded that the degree to which it varies between males and females within this sample is most likely due to muscle attachment. Previous studies have found that males have a larger individual variation in muscle fibre and muscle mass (Komi and Karlsson, 1978), which can ultimately result in more robust muscle attachment sites.

Supranasal Suture (SPS)

The SPS is the suture that is superior to the cranial landmark nasion, that may or may not continue into adulthood (Hefner and Linde, 2018). It has been found in previous studies that the SPS is often associated with sexual maturation, and that a persistent SPS is frequently seen on robust male crania (Hefner and Linde, 2018). Furthermore, increased masticatory strain could be a potential stressor leading to the noted association with robust males. This was confirmed by the present study, as 22% of males were found to be scored a 1 (“open”), compared to 18% of females; and 79% of males were found to be scored a 2 (“closed, but visible”), compared to 63% of females. Given this, the degree the SPS varies between males and females within this sample is most likely due to muscle attachment and mechanical stress.

Chin Shape (CS)

The CS is the contour of the mental eminence (White *et al.,* 2011) on the mandible. The region of this trait is also an attachment site for the mentalis muscle, which is a muscle for facial expression. Within this sample, it is found that males were scored as a 3 (“square”) and 4 (“bilobate”) more often, which are more robust, as compared to 1 (“blunt”) and 2 (“pointed”). Given the variation in robusticity of the mandible ranging from males to females, it is most likely that the degree the CS varies within this sample is influenced by the muscle attachment site.

Lower Border of the Mandible (LBM)

The LBM is the contour of the inferior margin of the body of the mandible (Berg, 2008). Similar to the zygomatic processes of the maxillae, the mandible extends posteriorly during growth and development (Enlow and Bang, 1965). This extension helps shape the lower border of the body of the mandible. Furthermore, the LBM is located in the region of the masseter and mylohyoid muscle attachment sites. The masseter muscle wraps beneath the mandibular body and ramus, to assist with mastication by elevating the mandible (Basit *et al.,* 2019). The mylohyoid muscle attaches to the mylohyoid line inside the mandible and assists with the mastication process. Given that males typically have a larger muscle mass (Komi and Karlsson, 1978), which results in more robust bony landmarks, it is most likely that the degree of variation between males and females within this sample for the LBM is influenced by muscle attachments and the process of mastication.

Ascending Ramus Shape (ARS)

The ARS is the shape of the ramus of the mandible (Berg, 2008), and similarly to the LBM, this trait was most likely shaped by the growth and development of the mandible as it extended posteriorly during this period (Enlow and Bang, 1965). Furthermore, it is also a site for muscle attachment, including the medial pterygoid and the temporalis, both assisting with mastication. The temporalis, as discussed previously, attaches onto the coronoid process of the mandible, where the medial pterygoid attaches directly onto the ramus of the mandible (Basit *et al.,* 2019). This muscle assists with the elevation and protrusion of the mandible, as well as the side to side motion (Basit *et al.,* 2019). Within this sample, males were more often scored a 1 (“pinched”), as compared to females who were more often scored a 2 (“wide”). This could be due to the fact that the more often and more rigorously the muscles of mastication, that attach to the ramus, are used, they could potentially pull and alter the shape of the feature. Thus, the degree to which ARS varies between males and females within this sample, is most likely influenced by muscle attachments and the process of mastication.

Gonial Angle Flare (GAF)

The GAF is the degree to which the gonial angle of the mandible projects (Berg, 2008). Similar to the LBM and ARS, this trait is shaped by the growth and development of the mandible as it grows posteriorly (Enlow and Bang, 1965). Furthermore, this trait is also the site of the muscle attachment for the masseter, which assists with mastication. As stated previously, it is found that males have more muscle mass (Komi and Karlsson, 1978) resulting in more robust bony landmarks, and the muscles of mastication are large enough muscles to directly affect the shape of bones. For this sample, males were more often scored a 3 ("medium") and 4 ("everted"), as compared to females who were more often scored as a 0 ("absent"), 1 ("inverted"), or 2 ("slight"). It appears that the more robust and larger the masseter muscle, the more likely the GAF is to be everted. Thus, the degree to which the GAF varies between males and females within this population, is most likely influenced by muscle attachment and the process of mastication.

Posterior Ramus Edge Inversion (PREI)

The PREI is the degree to which the edge of the posterior ramus border projects invertedly (Berg, 2008). Similar to the LBM, ARS, and GAF, this trait is most likely shaped by the growth and development of the mandible as it grows posteriorly (Enlow and Bang, 1965). Furthermore, given that males within this sample were more often scored as "everted" for the GAF, they were thus more often scored as 0 ("absent") for the

PREI as the gonial angle is not going to be everted while the posterior ramus edge is inverted. This trait is also a site for muscle attachment for the medial pterygoid, which assists with mastication (Basit *et al.,* 2019), as stated previously. Overall, the degree to which the PREI varies between males and females within this population, is most likely influenced by muscle attachment, the process of mastication, and potentially by the GAF.

Intraobserver Error

The Cohen's Kappa test for intraobserver error indicated that 13 of the 23 nonmetric traits had either a "substantial," "almost perfect," or "perfect" agreement. This illustrates that more than half of the traits observed are reliable when estimating ancestry. The nasal aperture width (NAW) had the highest agreement rate (k=1.000; perfect), which can be attributed to the trait's two-point ordinal scale. Such studies as Hefner (2009), Tallman (2016), and Atkinson and Tallman (2019) found that the majority of the traits were greater than or equal to a "substantial" agreement rate following Landis and Koch (1977). Of the traits with an agreement rate of "substantial" or "almost perfect," listed in the previous chapter, the following are in accordance with Hefner (2009): INA, IOB, MTh, and ZS; Tallman (2016): ANS, IOB, MTh, NFS, NAW, ZS, and PREI; and Atkinson and Tallman (2019): IOB, NFS, NAW, CS, and MTb. The level of agreement between the findings in this study, and Hefner (2009) and Tallman (2016), could be the result of the level of experience of the observer.

Three patterns of error relating to intraobserver error have been noted in Kamnikar *et al.* (2018), which are observer experience, the introduction of new technologies, and the errors inherent within the method utilized. It was found that the effect of error on macromorphoscopic trait analysis does not significantly impact their use (Kamnikar *et al.,* 2018), however, several of the published intraobserver error rates are only at the moderate to good observer agreement.

The remaining 10 morphoscopic traits (NAS, NBC, NBS, NO, OBS, PS, PD, SPS, TPS, and LBM) had either a "fair" or "moderate" agreement; however, it does not necessarily denote them as unreliable, but simply as less reliable compared to the other observed traits. The fact that these 10 morphoscopic traits had a lower agreement most likely has to do with a greater number of ordinal points per trait. The orbital shape (OBS), exhibited the lowest agreement rate ($k=0.29$; fair), for example. This trait has a three-point ordinal scale, which is typically easier to score as compared to a trait with a higher ordinal point scale, the low agreement rate could thus be attributed to the observer's experience. The remaining traits that scored within the same range are supranasal suture (SPS) (k=0.34) and nasal overgrowth (NO) (k=0.39; fair). In accordance with Hefner (2009), Tallman (2016), and Atkinson and Tallman (2019), the only traits with a similar intraobserver error rate within the "fair" to "moderate" range is the transverse palatine suture (TPS) and the lower border of the mandible (LBM).

Furthermore, the 10 morphoscopic traits with a "fair" to "moderate" error rate consist of only cranial morphoscopic traits; none of the six mandibular morphoscopic traits are included. This could be due to the way in which the observer felt comfortable with the descriptions and illustrations of the mandibular traits, as compared to the cranial traits; or it could also be due to the simpler morphology of the mandible as compared to the morphology of the facial bones.

Overall, the majority of the intraobserver agreement for the 23 morphoscopic traits ranged from “substantial” to “perfect” (k=0.61-1.00), while the remaining 10 traits scored at or below a 0.40. Although more than half have promising agreement scores, it should be noted that many of the traits are still affected by various factors, such as observer experience and inherent errors within the method (Kamnikar *et al.,* 2018). In order to improve intraobserver agreement, measures will need to be taken in order to improve the experience of the observer over time, and to potentially reevaluate the methods themselves. Many of the morphoscopic traits observed within this study have an ordinal point scale of at least three, which allows for more variation, and thus a potential lower intraobserver agreement. Although variation is important, it makes the process of scoring increasingly more difficult, especially if the observer is lacking in key experience. Hopefully, as time progresses, the intraobserver agreement will steadily improve alongside the growth of the standardization of morphoscopic traits.

CHAPTER 6: CONCLUSIONS

This chapter summarizes what was found from the results of the statistical analyses, what they ultimately mean for the study, and the future research that is needed in order to create a more standardized scoring system for ancestry estimation. Furthermore, limitations of the study will be discussed, specifically illustrating restraints to the study that will need to be improved in future research. Ultimately, from this study more research will hopefully be conducted in order to have a better understanding of sexually dimorphic ancestral morphoscopic traits, and potentially develop a more standardized model of ancestry estimation from it.

Summary

Ancestry estimation is a crucial component to the development of the biological profile within a forensic context, for it allows the forensic anthropologist as well as law enforcement to create an image of what the individual would have appeared when alive. Although ancestry estimation was not standardized within the field of forensic anthropology for many years, it has come a long way since the early days of biological anthropology and research that attempted to develop ways in which researchers could estimate the ancestry, or "race", of an individual. Today, nonmetric and metric ancestral traits have been incorporated into models in which they can be used to more accurately estimate the ancestry of individuals in a forensic context. However, there is little standardization on the sexual dimorphism of these traits, specifically the nonmetric or morphoscopic traits. Thus, the current study was developed in order to explore the factor of sexually dimorphic ancestral nonmetric traits within a specific population.

The goal of this study was to test for any significant relationship between cranial and mandibular ancestral nonmetric traits, and sex in European Americans. This was to ultimately determine if there is, in fact, any degree of sexual dimorphism within these traits within this sample. The proposed hypothesis was that there are statistically significant differences between European American males and females, and when analyzed, ancestral cranial and mandibular traits will be found to be sexually dimorphic. The hypothesis was proven to be correct, in that 14 of the 23 total morphoscopic traits scored within the sample population were found to have a significant relationship with sex. Furthermore, each of these traits had sexually dimorphic scores within them, illustrating the variation between the sexes. These results emphasize that pooling males and females together when estimating ancestry for such populations as European Americans can potentially influence the outcome of the estimation. Although not all populations will exhibit this degree of sexual dimorphism, it should be noted that it can occur to a certain extent. This ultimately signifies the need for a solution to this issue, be that developing separate models for males and females, or to not utilize the morphoscopic traits that are found to be sexually dimorphic for the European American population.

First, however, researchers need to test to see if adding sex into ancestry estimation methods does, in fact, impact the outcome.

Limitations and Future Research

Several solutions could be implemented to prevent the effect of sexual dimorphism when estimating ancestry in a forensic context. One solution would be to eliminate the traits that are found to be sexually dimorphic from any future ancestry estimation when developing a biological profile. Another solution would be to develop a better standardized method for estimating ancestry where there are separate models for males and females. This, of course, will ultimately depend upon the population in question given that not all populations exhibit sexual dimorphism. In order to implement such a method, all of the populations that are documented in ancestry estimation methods, as well as *FORDISC 3.1* (Jantz and Ousley, 2005), will need to be studied further for potential sexual dimorphism within the morphoscopic traits typically used for such an estimation. It is still important to emphasize that this study did not test how sex factors into ancestry estimation methods and implementing this in future studies is important to understanding if any of these solutions that were just discussed, do in fact need to be applied.

Moving forward, there were several limitations to this study that must be discussed. The sample size is relatively low with only 97 females and 113 males, and several traits could not be scored on some of the individuals, either due to alveolar resorption or postmortem breakage. Furthermore, when conducting the correspondence analyses for the 14 morphoscopic traits, several of the individuals had to be removed from the sample because they had scores missing from certain traits due to damage, ultimately reducing the size of the sample.

Besides the sample size, there were several other limitations to this study. Mainly, only one population was observed and scored, and that population that is typically found in most skeletal collections and has been heavily recorded over the last century. In order to have a better understanding of the extent of sexual dimorphism for ancestral morphoscopic traits, more populations will need to be recorded, as well as increasing the sample size. Overall, the results presented here, while provide an advancement to the field, still leave an open field for future research to be conducted in which such limitations mentioned can be corrected, and the development of more accurate estimations of ancestry.

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