SEX ESTIMATION IN A MODERN FORENSIC SAMPLE

USING A DISCRIMINANT FUNCTION ANALYSIS

FROM THE CALCANEUS

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by

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ABSTRACT

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Reliable methods for sex estimation during the creation of a biological profile are important to the forensic community in instances when the common skeletal elements used to assess sex are absent or damaged. Sex estimation from the calcaneus has potentially significant importance for the forensic community. Specifically,

measurements of the calcaneus provide an additional reliable method for sex estimation via discriminant function analysis based on a North American forensic population.

The calcaneus was chosen for study because of its size and the durability, which permit it to withstand postmortem alteration (Bidmos and Asala 2003, 2004; Drechsler et al 1996; Introna et al. 1997). Previous studies have estimated sex using the calcaneus and other tarsal bones (Bidmos and Asala 2003, 2004; Gualdi-Russo 2007; Introna et al. 1997; Murphy 2002; Steele 1976; Wilbur 1998). However, these studies use populations from an older American sample (birth years from late 19th-early 20th century), Italy, South Africa, prehistoric Polynesian, and prehistoric Native American and thus are not applicable a modern North American population. It is important to take into account demographics, secular change and regional origin of the collection being used (Komar and Grivas 2008). Due to secular change and regional origin, previous studies must be revised and existing methods evaluated for populations of differing geographic origin.

Research on a modern American sample was chosen in order to develop up-to-date population specific discriminant functions for sex estimation. The current study addresses this matter, building upon previous research (Bidmos and Asala 2003, 2004; Gualdi-Russo 2007; Introna et al. 1997; Murphy 2002; Steele 1976; Wilbur 1998) and introduces a new measurement, posterior circumference that promises to advance the accuracy of use of this single, highly resistant bone in future instances of sex determination from partial skeletal remains.

Data were collected from The William Bass Skeletal Collection, housed at the University of Tennessee. Sample size includes 320 adult individuals born between the years 1900 and 1985. The sample was comprised of 136 females and 184 males.

Skeletons used for measurements were confined to those with fused diaphyses showing no signs of pathology or damage that may have altered measurements, and that also had accompanying records that included information on ancestry, age, and sex. Measurements collected and analyzed include maximum length, load-arm length, load-arm width, and posterior circumference.

The sample was used to compute a discriminant function, based on all four variables, and was performed in SAS 9.1.3**.** The discriminant function obtained an overall cross- validated classification rate of 86.69%. Females were classified correctly in 88.64% of the cases and males were correctly classified in 84.75% of the cases. Due to the increasing heterogeneity of current populations further discussion on this topic will include the importance that the re-evaluation of past studies has on modern forensic populations. Due to secular and micro evolutionary changes among populations, the near future must include additional methods being updated, and new methods being examined, both which should cover a wide population spectrum.

CHAPTER I

INTRODUCTION

One of the first steps in the identification of skeletonized remains is to create a biological profile, which includes the assessment and estimation of sex. When using visual methods such as the Phenice (1969) technique, which uses the ventral arc, ishiopubic ramus, and sub pubic concavity, the os coxae can yield around 95 percent accuracy in sex estimation by observing the ventral arc, subpubic concavity, and the medial aspect of the ischiopubic ramus. Byers (2005) states that the pelvis "contains the greatest number of characteristics useful for determining sex" (183) and "the skull is the second must useful structure for determining sex" (190). Spradley and Jantz (2003) have recently suggested otherwise, however, arguing for the usefulness of the postcranial skeleton in metrically estimating the sex of fragmentary remains. Skeletal remains that have undergone taphonomic changes and postmortem destruction may not contain the most reliable elements, including the pelvis, which are required for certain visual and statistical methods used in the estimation of sex.

The calcaneus is the largest bone in the foot. The density of this bone, as well as the fact that the tarsal and metatarsal bones are often encased within socks and/or shoes give the calcaneus the ability to withstand the majority of postmortem alteration (Bidmos and Asala 2003; Pickering 1986). Researchers such as France (1998) have found postcranial elements to be highly accurate in sex estimation. More specifically, past research has utilized the calcaneus as a means of sex estimation with high accuracy rates (Bidmos and Asala 2003; Bidmos and Asala 2004; Gualdi-Russo 2007; Introna et al. 1997; Murphy 2002; Pickering 1986; Steele 1976). The goal of the present study is to provide a method for sex estimation utilizing the calcaneus based on a recent forensic sample from the United States.

As a consequence of secular change and population demographics, data from older time periods are not applicable for use in developing new anthropological methods. Therefore, when developing new anthropological methods, especially for a population as diverse as the United States, population specific data must be utilized. Studies of secular change in skeletal elements have been researched in the past (Jantz and Jantz 1999; Jantz and Jantz 2000). However, research within this area involving the calcaneus has not yet been examined. The present study will also examine whether differences exist between previous results obtained though research on calcanei of an American sample from the Terry Collection, and the present results, which is obtained from a recent sample utilizing the William M. Bass Donated Skeletal Collection.

Research on a recent sample of Americans was chosen in order to develop current population-specific discriminant functions to be utilized for the estimation of sex in the United States. The present study addresses the matter of sex estimation, building upon previous research (Bidmos and Asala 2003; Bidmos and Asala 2004; Gualdi-Russo 2007; Introna et al. 1997; Murphy 2002; Steele 1976; Wilbur 1998) as well as introducing a new measurement, posterior circumference. Posterior circumference will be tested for accuracy to determine whether it will increase the usefulness of this single skeletal element for sex estimation. The basis of this new measurement comes from the existence of current circumference measurements on skeletal elements such as the tibia, femur, and ulna (France 1998). The results of the present study should thus aid investigators who have to estimate the sex of an individual when only partial skeletal remains are available.

Secular change over the last century is one of the inspirations for the present research outlined in this paper. Changes in disease and nutrition levels have played a large role in small scale changes in the human skeleton (Jantz and Jantz 1999). Meadows and Jantz (1999) state in an article discussing secular change in long bone length from 1800 to 1970 that “the pattern of secular change beginning in the early 19th century seems to be very general and to cut across socioeconomic lines” (66). Positive secular trends, relating to increases in long bone size, may be correlated with improvements in environmental conditions, over the past few centuries, such as diet, medical care, and industrialization. Growth and development during the first three years of life have improved due in part to the advancements in living standards and environmental conditions. Jantz and Jantz (1999) report that secular changes are established in early childhood development during the times when environmental impact is most influential (Jantz and Jantz 1999).

Skeletal collections are very population-specific due to demographic differences, as well as secular change and population migration. This has led to a reasonable amount of research, both current and past (Bidmos and Asala 2003; Bidmos and Asala 2004; Gualdi-Russo 2007; Introna et al. 1997), dealing with the sex estimation of prehistoric New Zealand Polynesian (Murphy 2002) and prehistoric American (Illinois) (Wilbur 1998) skeletal populations. Unfortunately, this research is no longer applicable for use in a recent American forensic setting, the affects of secular change and population demographics (Jantz and Jantz 1999; Komar and Grivas 2008). Several examples of research collections based on skeletal samples utilizing older samples will be discussed, as they apply to past research in sex estimation using the calcaneus. The Robert J. Terry Collection, located at the Smithsonian Institution in Washington, DC is one such collection, and represents a population consisting of individuals from the St. Louis, Missouri area that were from a lower socioeconomic class in the late 19th and early 20th century. The Raymond A. Dart Collection of Human Skeletons, located at the School of Anatomical Sciences of the University of the Witwatersrand in Johannesburg represents an immigrant population from southern Africa, Asia, and Europe. The individuals in this collection were collected before 1958 and primarily came from South African hospitals in cases where bodies of the deceased were not claimed (Dayal et al. 2009). The Frassetto Collection, housed at the Museum of Evolution at The University of Bologna represent individuals that died around the beginning of the 20th century (Murphy 2002). The skeletal collection at the Institute of Legal Medicine at the University of Bari consists mostly of a contemporary southern Italian population who died around 1970 (Introna et al. 1997). These skeletal collections are a few examples from which recent studies (Bidmos and Asala 2003; Bidmos and Asala 2004; Gualdi-Russo 2007, Introna et al. 1997) have obtained population samples in order to estimate sex using the calcaneus. These collections prove to be either population-specific or are too old for use in a recent American forensic context.

Background

Sex is a fundamental category of the biological profile, which also consists of age, stature, and ancestry. The os coxae is one of the most accurate diagnostic tools for assessing or estimating sex due to skeletal changes during adolescence, as well as morphological changes that occur in the human skeleton during adulthood (Byers 2005; Komar and Buikstra 2008; Phenice 1969). Multiple methods for sex estimation using postcranial elements and/or the skull have been developed as alternate means for sex assessment or estimation when the os coxae is absent or damaged (Acsádi and Nemeskéri 1970; Bass 1995; Bidmos and Asala 2003; Bidmos and Asala 2004; Byers 2005; France 1998; Giles 1970; Gualdi-Russo 2007; Introna et al. 1997; Jantz and Jantz 1999; Komar and Buikstra 2008; Murphy 2002; Phenice 1969; Pickering 1986; Riepert et al. 1996; Steele 1976; Suchey et al. 1988; Suchey and Sutherland 1991; Symes and Jantz 1983; Walker 2005; Wilbur 1998; Wilder 1920; Williams and Rogers 2006). While morphological assessment of bony features on the os coxae have been proven to be the best method to assess sex, yielding accurate results, the metric analysis of postcranial elements has also been shown to be accurate and preferred at times due to its "objectivity and repeatability" (Bidmos and Asala 2003:1213).

The metric estimation of sex using this single skeletal element, the calcaneus, has been studied in the past using a number of population samples from around the globe. The earliest published study on the calcaneus was performed by Gentry Steele in 1976. In this study, he focused on sex related differences in the tarsal bones of a North American sample. Steele utilized The Terry Collection, which is housed in the Smithsonian Institution's National Museum of Natural History. He found that the tarsal bones of the foot show a great enough degree of sexual dimorphism to be of diagnostic value for use when estimating the sex of an unknown individual. Steele admits, however, that the population represented in the Terry Collection does not encompass individuals from across the United States but rather consists primarily of individuals from St. Louis, Missouri who died around the beginning of the 20th century. He states,

> Currently there is no way to measure the effect of socioeconomic differences or continuation of secular changes in America. This study may be using a population smaller in foot-bone size than today's, and thus tend to misclassify larger females. But until we have new collections these discriminant functions should prove the most effective in distinguishing sexes. (Steele 1976:587)

Skeletal populations such as The Terry Collection are not representative of contemporary populations and thus only represent the population from which they were derived. Secular change and the demographics of specific collections have caused many skeletal collections to become outdated for use in a forensic anthropological setting in the United States (Jantz and Jantz 1999; Komar and Grivas 2008), thus requiring the creation of updated population specific methods.

Reipert et al. (1996) used the calcaneus to estimate sex on a population of 800 central European individuals from Mainz, Germany. Linear measurements as well as measurements of different angles were taken on the calcaneus via radiographs. While the authors state that radiographs produce an image slightly larger than the actual bone, it did not affect the outcome of the study, which through the use of discriminant function analysis acheived an accuracy rate of 84.4 percent. Introna et al. (1997) performed a population-specific study on the use of the calcaneus in estimating sex among a contemporary population from southern Italy located at the Institute of Legal Medicine at the University of Bari. A small sample size of 40 male and female calcanei was measured, and through multivariate analysis, 80-85 percent of the individuals studied were correctly classified according to sex. The authors conclude “our discriminant functions should be tested on recent skeletal collections of different populations to compare the differences and compile a list of sex discriminant functions applicable worldwide” (1997:727).

Murphy (2002) examined a prehistoric New Zealand Polynesian skeletal collection. While it consisted of a rather small sample size, 26 males and 23 females, specimens were correctly classified 93.5 percent of the time. The origin of the skeletal sample was The Department of Anatomy and Structural Biology, at the Otago School of Medical Sciences in Dunedin, New Zealand. Through use of univariate statistics, Murphy (2002) was able to show statistically significant differences in calcanei of males and females with maximum length of the calcaneus proving to be the most reliable measurement when estimating sex. While this study has shown sexual dimorphism among the prehistoric New Zealand Polynesians, the study is extremely population specific. Likewise, Gualdi-Russo (2007) created discriminant function equations derived from 62 males and 56 females from northern Italy housed in The Frassetto skeletal collection, which is located in the Museum of Evolution at University of Bologna. The accuracy percentages obtained from the stepwise analysis ranged from 87.9-95.7 percent, and were based on eight calcaneal traits measured. Gualdi-Russo (2007) also remarks that the calcaneal maximum length and breadth are major contributors toward sex estimation.

Continuing the trend of population specific studies involving the calcaneus as a basis for sex estimation, Bidmos and Asala (2003, 2004) focused on South African

Blacks and Whites. The first of two studies (Bidmos and Asala 2003) of South African populations was performed on a South African White sample consisting of 53 males and 60 females from the Raymond A. Dart Collection of Human Skeletons located at The University of Witwatersrand in Johannesburg. According to the findings of Bidmos and Asala, the male calcaneus was statistically different ($P < 0.001$) than the female calcaneus. Additionally, as should be expected, a multivariate analysis resulted in a greater percentage of accuracy than a univariate analysis. The multivariate approach correctly classified 92 percent of individuals while the highest univariate accuracy rate came from dorsal articular facet breadth with nearly 86 percent of individuals being correctly classified. The subsequent year, Bidmos and Asala (2004) conducted another study dealing with the estimation of sex using a South African Black sample. The sample size consisted of 58 males and 58 females of different African tribes from the same collection. The results of this study paralleled those of their earlier study (2003). Results show there were sexual differences between males and females in the population studied, although the authors acknowledge that the discriminant function equations obtained in this study are population specific to the South African populations studied.

Through examination of past research, it is evident that the use of the calcaneus is a reliable indicator of sexual dimorphism between males and females, but each author admits that their sample is population specific, suggesting that when a skeletal element is used in sex estimation or sex assessment, it is important that the method be population-specific. The objective of the present research is to use discriminant function analyses to create a reliable sex estimation technique, using male and female calcanei representing a recent American forensic population, for use by forensic anthropologists in the United States.

CHAPTER II

MATERIALS AND METHODS

The sample used in this study to calculate discriminant functions for estimating sex consisted of individuals from the William M. Bass Donated Skeletal Collection located at The University of Tennessee, Knoxville. The individuals represented in this sample exemplify a population with birth years spanning from 1900 to 1985. This is a significant date range for this study because the individuals embodied within the collection are representative of a recent forensic population and are thus applicable to modern forensic studies. The individuals used in this study were adults that had accompanying records on age, sex, and ancestry. Individuals with missing demographic information were excluded. Calcanei that showed damage or exhibited pathological conditions such as severe osteoarthritis or lipping that hindered accurate measurements were not included in this study. The sample for this study is comprised of 320 adult individuals, measured over a five day period, which include 136 females and 184 males, with an age range of 19 to 97 years old. The female sample includes 135 American White females and 1 American Black female. The male sample includes 135 American White males, 37 American Black males, and 12 Hispanic males.

Methods

Only left calcanei were used in this study for the purpose of consistency. The right calcaneus was used in cases when the left calcaneus was unavailable or did not meet the criteria delineated in this study. Four measurements were taken on each specimen maximum length (MXL) (Moore-Jansen et al. 1994), load arm length (LAL), load arm width (LAW) (Steele 1976), and posterior circumference (PCF). The definition for maximum length was adopted from Standards for Data Collection from Human Skeletal Remains (Buikstra and Ubelaker 1994 after Moore-Jansen et al. 1994). Load arm length and load arm width were adopted from Steele (1976). Wording for the measurements used by Steele has been modified to include appropriate contemporary osteological terminology. For example, Steele (1976) refers to the "posterior articular surface" (582), whereas definitions used in present research refer to this skeletal feature as "dorsal articular facet".

Posterior circumference is an original measurement developed for this study. The cranial and postcranial skeleton of males and females is markedly different in size. The purpose of measuring the calcaneus stems from the hypothesis that, due to the amounts of sexual dimorphism seen in the rest of the skeleton, the calcaneus should be no exception. Circumference measurements of skeletal elements such as the femur and tibia have been utilized in past methods of sex estimation (France 1998). Therefore, the appropriateness and accuracy of this measurement for use in a forensic context will be tested.

Measurement Definitions

Maximum length (Buikstra and Ubelaker 1994; Moore-Jansen et al. 1994) (Figure 1)

Distance between the most projecting point on the tuberosity and the most anterior point on the superior margin of the articular facet for the cuboid measured in the sagittal plane and projected onto the underlying surface.

Load arm width (Steele 1976) (Figure 2)

Defined as a transverse projected line perpendicular to the long axis from the most lateral point on the dorsal articular facet to the most medial point of the sustentaculum tali.

Load arm length (Steele 1976) (Figure 2)

Defined as the projected line from the most posterior point of the dorsal articular facet, to the most anterior/superior point of the cuboidal facet.

Posterior circumference (Figure 1)

Defined as the minimum circumference of the area between the posterior point of the dorsal articular facet and most posterior point of the calcaneus. To properly take this measurement, lay measuring tape flat against the surface of the bone. Pass the measuring tape around anteriorly to the inner and outer tuberosity of the calcaneus. Avoid projecting heel spurs located on the inferior surface of the calcaneus by laying the measuring tape beneath them. In certain cases, calcaneal tuberosities have been seen to be located at a more anterior position, in which case it may be appropriate to measure on the posterior side of the tuberosity, avoiding the feature, in order to properly obtain the minimum circumference.

Length and width measurements were obtained using Mitutoyo Absolute Digimatic Calipers, and measuring to the nearest 0.01 mm. Circumference measurements were taken using a retractable fabric tape measure.

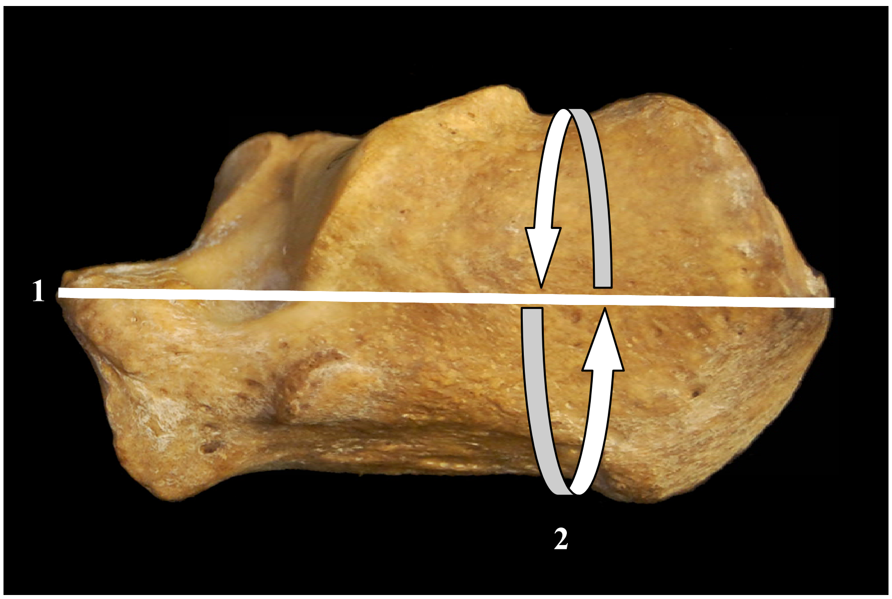

Figure 1. Maximum Length and Posterior Circumference. This image is depicting the area that should be measured when recording maximum length (1) and depicting the area that should be measured when recording posterior circumference (2). For the correct measuring technique refer to the written measurement definition outlined in the above text.

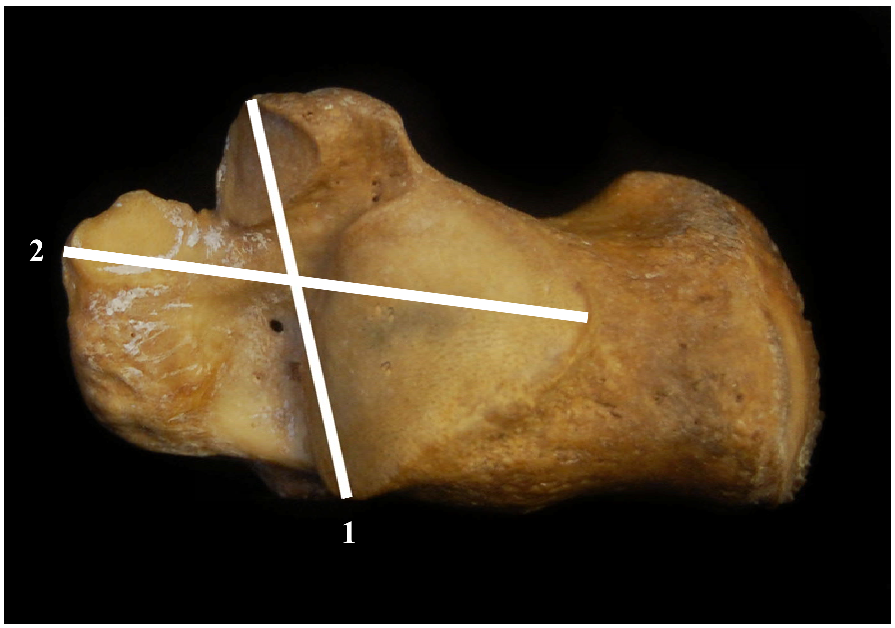

Figure 2. Load Arm Width and Load Arm Length. This image is depicting the area that should be measured when recording load arm width (1) and depicting the proper area that should measured when taking the measurement for load arm length (2). For the correct measuring technique refer to written description of measurement outlined in the above text.

Statistical Analysis

Intraobserver error

The University of Tennessee William M. Bass Donated Skeletal Collection is organized by year. Each year the donations are numbered beginning with “01”. For example, a donation numbered UT01-02D means this is the first skeletal donation for the year 2002. A subset of the main sample consisting of 20 male and female individuals was selected take the first available donation with a calcaneus beginning in the year 1987 and ending in 2007. This subset sample, was used to test for intraobserver error. Intraobserver error was tested to ensure that consistency was kept throughout the data collection by the single researcher. The samples used to test for consistency included right and left calcanei. The same 20 specimens were measured in the morning on the first day of research and re-measured in the morning on the third day of research.

The purpose for testing intraobserver error rate is to make sure the researcher is taking the same measurement the same way each time a specimen is examined. The resulting correlation coefficient is based on a linear relationship between the two variables being tested. A positive correlation close to 1.0 indicates a perfect relationship while a correlation coefficient of -1.0 would indicate a negative correlation between variables. A correlation coefficient of 0 would thus indicate no linear relationship (Grimm and Yarnold 2001).

To test for correlation between the variables in the subset sample of 20 specimens, a Spearman’s rho correlation analysis was performed in SPSS 16.0. The usefulness of a Spearman’s rho correlation analysis in this case is due to the fact the present study is dealing with a small sample size. This correlation analysis is a non-parametric test; therefore, no assumptions are made about the distribution of the subset sample on hand.

Sex Estimation

Analysis of Variance

A statistical approach using multiple variables has been utilized in this instance as it allows for a more thorough analysis of the data than a univariate approach (Grimm and Yarnold 2001). An analysis of variance (ANOVA) test was performed in order to control for Type 1 error, and to identify an interaction for ancestry between American Blacks and Whites between the dependent variables measured. Before sex differences could be examined, it was important to test for ancestry differences in maximum length (MXL) (Moore-Jansen et al. 1994), load arm length (LAL), load arm width (LAW) (Steele 1976), and posterior circumference (PCF). This was performed using an ANOVA test using the General Linear Model in SAS 9.1.3. Usually in cases when an analysis of variance test indicates population differences in a sample, further population specific analyses must be performed. In the present study, the sample size was too small for female individuals from varying population groups, or ancestries. The ANOVA used in this study tested for differences in sex, ancestry, and for an interaction between sex and ancestry.

Discriminant Function Analysis

A discriminant function analysis (DFA) using all four variables was performed in SAS 9.1.3. Using the data collected on 320 adults from The University of Tennessee William Bass Donated Skeletal Collection, cross-validated classification rates were generated for males and females. A stepwise variable selection method was employed to determine if a subset of measurements provided better classification rates than using all measurements. To determine which subset of variables was the best for use in the DFA, a stepwise discriminant (PROC STEPDISC) function was performed in SAS 9.1.3. The stepwise method uses a combination of backward and forward selection procedures. During each step of the DFA, a different variable is subtracted from or added to the model during the variable selection process. The STEPDISC procedure excluded any non-qualifying measurements, more specifically, those variables that did not have an alpha level of .05 using the Wilks' Lambda and Pillai's Trace multivariate tests. The DFA was run with the stepwise selected variables, as well as with all variables to see which provided better classification rates.

Cross-validation classification rates were generated for the reference sample, and a classification function was created. The linear DFA maximized group differences for males and females for explain group separation. The purpose of creating a classification function is for practical use in sex estimation by forensic anthropologists.

Sectioning Points

A recovered skeleton in a forensic context may not always have the appropriate elements for sex estimation. Additionally, the parts of the skeleton recovered may be damaged, therefore not allowing all measurements to be used in a discriminant function formula. As a result, a univariate analysis can prove useful. Sectioning points were created by taking the mean of each measurement for male and female samples, adding them together, then dividing the resulting number by two. All measurements that fall above the sectioning point will be classified as male, all measurements that fall below the sectioning point will be classified as female, and measurements that fall exactly on the sectioning point are classified as indeterminate. The resulting classification frequencies were calculated by totaling the number of males that were correctly classified as male (falling above sectioning point for appropriate measurement) and dividing that number by the total number of male samples. The same was performed on the female samples to create the classification frequencies for that group.

Using the appropriate statistical methods it is hypothesized that differences in male and female calcanei will exist. A discriminant function analysis will prove useful in creating a reliable sex estimation technique representing a recent American forensic population.

CHAPTER III

RESULTS

Intraobserver Error

The Spearman's rho correlation analysis, run on the subset of the sample, tested for consistency between the first and second time each of the twenty specimens was measured. The results of the Spearman's rho correlation analysis provided significant results for each set of variables, reaching confidence levels close to, and upwards of 0.01. Maximum length (MXL) had a correlation of .998. Load arm length (LAL) had a correlation of .997. Load arm width (LAW) had a correlation of .994, and lastly, posterior circumference (PCF) had a correlation of .984.

Additionally it was discovered that there was a significant correlation between maximum length (MXL) and load arm length (LAL), which had a correlation of .846. Load arm length (LAL) also showed a significant correlation to load arm width (LAW) with a correlation coefficient of .702. Posterior circumference (PCF) had the lowest correlation when compared with load arm width (LAW) with a .307 correlation coefficient.

Analysis of Variance

The ANOVA test indicates that there are statistically significant differences between the variables examined for sex and ancestry. Ancestry differences among the male groups were statistically significant ($P < 0.001$); however, as previously stated, all male groups were pooled together due to lack of a diverse female sample as well as the fact that if one were to find a single calcaneus there would not be a way to identify ancestry at that point in time.

Stepdisc

The four variables (MXL, PCF, LAL, and LAW) were entered into SAS 9.1.3 and the STEPDISC procedure (PROC-STEPDISC) selected the best three variables for use in sex estimation. The top three measurements selected were load arm width (LAW), load arm length (LAL), and posterior circumference (PCF). When using the STEPDISC selected measurements, males were correctly classified 83.80 percent of the time and females were correctly classified 88.64 percent of the time (Table 1). When using all four measurements, males were correctly classified 84.75 percent of the time and the classification rate for females remained unchanged at 88.64 percent correctly classified (Table 2). The overall classification rate for the stepwise selected measurements is 86.22 percent and when all measurements were used the overall classification rate was 86.69 percent. The differences in classification rates were not significant, and therefore when generating classification functions, all measurements should be used.

Discriminant Function Analysis

Using the linear DFA statistics for all variables a discriminant function score equation was formulated where:

$$\mathbf{y = (0.07548 \times MXL) + (0.06197 \times PCF) + (0.1707 \times LAL) + (0.55351 \times LAW) + (-45.2601)}$$

y equals the discriminant function score. If the resulting calculation causes y to be greater than the sectioning point 0.000, the bone is classified as male; if the resulting calculation causes y to be less than the sectioning point the bone is classified as female. If the resulting calculation causes y to be 0.000, then the bone is considered to be indeterminate. The average accuracy of correctly classifying males and females using this discriminant function is 86.69 percent.

Sectioning Points

The average of the mean values for each male and female measurement provides sectioning points. The resulting sectioning points presented accuracy rates for MXL, PCF, LAL, and LAW of 80.09 percent, 81.98 percent, 82.48 percent, and 88.1 percent respectively (Table 3). When maximum length (MXL) was used alone, it correctly classified 141 of the 182 measured male samples, giving it a 77.47 percent accuracy rate. In addition, maximum length correctly classified 110 of the 133 measured female samples, giving it an 82.7 percent accuracy rate. Posterior circumference (PCF) alone correctly classified 152 of the 182 measured male samples, resulting in an 83.51 percent accuracy rate. This measurement correctly classified 107 of the 133 measured female samples, resulting in an 80.45 percent accuracy rate. Load arm length alone correctly classified 142 of the 184 measured male samples, giving it an accuracy rate of 77.17 percent. Load arm length correctly classified 115 of the 131 measured female samples, resulting in an 87.78 percent accuracy rate. Finally, load arm width when used alone correctly classified 155 of the measured 182 male samples resulting in an 85.16 percent accuracy rate. In addition, Load arm width correctly classified 122 of the measured 134 female samples, resulting in a 91.04 percent accuracy rate.

Table 1. Cross-validated Classification Rates using Stepwise Selected Variables

		Males		Females		
Variables	**Total No.**	**% correct**	**N**	**% correct**	**N**	**Avg Accuracy (%)**
LAW, LAL, PCF	311	83.80	150/179	88.64	117/132	86.22

Table 2. Cross-validated Classification Rates using All Variables

		Males		Females		
Variables	**Total No.**	**% correct**	**No.**	**% correct**	**No.**	**Avg Accuracy (%)**
LAW, LAL, PCF, MXL	309	84.75	150/177	88.64	117/132	86.69

Table 3. Sectioning Points for Calcaneal Measurements

	Females				**Males**					
Variable	N	Mean	Std Dev	% correct	N	Mean	Std Dev	% correct	**Sect Point**	**Overall Classification**
Maximum Length	133	79.79	4.17	82.7	182	87.81	5.09	77.47	83.8	80.08
Posterior Circumference	133	104.03	6.49	80.45	182	116.56	7.77	83.51	110.3	81.98
Load Arm Length	131	48.82	2.84	87.78	184	54.4	3.44	77.17	51.61	82.47
Load Arm Width	134	39.44	2.08	91.04	182	44.61	2.69	85.16	42.02	88.1

CHAPTER IV

DISCUSSION

Human sexual dimorphism is evident in the fossil record in human ancestors (Reno et al. 2003). Paleoanthropologists are able to calculate the index of dimorphism for early humans, showing size differences in our earliest ancestors such as *Australopithecus afarensis* (Frayer and Wolpoff 1985; Reno et al. 2003)**.** These differences still exist today and can be seen in recent human skeletal remains. The application of sexual dimorphism comes into play when the estimation of sex is being performed on an unknown individual through use of postcranial remains.

Temporal and Spatial Variations

When examining group means for maximum length, load arm width, and load arm length using the data of the previous studies for these past population groups, the author finds that the sample means of both Steele (1976) and Wilbur (1998), who have studied American samples, fall below the sectioning points in the present study (Table 4). Table 4 shows how changes in these measurements have increased. As a result of these temporal variations, the sectioning points of the past studies tend to classify the majority of the current sample as male, and highly misclassify females. For example, when sectioning points for maximum length taken from Wilbur (1998) are used on recent American

Female calcanei, 9 percent of females were accurately classified as female, while an astounding 91 percent were incorrectly classified. Similar results were seen when sectioning points from Steele's 1976 study, which utilized a population from the late 19^{th} and early 20^{th} century, is applied to a recent American sample. Bidmos and Asala (2003) found that breadth measurements were the most sexually dimorphic among South African Whites. In contrast, a follow-up study on South African Blacks performed in 2004 by Bidmos and Asala found that length measurements were the most sexually dimorphic among the South African Black sample. Introna et al. (1997) utilized a southern Italian population, and discovered that while the results varied between classification rates of length and breadth measurements, the highest classification rates were achieved when both breadth and length measurements were used in conjunction with one another. Gualdi-Russo (2007) studied a northern Italian population and found that the best results were achieved when length, breadth, and height measurements were used together. Riepert et al. (1996) examined a central European population and found that length measurements, specifically maximum length, provided the best accuracy rate, correctly identifying 80 percent of the individuals measured.

Supporting the validity that measurements are population-specific, sectioning points from the studies mentioned above were used to classify individuals from the University of Tennessee William M. Bass Donated Skeletal Collection. Sectioning points for length and breadth measurements created from the present study were larger than each of the European and South African population group sectioning points, with the exception of central Europeans (Table 4). As a result, male individuals had very high classification rates, ranging from 94 to 100 percent correctly classified. Females ranged from 1 to 77 percent being accurately classified.

Notable population specific studies concerning sex estimation using the calcaneus have been performed using recent European (Gualdi-Russo 2007; Introna et al. 1997; Riepert et al. 1996) and South African samples (Bidmos and Asala 2003; Bidmos and Asala 2004). Accuracy rates using univariate statistics from the present study ranged from 80 to 88 percent. This was slightly higher than the South African White (Bidmos and Asala 2003) study, which ranged from 72.9 to 85.8 percent, and the South African Black (Bidmos and Asala 2004) univariate classification rates that had a range of 69.8 to 79.3 percent. In addition, the present study was slightly higher than the accuracy rates of the Southern Italian population (68.75 to 83.75 percent) (Introna et al. 1997) and the Northern Italian population (79.6 percent). Low indices of dimorphism for different populations may be a reason for low accuracy rates, as low accuracy rates suggest that there is not a strong difference between male and female calcanei of a population. The levels of dimorphism among population groups should be addressed in future anthropometric research.

The use of anthropometric research in the past has been employed to study trends in human growth and development (Komlos 1994). It has allowed researchers to study change affected by industrialization, disease, climate, nutrition and numerous other factors that influence biological human growth (Cardoso 2008; Jantz and Jantz 1999; Jantz and Jantz 2000; Ji and Chen 2008; Lin et al. 1992; Martin and Danforth 2009; Stewart and McKern 1957). Studies of human growth are also affected by regionally specific factors. Different geographic locations are subjected to different environmental influences (Jantz and Jantz 1999) that have an effect on variables such as health and socioeconomic status (Komar and Grivas 2008).

Table 4. Correctly Classified Individuals Using Population Specific Sectioning Points. This table illustrates the percentage of individuals who were correctly classified when sectioning points from past studies are applied to the current sample.

				Correct Classification of American Sample Using Population Specific Data								
	Corresponding Sample Means			**American Male % Correct**			**American Female % Correct**			**Overall % Correct**		
	MXL	**LAW**	**LAL**	**MXL**	**LAW**	**LAL**	**MXL**	**LAW**	**LAL**	**MXL**	**LAW**	**LAL**
Current Study	83.8	42.02	51.61	77.47	85.16	77.17	82.7	91.04	87.78	80.09	88.1	82.48
Steele (1976) Americans	78.8	40.7	48.55	95	94	98	36	77	50	65.5	85.5	74
Wilbur (1998) Prehistoric Illinois	74.7	40.2	-	100	96	-	9	67	-	54.5	81.5	-
Bidmos & Asala (2003) S.A. Whites	80.32	39.95	45.75	93	96	100	59	62	15	76	79	57.5
Bidmos & Asala (2004) S.A. Blacks	76.75	40.87	42.59	99	93	100	21	78	1	60	85.5	50.5
Introna et al. (1997) S. Italians	75.8	39.7	-	99	96	-	14	56	-	56.5	76	-
Riepert et al. (1996) C. Europeans	85.9	-	-	64	-	-	95	-	-	79.5	-	-

Sexual dimorphism has not only been shown to be temporally varied but is also spatially varied. Data obtained in previous studies cannot be applied to modern day samples without taking into account both secular change and regional origin (Komar and Grivas 2008). Secular trends for increases in body size are indicative of improving socioeconomic conditions, including improvements in health, nutrition, and social wealth (Ji and Chen 2008). Changing environmental conditions can be brought on by war, famines, economic downturns, and industrial growth. Environment can play a dramatic role in the health and nutritional status of populations. Many times, factors altering environmental conditions can be both beneficial as well as maladaptive to the individuals residing within the changing environment. Availability of resources during an individual's growth and development stages is reflected in overall body size of the individual as an adult. Secular change in skeletal morphology is likely linked to improvements in diet and medical care, in association with the industrialization of societies (Martin and Danforth 2009). Environmental conditions, such as the examples mentioned above, play a large role in why population specific methods are necessary when estimating the sex of unknown skeletal remains.

Trends and Generalizations

It has been shown in past research, markedly, seen in the work of Thomas Dwight in 1905, that the differences in sizes of the articular surfaces are a good indicator of sex. Dwight states, "it is demonstrated that the differences in the size of the articular surfaces in the sexes is very much more marked than that of the length of the respective bones" (Dwight 1905:28). The measurements involving articular surfaces in the present study follow this trend. The load arm width (LAW) and load arm length (LAL) measurements, which measures the dorsal articular facet, proved to be the most accurate of the univariate measurements taken. The dorsal articular facet is the articular surface where the talus articulates with the calcaneus, and the classification rates achieved using these measurements were 88.1 percent and 82.47 percent, respectively. Maximum length (MXL) of the calcaneus was the least accurate univariate statistic, classifying males and females correctly 80.08 percent of the time. The trends in the accuracy of the different measurements used in the present research are consistent with what was found by Dwight (1905). A possible explanation for the higher accuracy rates of articular surface measurements may lie in bone mechanics and the changes that occur in the human skeleton in response to musculature stresses. Musculature stress markers or size increases as a reaction to individual lifestyles may affect circumference or bone maximum length measurements. Thomas Dwight gives an example of this on page 28 of his 1905 publication, which focused on the size of articular surfaces on long bones in males and females (Dwight 1905). This would be an interesting topic in future research on the calcaneus.

The accuracy rate of 86.22 percent when only the stepwise selected variables load arm length, load arm width, and posterior circumference were used was not significantly different than the accuracy rate of 86.69 percent that was achieved when all variables were used. This demonstrates that including maximum length in the stepwise analysis does not affect the classification rate. In future studies, all variables should continue to be included if possible when estimating the sex of an unknown individual.

The sectioning points created in the present research are larger by at least 2 mm in each respective measurement than those obtained in past research by Steele (1976), Wilbur (1998), Bidmos and Asala (2003; 2004), and Introna et al. (1997) (Table 4). American sectioning points had higher classification rates for males when applied to all studies except that of the Reipert et al. (1996) study. Central European males were only correctly classified 64 percent of the time using American sectioning points. This could mean that the calcanei in the sample of Central European males are on average larger than the calcanei in the sample of American males studied. Size differences and spatial differences among populations from different geographic locations proves that studies such as these are population specific and thus require population specific, classification rates (France 1998; Pearson 1915).

By the turn of the 20th century, the standard of living in many first world countries, including the United States, had improved drastically and positive secular trends in skeletal elements has been seen (Jantz and Jantz 1999; Martin and Danforth 2009). Improvements in disease control, healthcare, and economic growth are a few examples of changes over the last century that have played a role in the positive secular trends seen in human body size. On average, this holds true across the globe. Studies performed on populations worldwide provide supporting evidence that human beings are becoming taller (Cardoso 2008; Carrion 1994; Garruto 1995; Jantz and Jantz 2000; Ji and Chen 2008; Lin et al. 1992; Meredith 1979). Evidence of this can be seen in American samples when the sectioning points from the present study are compared with the study performed by Steele (1976). Table 4 illustrates the differences in sectioning points between the present study, which utilizes a sample from a recent forensic population and those of the sample from the Terry Collection, which was composed of Americans who had died around the beginning of the 20th century. Maximum length of the calcaneus for individuals from the present study is 5 cm larger than that of individuals from the Steele (1976) study. The average load arm width in the present sample is 2 cm larger than the average load arm width of samples from the Steele (1976) sample. And lastly, the load arm length of the calcaneus was 3 cm larger in the present sample when compared to the sample studied Steele (1976).

In general, the accuracy rates achieved in the present study are comparable to accuracy rates that have been achieved by other researchers who have utilized the calcaneus as a method for sex estimation. It is not appropriate, however, to apply univariate sectioning points from population specific studies to the present study, because the results prove to be inaccurate. The skeletal remains studied in the present research represent an American population of individuals who both were born and lived during the 20^{th} century. Prior to the present study, there were no experimental studies demonstrating that the calcaneus of a recent forensic sample could prove to be reliable indicator for sex estimation. Steele (1976) showed that the calcaneus was a reliable indicator of sex. Over time, however, researchers have shown that through the influences of secular change, it is no longer applicable to a recent forensic sample. The present study has great implications for the modern forensic community for use in instances when partial skeletonized remains are found that lack the traditional elements used for assessing sex.

The analysis of the calcaneus as an accurate estimator of sex is only one area of research that can be studied using this skeletal element. Research on the topic of secular change and the causes for sexual dimorphism in the calcaneus should be examined further. There has been a reasonable amount of research dealing with secular change in stature in specific populations (Carrion 1994; Ji and Chen 2008; Komlos 1994; Meredith

1979). An interesting topic for future research would be to examine whether there is any correlation between increases in stature and increases in other skeletal elements, such as the calcaneus. The idea that correlation does not always mean causation could be examined to explore whether increases in stature are accompanied by increases in other skeletal elements.

CHAPTER V

CONCLUSIONS

The results of this study suggest that the calcaneus can be used as a reliable indicator of sex when the appropriate measurements are taken. Load Arm Width has been shown to be the most accurate of the univariate measurements taken from the calcanei of the American sample that was utilized. The sectioning points and classification rates created using a recent sample from the William M. Bass Donated Skeletal Collection provide a reliable resource in cases where a forensic anthropologist or death investigator is presented with fragmented skeletal remains.

Studies by Bidmos and Asala (2003; 2004), Wilbur (1998), and the present study show that the most accurate measurements on the calcaneus are those that include articular surfaces. In future studies on the calcaneus, it would be advised that additional measurements, including the anterior articular surface for the cuboid and articular facet on the superior side of the sustentaculum tali, be measured. As mentioned earlier, examination of calcaneal shape in response to musculature stresses and mechanical stresses placed upon this skeletal element, due to certain lifestyles, would be a very interesting avenue for future research. Additionally, the stature of an individual should be taken into account, if accompanying records allow, examining whether there exists a correlation between height and size of the calcaneus.

It is clear from the present and past studies on the calcaneus and other postcranial skeletal elements that sexual dimorphism between male and female individuals still exists. It is also important to note the broader implications of this study, such as the presence of secular trends in individuals in the United States over the past century and population demographics. Jantz and Jantz (1999) have shown that secular trends in long bone lengths exist among Americans over the last century. The average size of the calcaneus is larger in the present study when compared to the sample utilized by Steele (1976). This suggests the existence of possible secular trends in the calcaneus and could prove to be an interesting focal point in future studies on the calcaneus. Size differences in calcanei exist between the world populations that have used this postcranial element for the estimation of sex (Bidmos and Asala 2003; Bidmos and Asala 2004; Gualdi-Russo 2007; Introna et al. 1997; Murphy 2002; Pickering 1986; Riepert et al. 1996; Steele 1976). Due to the existence of geographic differences in populations, it is important that the discriminant functions used to estimate sex from postcranial elements are population specific. By providing methods to estimate the sex of skeletal remains with the calcaneus, positive identifications may become more common when only a partial skeleton is recovered

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VITA

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