To the Graduate Council:

I am submitting herewith a thesis written by Juliet Allen Cleaves entitled "Sex and Race Determination From The Base Of The Skull." I have examined the final copy of this thesis for form and content and recommend that it be accepted in partial fulfillment of the requirements for the degree of Master of Arts, with a major in Anthropology.

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We have read this thesis and

recommend its acceptance:

Accepted for Council:

Associate Vice Chancellor and
Dean of The Graduate School

SEX AND RACE DETERMINATION FROM THE BASE OF THE SKULL

A Thesis

Presented for the

Masters of Arts

Degree

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Juliet Allen Cleaves

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ABSTRACT

The ability to determine sex and race from skeletal remains is a fundamental feature of any skeletal analysis, including population studies and personal identification. Typically, sex and race is estimated from the cranium (Giles and Elliot 1962, 1963) and recently from the base of the cranium (Holland 1986). This study investigates the application of seven craniometric measurements from the base of the skull for the identification of sexual and ethnic groups.

This study employs samples from two skeletal collections, the Hamman-Todd (n=211) and the University of Tennessee donated and forensic collections (n=81). Seven measurements are taken on 292 (101 white males, 68 white females, 68 black males and 55 black females) individuals of known sex and race. The ability to discriminate sex and race for both the Hamman-Todd and the University of Tennessee sample is investigated. The implication of secular trends, as well as dimensional change of the measurements occuring in the sample is considered in the analysis.

Multivariate and discriminant analyses on the craniometrics are used to test for differences between the variables sex and race. The variables demonstrate sexual dimorphism and racial distinctions in the Hamman-Todd and University of Tennessee collections. The statistical tests indicate the probability of accurately assigning the correct sex to be 70.01% and the probability of assigning the correct race to be 66.96%. The ability to accurately classify the variables of

sex and race from this data suggest this method be used if complete skeletal remains are unavailable.

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CHAPTER I

STATEMENT OF PURPOSE

This study investigates the application of seven specific craniometric measurements for the identification of sexual and racial groups. Previously, craniometric evaluations of the entire skull were based on linear and/or angular measurements, incorporating either the face or cranial vault. The present study investigates the relevance of linear measurements at the base of the cranium and their application for the classification of sex and racial affiliations on fragmentary cranial remains.

In an attempt to ascertain sexual and racial affiliations from the cranium, it is necessary to understand cranial differences, via secular trends or changes with age of the individual, in the size and shape of the cranium. The present study attempts to illustrate sexual dimorphism and populational differences from skeletal samples collected from American populations representing Caucasian and Negroid descent during the last two centuries. For this study, Caucasians (white) are considered to be of European ancestry, while Negroes (black) are considered to be of African descent (White and Folkens 1991). This study investigates whether secular changes and age at death impact the ability to statistically identify sex and racial affiliations accurately from the base of the cranium.

The primary objectives are the statistical examination of the evidence for sexual dimorphism and racial differences at the base of the skull. Other issues are discussed, such as the implication and

possible influences of secular trends and age at time of death in the ability to classify unknown crania. The evaluation and application of discriminant function analysis on the classification of sex and race and their applicability for the identification of ethnic affiliations for both sexes will be discussed.

CHAPTER II

STATEMENT OF PROBLEM

The separation of biological populations based on skeletal variation has been a vital component of physical anthropology since inception of the field. Physical anthropologists apply multivariate statistical techniques to define sexual and ethnic variation among human populations. Classifications of individual skeletal remains are frequently rooted in these predefined clusters of population variation. Multivariate statistical techniques developed from the morphometric data provide an avenue for physical anthropologists to test hypotheses and explore shifting variation among populations.

Research pertaining to the cranial base has had various definitions depending on the investigator. Historically, cranial base measurements have been used in the examination of cranial growth and the exploration of significant morphological and phylogenetic characteristics. Although there is a vast literature on the cranium, most research is based on measurements pertaining to both the base of the skull and frontal measurements as well as skull height measurements (Scott 1958, Schulter 1976, Angel 1982). For example, J. H. Scott (1958) uses seven structural units as his definition of the cranial base. He proposes that "The midline cranial base, extending from the anterior edge of the foramen magnum (basion) to the frontal-nasal suture (nasion), is one of the most important regions in the skull..."(Scott 1958 p319). He, like many other researchers, considers the cranial base an important component influencing the

upper facial skeleton shape and size. Therefore, most authors did not separate measurements such as basilar and lateral occipital from the facial structures when examining cranial base characteristics.

Morphologically, the relationships between the cranial base and facial structures are very significant. Many discriminant function analyses directed at determining sexual and racial identifications combine height, length and width measurements taken throughout the cranium (Jantz and Moore-Jansen 1987 and Giles 1966, Giles and Elliot 1963, 1962). However, these measurements depend on the presence of a complete skull. Physical anthropologists are presented with the continuous challenge of identifying sex and race from fragmented skeletal remains and statistical methods have been developed to deal with fragmented data (Konigsberg and Frankenberg 1993). Many authors have investigated postcranial fragments and developed multivariate and discriminant functions to aid in the interpretations of the postcranial remains (Steele 1970). Few physical anthropologists have used the cranial base as a possible source for sex and racial identification. In contrast to postcranial elements, the base of the cranium, due to cranial thickness and protection from muscles and ligaments, is more likely to survive taphonomic insults. Holland(1986 a,b,1989), in a series of three articles, proposed eight to nine measurements located at the cranial base, to determine sexual and racial affiliations. However, Holland states "...the technique should be applied with appropriate caution" (Holland 1986a). Holland does not elaborate why his technique should be applied with caution.

In the absence of any prior information, the estimation of sex in the skeleton always begins with a 50% chance of assuming the correct gender (random guessing will be correct half the time). For trained and experienced oseologists, correct identification may occur as often as 80% - 90% of the time (Stewart 1954). However, normal individual variation may produce small, gracile males and a few large, robust females, all of which would fall into the center of the distribution. This sexual dimorphic overlap is reflected in the 10% -20% error for predicting accurately the sex from cranial and postcranial remains by statistical and visual methods (White and Folkens 1991, Iscan and Miller-Shaivitz 1984 and Ubelaker 1978). Adding to the complication of individual variation within a given skeletal population is the difficulty of incorrect identification due to variation between populations (Keen 1950 and Meindl et al 1985). Some populations are generally composed of larger, heavier, robust individuals of both sexes. While in contrast, other populations are smaller and less robust. The male of the second population could easily be identified as a female of the first population. However, areas such as the pelvis and the skull are considered the best area to use for the determination of sex (Meindl et al 1985 and White and Folkens 1991). This study will determine whether seven measurements taken from the base of the cranium can be used to determine sex.

The skull is the only component of the skeleton that has been widely used in the estimation of racial affiliations. Many researchers agree that racial estimations from the skeleton are very difficult and are less reliable than predictions of age, sex, or stature (Ubelaker

1978). The determination of racial affiliation is subjective and has generally been confined to areas of the face. Racial identification has followed two major approaches, one is based on gross morphological observations of the skull and the other requires the use of craniometric measurements.

Morphologically, skeletons with a African ancestry are most noted for the alveolar prognathism, or an anterior protusion. Other population specific traits are nasal guttering, rounded forehead, bregmatic depression, wide nasal opening and what has been described as a dense or "ivory texture" to the bone (Bass 1987). Caucasians are described in juxtaposition to Negroids. Whites have little or no prognathism, a long narrow face, a narrow nasal opening, and a narrow high bridge nose. This study only examines skeletal remains from individuals whose recorded "race" is listed as Negroid (black) or Caucasian (white) and will attempt to determine if a statistical avenue for the determination of race from the measurements taken at the base of the cranium is applicable in modern identification procedures.

The ability to conceptualize sexual and racial morphologies descriptively as well as statistically, requires large collections of data. Metric observations from comparative collections were used to identify and calculate parameters of skeletal variation among sexual and racial groups. It is against these parameters that unidentified skeletal remains may be evaluated. The existence of contemporary human skeletal collections sufficiently large to develop appropriate population parameters is limited. Most research examining variation is based on a limited number of anatomical collections, such as the

Hamann-Todd (Cobb 1981) and Terry collections (Trotter 1981). These collections were assembled largely during the first three decades of the twentieth century (Cobb 1981, Trotter 1981). As physical anthropologists studied data sets such as the Hamann-Todd collection, other issues have surfaced which might influence the outcome of the investigation and its application on modern crania, such as secular change and the age of the individual at time of death. Recently, the internal biases of the collections have also been called into question and thus the applicability of these collections to assist in estimation of modern population parameters (Moore-Jansen 1989). Concerns about the collections relate to accuracy in the age documentation (Ericksen 1982), and the inherent biases in the demographic and temporal structures found in the collections (Moore-Jansen 1989).

Replicable and reliable methods for identification of sex and racial affiliation are paramount for the investigation of forensic fragmented human remains. In this thesis, multivariate statistical techniques will be used to perform an analysis on sexual dimorphism and racial affiliation. The influences of secular trends and aging trends are then evaluated. Discriminat function analyses will be used to determine the probability of assigning the correct sex and racial affiliation from the data, and will be used in the discussion concerning the application of the seven craniometrics for identification of sex and race.

CHAPTER III.

LITERATURE REVIEW

Introduction

Since the beginning of physical anthropology as a scientific discipline, growth of the cranium and the identification of individual structures composing the cranium, have been defined, studied and analyzed. Craniological measurements, which were used either separately or in conjunction with other cranial structures, have been applied to research questions in anatomy, primatology, human evolution and the variation found among and within human populations. Research on the cranium reveals a complicated relationship of growth and function between muscle, bone and fluid.

Growth of the Cranium

The adult skull contains 22 bones and together they form what is referred to as the skull or cranium. Categorically, the vault of the cranium consists of eight bones and the area of the face contains fourteen distinct bones. The cranial vault is structurally composed of the occipital bone, two parietals, the frontal, two temporals, the sphenoid and the ethmoid. The face is defined as containing two nasals, two lacrimals, two malars, two palatines, the vomer, two maxillae, the mandible and two inferior nasal conchae (Bass 1987 and Gray's Anatomy 1977). Together, the cranial vault and the face

are supported on the summit of the vertebral column and articulates with the atlas or first cervical vertebra (White and Folkens 1991). Morphologically, the skull is oval in shape, the front being narrower than the back. Functionally, the cranium serves as the supporting structure which protects and supports neural and visceral structures. The growth and development of the skull arises and matures from the matrix of tissues, brain, orbital contents, muscles, meninges, tongue, and teeth. The shape of the cranium closely relates to the functional demands of these soft tissues (Moss and Young 1960).

The occipital bone, which incorporates the base of the skull, is located at the rear of the vault and articulates with the temporals, sphenoid, parietals, and the first cervical vertebra. Of particular importance to this study, are the foramen magnum, the basi-occipital, the lateral portions and the occipital condyles. Anatomically, the foramen magnum is the large passage in the occipital which transmits the brainstem inferiorly into the veretebral canal. The basilar portion is described as a thick, square projection anterior to the foramen magnum. It is the basilar portion which articulates with the sphenoid via the sphenooccipital suture. The lateral portions of the occipital bone lie to either side of the foramen magnum, articulating with the temporals. The occipital condyles are raised oval structures existing on the laterals portions and are on either side of the foramen magnum. The articular surfaces of these condyles fit into the concave facets of the atlas vertebra (Gray's Anatomy 1977 and White and Folkens 1991).

The development and growth of the cranium begins during the first month in utero and it is not until the third month that the basic

components of the cranium are present (Fazekas and Fosa 1978). During the third lunar month, components of the fetal cranium begin to transform from ossification of sheets of condensed intramembranous material to bone and start to expand. Generally, the embryonic development of the cranial bone proceeds from the ossification centers and the growth radiates outward. The development for the ossification centers of the base of the skull, defined as the basilar (pars basilaris ossis occipitalis) and laterial occipital bone (pars lateralis ossis occipitalis), begins approximately in the third lunar month of the fetus (Fazekas and Kosa 1978).

At birth, the occipital consists of four parts, the squamous portion, the lateral parts, containing the condyles, and the basilar structure. The squamous portion and lateral portions become fused approximately at the age of 4, and by the age of 6 the basilar portion fuses with the occipital. The fusion between the occipital and the sphenoid normally takes place between the ages of 18 and 25 years of age (Zuckerman 1955, and White and Folkens 1991).

The Skull and Aging Processes

During the 1930's and 40's, anthropologists began to research dimensional changes of the face and the cranial vault to comprehend the complex relationships of shape and size. However, the investigation of shape and size focused on the growth of adolescent individuals and the remodeling of the elderly skull. Anthropologists noted sexual and racial differences in the chronological development of the cranium (Michelson 1944, Kitson 1931, Todd and Tracy 1930).

Yet, researchers did not consider the crania of middle-aged individuals and the possibility of continued change in cranial shape and size throughout life (Goldstein 1936). Tantalizing evidence of dimensional change in the cranial vault among aging adults was offered by Hrdlicka (1938) and Baer (1956). This tentative evidence stimulated anthropometric studies pertaining to age changes in the adult cranium. However, the studies which focused on age changes in human crania were designed to survey the total age range of the cranium from adolescent to elderly. The investigation into total age range resulted in the grouping of the data into large age classes. Consequently, analyses of the large data groups were directed toward contrasting mean size differences between younger and older age groups or describing general trends observed in the data. Therefore, changes occurring during midlife could not be reported (Baer 1956).

Cephalometric and craniometric changes due to the aging of an individual were not earnestly studied until the 1950's and thereafter (Thompson and Kendrick 1964, Baer and Harris 1969, Isreal 1977, 1973, Macho 1986). This research, which involved measurements of the cranial base, did not examine the cranial base as an individual component, but rather as an integrated unit influencing the overall shape and size of the skull (Scott 1958, Baer and Harris 1969, Schulter 1976, and Taylor and Dibennardo 1980). The examination of height and breadth measurements in the skull which are significant in the growth and change of the cranium, suggested height and breadth dimensions of the face will increase until the fourth decade of life, then decrease thereafter (Thompson and Kendrick 1964 and

Macho 1986). Other research indicates bone growth continues through the eighth decade of life and does not seem to be population specific or sex limited and that it appears to be a general phenomenon in humans (Garn et al. 1967, p316).

Longitudinal information collected and analyzed through the many decades of anthropological research, has indicated cranial growth through all decades of an individual's life. Logically, the entire craniofacial complex, the cranial vault and chondrocranial base are involved in a process of symmetrical enlargement.

Secular Change

Secular trends are generally defined as the micro-temporal patterns of shape and size reflected in the growth, development and maturation in populations (Tanner 1978). Skeletally, secular trends are described by physical anthropologists as the temporal observations in the fluctuation of growth due to the plastic nature of the skeletal frame (Moore-Jansen 1989).

The relationship between health and growth has been considered in the anthropological literature since the early part of our century. Hrdlicka notes that skeletal growth is doubtlessly affected by physiological factors such as work and nourishment (Hrdlicka 1938). From the time of conception, the growth and the development of the individual will be dependent upon the interactions of their genes and the surrounding environmental conditions (Frisancho et al 1977). The popular perception of this interaction is that the environment provides the external influences

for the expression of the genetic potential. All living organisms require energy and nutrients to survive and grow, and nutrients are considered as one of the most important environmental factors contributing to the growth of the organism (Frisancho 1978). When the dietary intake and quality of the nutrients is disrupted, changes occur in the growth, development and timing of maturation. The effects of under nutrition on skeletal maturation are greater during childhood than during adolescence and adulthood (Frisancho et al. 1970). Good health is considered to be a result of a balanced diet and adequate intake of nutrients, which results in the timely development of the skeletal frame. Poor health will result in slower, retarded growth of the person and their skeletal frame. Therefore, secular change found in a skeletal series is commonly believed to be a reflection of the standards in health at the time of physiological development (Angel 1982).

Anthropologists have documented secular change in relation to height and weight of various geographic populations (Frisancho 1978 and Richter and Kern 1987) and more recently, in the skull (Angel and Olney 1981, Angel 1982, Angel 1978, and Moore-Jansen 1989). The investigation of secular trends found in skeletal collections provides a challenge for physical anthropologists. As demonstrated with cranial measurements, discriminant functions developed 20 years ago, are now outdated and need to be calibrated to modern populations (Moore-Jansen 1989). Cranial measurements taken from non-modern skeletal collections should be investigated for secular trends before application on modern cases.

Deformation of the Skull

Cranial deformation has been practiced by various human groups through-out the world. The cultural practice of manipulating the shape of the head has generally been defined by anthropologists as head-binding, exclusive of unintentional cradle-boarding. Although cranial deformation is seen throughout the world, geographically, artificial deformation has been widely observed in prehistoric populations from North and South America. Classificatory systems developed to describe these deformations have been based on the type of apparatus used to deform the skull (Hrdlicka 1919). Many different classifications are recognized; two types of cranial deformation are observed and defined in this review, they are anteroposterior and circumferential. Anteroposterior deformations are characterized by anteroposterior flattening of the frontal and occipital, or occasionally just the occipital bone. The characteristic affect of the manipulation is that the lateral parietals tend to bulge. This deformation results in a triangular or bilobe appearance in superior view of the skull (Anton 1989). The circumferential deformed crania exhibit a conical shaped vault that extends posterosuperiorly. The circular elongation affects the frontal temporal squamae and portions of the parietal and occipital, while parietal bulging is observed with this deformation (Anton 1989). The pattern of circumferential deformation is attributed to the cultural practice of encircling the immature vault with textiles (Hrdlicka 1919, 1922).

The deformation of the skull and its quantifiable affect on other components of the cranium offers insight into the relationships between these functional cranial units (Cheverud et al. 1992, Anton 1989, McNeill and Newton 1965, Moss 1958 and Goldstein 1940). However, Anton (1989), McNeill and Newton (1965) and Goldstein's (1940) main research questions surrounding the cranial base, sought to clarify the different types of vault deformation and their affects on the cranial base angle. The cranial base angle has variously been defined as the declination of the pars basilaris and the basis cranii with respect to the planum angle (Moss 1958), and the angle N-S-Ba (McNeill and Newton 1965). This research was inconclusive as to the relationship between the vault deformation and the direction of cranial base angle modifications.

Anton (1989), in her research of cranial vault deformation of Peruvian skulls, demonstrates that nonangular measurements of the cranial base showed differences reflective of the morphological changes brought on by the two types of vault deformation (Anton 1989). Both deformed cranial vault groups do show differences in the base. The causations of these differences may be a result of partially or wholly different structural relationships in the skull. In the circumferential groups, the frontal and occipital migration seems to play key roles in the facial and cranial base changes. In contrast, the extent to which frontal migration alters similar structures in the anteroposterior deformations appears to be limited. The changes in the anteroposterior group appear to be the result of anteroinferior displacement of the basion-sella plane. Specific changes Anton (1989) notes in the cranial base are the correlated lateral vault

expansion with widening of the breadth of the foramen magnum in the anteroposterior deformations. Circumferential manipulations have been correlated with the narrowing of the base and the elongation of the foramen magnum in the posterosuperior cranial vault.

Pathologies, such as the hereditary disease achondroplasia will also deform the base of the cranium. Achondroplasia will distort the foramen magnum by thickening and constricting the hole and tends to shorten the basioccipital (Ortner and Putscher 1985 and Boyd 1973). Cranial deformation studies demonstrate the cranial base can be culturally and pathologically manipulated and that the cranial base shape exhibits plastic behavior as noted in secular trends studies.

Sex Discrimination

The expression of human sexual dimorphism results from a complex interaction between behavioral, physiological, and anatomical dimensions (White and Folkens 1991). Anatomical sexual extremes are more expressive in some biological areas, such as soft tissues and more reserved in other areas, such as the skeleton. Nonetheless, the skeleton does reflect differences between males and females. In general, those difference do not become pronounced until the individual reaches maturity.

Historically, anthropological investigations identifying sex from skeletal remains have focused on two techniques, gross observation and statistical computations. The morphological estimation of sex

from the skull follows similar generalizations as applied to the postcranial skeletal components. Physical anthropologists follow general descriptive characteristics applied to the skull to tentatively identify male and female crania. In general, males tend to be robust, rugged, and have more marked lines of muscle attachment than their female counterparts. The face of a male has more prominent supraorbital ridges than the female. The upper edges of the eye orbit are blunt in males, and tend to be sharper in females. Generally, the palate and teeth are larger in males. The chin of a male has more of a square shape, while the female mandible is more rounded. The vault in the female is smaller, smoother and more gracile in shape. The muscle ridges are much more pronounced in males, than in females. The posterior end of the zygomatic process extends farther, often past the auditory meatus, in males. Typically the mastoid processes and the frontal sinuses are larger in the male (Bass 1987).

In an attempt to move beyond the traditional gross morphological method of identifying sex in the skull, Keen (1950) tested his visual identification of sex by testing for significant differences between male and female craniometrics. Keen's investigation led him to outline the difficulties in distinguishing sexual identities from a skull of unknown origin. Keen noted difficulty in the determination of sex due to the variation within the population group, which he attributed to endocrine influences. Keen (1950) also noted the added complexity of sexual variation between populations.

In an attempt to move beyond the traditional gross morphological method of identifying sex from the skull, Giles and

Elliot followed Keen's lead by testing measurements via multivariate discriminant functions (Giles and Elliot 1963). Measurements of the skeleton and their statistical analysis were understood to diminish the subjectivity involved with sexing crania by gross observation. However, diverse techniques designed to perfect the sexing of skulls had not achieved great accuracy. Considerable variation of anthropological techniques for sexing crania were found in the literature. Giles and Elliot (1964 and 1963) had developed multivariate discriminant functions to aid in the investigations of unknown skulls. However, questions concerning how well the Hamman-Todd and Terry skeletal collections represent modern populations is still being investigated (Ousley 1993) .

Statistical techniques, such as multivariate analysis, are used for accurate prediction of sex (Meindl et al. 1985, Giles and Elliot 1966, 1963). However, for these statistical techniques to be accurate, the techniques must deal with multiple issues. Factors of individual variation within the given skeletal population and variation among other skeletal populations have been documented by Keen (1950) and Meindl et al. (1985). Currently, sexual classification of skeletal remains are being tested in the anthropological literature for influencing factors such as geographical representation and bias in the representation of males and females in the skeletal collections (Ousley 1993). Even though current anthropologists are discovering factors which influence the outcome of the Giles and Elliot method, Giles and Elliot (1963) outlined a statistical avenue for the objective application of sexing the skull.

Race

Defining the term "race" has proven difficult in the history of physical anthropology (Livingstone 1962, Dobzhansky 1962). Concepts of race are a mixture of biological, social and ethnic criteria used in typological fashion (White and Folkens 1991). By definition, all members of *Homo sapiens* have the potential for reproduction, and any subspecific category is arbitrary. The confusion arising from these difficulties has led physical anthropologists to view the term 'race' as counterproductive in their investigations. However, in investigating forensic cases and geographic ancestry, "race" has important repercussions for the positive identification of missing individuals and the understanding of adaptation and migration of human populations. Questions concerning "race" have dealt with anthropological issues of origins, antiquity, taxonomy of races, evolution through environmental and social adaptation and definitions of various biological populations (Coon 1963). Different approaches have been developed and refined for the investigations of these issues. Genetic research, on characters such as blood-group alleles, dermatoglyphics, nuclear DNA and mitochondrial DNA (mtDNA), have been used to research ethnic population affinities and hypotheses of migration (Micle and Kobyliansky 1985, Boyd 1956, Roberts 1955 and Glass and Li 1953). One series of studies which examined the skull for structural components that contain racially distinct characteristics, was produced by John Cameron (1926a, b, 1927a, b.). Cameron noted in three cranial studies, that it was

evident that racial affiliation played an important role in cranial size and shape differences.

Anthropological investigations to identify race from skeletal remains have focused on two techniques, gross observation and statistical computations. Morphologically oriented research has focused on defining the differences between populations by means of physical appearances of skin color and skeletal attributes (Rightmire 1972, Herskovits 1930, Tobias 1959, Michelson 1944, Lewis 1942, Kitson 1931, Todd and Tracy 1930 and Todd 1929). Gross observation of the skeletal material such as the cranium follows a subjective framework for the identification of racial affiliations. Admixture between populations compounds the difficulty in the correct classification of the skeletal remains. Cranial metric evaluations such as multivariate analysis and discriminant function analysis have been developed to aid in the identification of racial affiliations and bypass the subjectivity of gross observations (Giles and Elliot 1962, Howells 1969). The assessment of racial affiliation by means of statistical techniques must take into account issues of geography, admixture and representation of different populations in comparative collections (Jantz and Moore-Jansen 1987). The statistical assessment of the Giles and Elliot (1962) method by various authors, demonstrates the need for appropriate comparative collections when assessing race of the unknown cranium. For example, Birkby (1966), having Native American crania in his sample, indicated the Giles and Elliot method was inaccurate. In contrast, Snow et al. (1978), with a bias of white males in his sample, reported the successful use of the Giles and Elliot discriminant racial

function. Ayres et al. (1990) reported the method as inaccurate, using the Forensic Data Bank at the University of Tennessee. Despite the difficulties with the application of the Giles and Elliot method on modern samples, a statistical framework for the objective racial identification of an unknown crania has been identified.

CHAPTER IV.

MATERIALS AND METHODS

Introduction

The objective behind the collection of the data was to obtain a large series of complete and undeformed adult crania for statistical evaluation. To address the research questions of sexual dimorphism and racial affiliation, as well as secular and aging trends through time, it was necessary to locate collections which contain individuals of known sex and racial affiliations. The following gives a brief description of the content and sources of the collections used in this study. The methods of collecting the data and the anatomical definitions of the measurements gathered are also described.

Hamman-Todd Collection

The Hamman-Todd skeletal collection was originally maintained at the Western Reserve University (Case-Western Reserve), Department of Anatomy. Currently, the Hamann-Todd collection is housed at the Cleveland Museum of Natural History and maintained by Dr. Bruce Latimer and Mr. Lyman Jellema.

For this study, 211 crania were measured from the Hamann-Todd collection, which is the largest comparative anatomical skeletal

collection in the United States (Cobb 1981). The Hamann-Todd collection consists of over 2,000 individuals collected and macerated in the early 20th century in Cleveland, Ohio. The Hamann-Todd collection is unique due to the size of the collection and the assemblage of information pertaining to each individual skeleton. The name, age, ethnicity, gender, stature, date of birth and death, location of birth, among other ancillary information, have been recorded in association with the cataloged skeleton. The collection contains "races" known as Afro-Americans (black), American-Indians, Mexican-Americans, Asian-Americans and Euro-Americans (white). Published estimates maintain sixty percent of the Euro-American samples and one percent of the Afro-American samples were born outside of the United States (Cobb 1952:795). All segments of the Hamann-Todd collection can be described as representing the lower economic classes from specific geographical areas. This is elucidated from the records maintained on the cause of death. The majority of individuals died from tuberculosis, pneumonia or alcoholism. All of these diseases have been attributed as characteristics of lower socioeconomic groups (Cobb 1952).

The University of Tennessee Donated and Forensic Collection

The crania from 81 individuals, collected by Dr. William M. Bass, were measured from The University of Tennessee donated and forensic collection. The collection represents a known modern collection of skeletal remains from the Tennessee area. The donated collection represents individuals who were unclaimed bodies that

come through the medical examiners system. The measurements taken from the forensic skeletal sample represent individuals whose sex and racial affiliation have been positively identified. Information containing basic cranial measurements with additional data documenting age, sex, ethnic affinity, place and date of birth are contained in the Forensic Data Bank. The Forensic Data Bank was developed and is directed by Dr. R. Jantz, and is currently the responsibility of Mr. Steve Ousley.

The Data

The cranial structures pertaining to this study are located at the base of the skull and are components of the occipital bone. The components are the basilar (pars basilaris ossis occipitalis) and lateral occipital bone (pars lateralis ossis occipitalis). These units, when fused in the infant, form the foramen magnum and the occipital condyles (Gray's Anatomy 1977).

Seven linear measurements were taken from the base of the cranium. These seven measurements were chosen for this study due to the homologous qualities of the measurements in skeletal populations and their presumed replicability for the investigation. Of the seven measurements, two measurements are taken on both the left and right sides of the foramen magnum. The measurements are defined as:

The Length of the foramen Magnum (lfm):

The maximum length of the foramen magnum as measured from basion to opisthion, along the mid-sagittal plane.

The Width of the Foramen Magnum (wfm):

The maximum width of the foramen magnum, as measured perpendicular to the mid-sagittal plane.

The Length of the Basilar Process (lb);

The maximum length of the basilar process, as measured from basion to hormion.

The Length of the Occipital Condyles (loc):

The maximum length of both the right and left condyles, as measured along their long axes from the ends of the articular surfaces.

The Width of the Occipital Condyles (woc):

The maximum widths of both the left and right condyles as measured from the articular edges along a line perpendicular to the length.

(Refer to Figure 1.) The crania that were measured for the study were selected only if they met the following requirements:

1.) The crania are of known sex and race.

2.) The crania showed no signs of deformation, cultural or pathological.

3.) The base of the crania are complete.

4.) Only mature specimens are measured.

The sex and race was not known to the author at the time measurements were taken. The concept of "blind" sampling was employed to limit bias during the measurement procedure. The measurements were taken with a Brown and Sharpe digital caliper and electronically input from the caliper into a data file. This allowed the author to avoid errors related to the manual input of data.

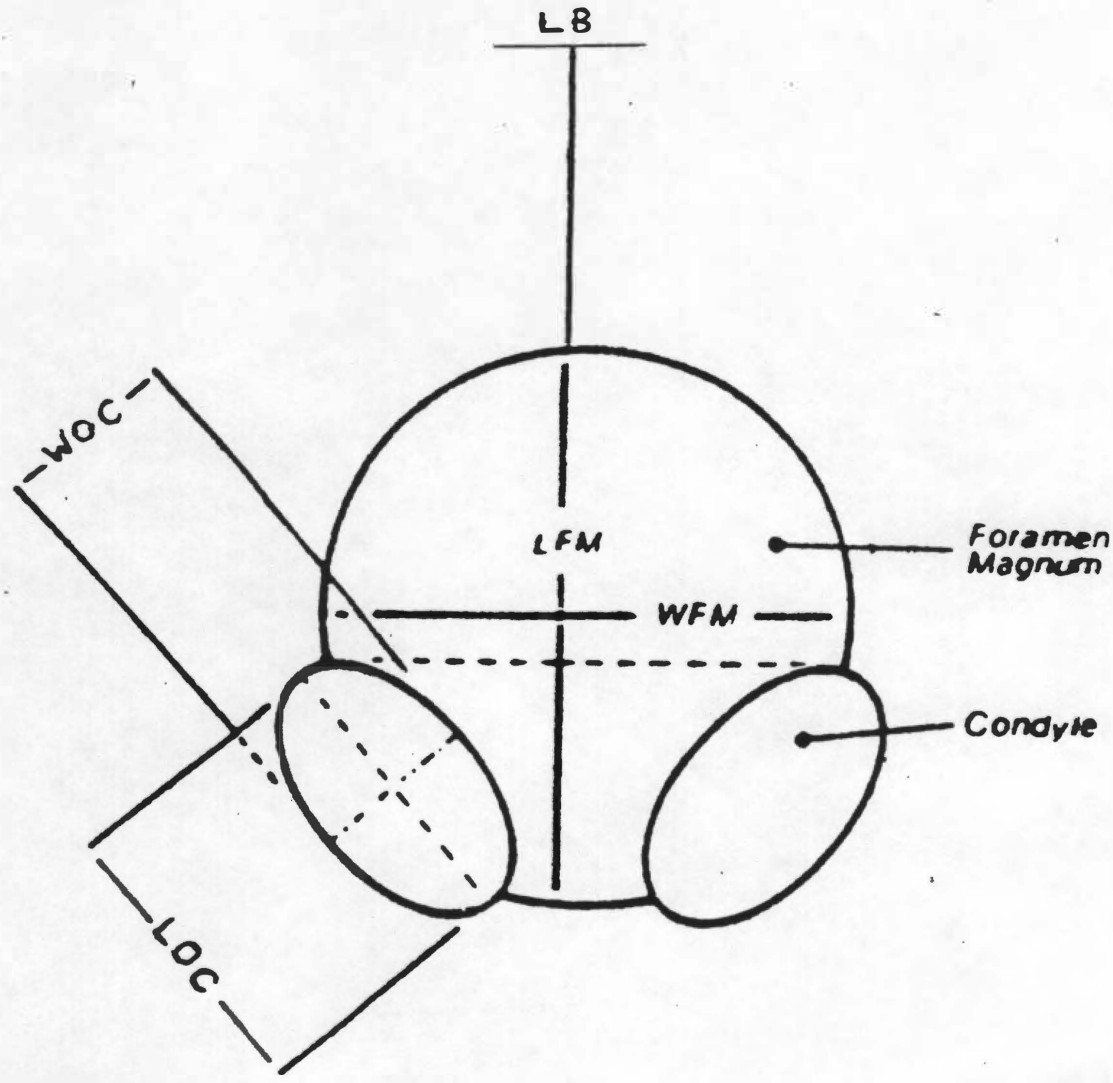


Figure 1.

Schematic representation of Cranial measurements

CHAPTER V.

ANALYTICAL PROCEDURES AND RESULTS

Introduction

The purpose of the statistical analysis is to determine whether sexual dimorphism and between group racial variation are statistically significant in the skeletal sample. The multivariate methods will investigate secular trends within and between the Hamman-Todd early twentieth century collection and the University of Tennessee's modern donated and forensic collection. Age at the time of death will be examined by similar statistical methods to determine if the age of the individual at the time of death influences the seven measurements. Dimensional change of the cranium, whether secular change or age related issues, will be examined to determine the potential impact on interpretations of the data.

Three statistical analyses are used on the skeletal sample, 1.) MANOVA, 2.) discriminant function and 3.) principal coordinate analysis. The statistical examination will test the null hypothesis that the criterion variables (the craniometrics) are unrelated to the predictor variables (e.g. sex or race), that is,

$$H_0: \sum yx = 0$$
$$H_1: \sum yx \neq 0$$

Where y represents the "n" by "p" matrix of craniometric data, and x represents the "n" by "k" matrix of dummy variables coding, for groups (e.g. sex or race). $\sum yx$ is a sub-matrix of the criterion and predictor sums of squares and cross-products matrix. Specifically, this submatrix is for the pairing of predictor with criterion variables. The MANOVA examines the simultaneous effect of the independent variable(s) (e.g. sex or race) on all of the dependent variables (craniometrics) and evaluates the relationship between groups in terms of homogeneity of their respective mean vectors. Discriminant analysis is a statistical technique which allows the simultaneous examination of variables into the differences between two or more groups of independent categories, with respect to several dependent variables (1980). The principal coordinate analysis of a D^2-matrix, which produces the same results as canonical variate analysis, allows the discrimination of data which contain very close clusters that may partly overlap (Sneath and Sokal 1973).

Summary Statistics

Means and the variance-covariance matrices for all craniometric variables were calculated (Refer to appendix, A.1 and A.2.). These statistics were computed for males and females, of Afro-American (Black) and European (Caucasian) samples from the Hamman-Todd and University of Tennessee collections.

Multivariate Analysis

Multivariate techniques differ from univariate and bivariate analyses in that multivariate analyses examine the covariances or correlations which reflect the extent of relationship among three or more variables (Dillion and Goldstein 1984). Multivariate analysis examines the simultaneous effect of the independent variable(s) on all of the dependent variables and evaluates the relationship between groups in terms of homogeneity of their respective mean vectors. The multivariate analyses applied to this study explore the relationship between one or more of the independent classification variables (e.g. sex, race and collection) and the dependent variables (e.g. the craniometrics).

The calculations of the multivariate analysis are based on the sum of squares and cross-product matrices. The data matrix is assembled into p columns representing the criterion (craniometrics) variables, and K columns, representing the predictor variables (race, sex, and age). The total data matrix is therefor an n by p+k matrix. The column means are subtracted from each entry, in a respectable column. Then the sums of squares and cross-products are formed as:

$$Syy = Y'Y$$

$$Syx = Y'X$$

$$Sxx = X'X$$

$$Sxy = X'X$$

A multivariate test statistic, Wilks' Lambda, is calculated to test the significance for the main effects and the interaction effect of the variables (e.g. sex, race, age).

Wilks' Lambda is computed as;

$$\Lambda = \prod_{j=1}^{m}\left(1-\hat{\lambda}_{(j)}\right) = \frac{|Syy^{-1}SyxSxx^{-1}Sxy|}{|Syy|}$$

where Λ is a Wilks' Lambda variable and M = min(k, p), where k is the number of variables representing the criteria, and p is the number of craniometrics (Dillion and Goldstein 1984). The eigenvalues are represented by:

$$\hat{\lambda}_{(j)}$$

Where each $\lambda_{(J)}$ is an eigenvalue. Wilks' Lambda tests for the statistical significance of the canonical correlations when the sample size is large. Wilks' Lambda can also be written as a ratio of the determinant of the sum of squares and cross-product error matrix of the effect being tested over the determinant of the sum of the corresponding sum of squares and cross-product matrix hypothesis and the sum of squares and cross-product error matrices (Klecka 1980). Wilks' Lambda is a measure of differentiation among groups, the probability of which is tested by the F test of significance. A decrease of the Wilks' Lambda is contrasted by an increase in the F value which in turn is indicative of improved statistical significance (Klecka 1980).

To test for interaction effects, the predictor variables can be crossed (i.e., multiplied across all combinations) and appended to the data matrix. A significant interaction effect for race crossed with sex indicates that there are different levels of sexual dimorphism between the two races considered in this study. If the interaction is not significant, then it can be dropped from the model, and only the main effects of sex and race need be considered. If the main effects are significant, then this indicates that there is significant sexual dimorphism and/or differences between the races.

Five models were run for the interpretation of homogeneity among the skeletal samples, the resulting raw scores are contained in the appendix. The tests performed on the data were a probability estimate of the effects on the dependent variable by the independent variable. For example, the estimate of effects statistically indicate if the dependent variable (i.e. foramen magnum length) is effected by the independent variable (i.e. sex).

The test for estimating effects was first computed for the model with the main effects of sex and race, and their interaction sex*race (refer to appendix, A.1). With a predetermined significance level of .05 (α= .05), the probability value of .573 from Wilks Lambda, and the Univariate F probability tests that examine for the effect of race*sex, cannot reject the null hypothesis (H_0: $\sum yx = 0$). Thus there are equivalent levels of sexual dimorphism within race.

The second model was run for the main effect of collections, sex and race, and the interaction of sex with collection and race with collection. The test controlled for sex and race in the two collections to determine if the association of the collection shows differences

within the variables of sex and race. Since α =.05 and the Wilks' Lambda probability value is .026, the null hypothesis is rejected for the interaction of sex*collection (refer to appendix, A.4). The Univariate F probability tests specifically indicate the measurements of basilar length (.012), and occipital condyle length on both the right and left side of the foramen magnum (.034 and .05) as representing different levels of sexual dimorphism within the collections. The estimate for effects between race and collection indicate no significant racial differences between the collection (refer to appendix A.4a). With α = 05, and the Wilks' Lambda probability value of .545, the null hypothesis cannot be rejected.

A third model examines collection variability(refer to appendix, A.5). The results of the multivariate test indicate variability between the collections. Therefor the null hypothesis of equal means in the Hamman-Todd and University of Tennessee collection can be rejected. The Univariate F probability test specifies the right occipital length and right occipital width as being significantly different between the collections (.001 and .019).

The fourth test examines sexual and racial differences in the Hamman-Todd and University of Tennessee skeletal collections (refer to appendix, A.6 and A.7). The test for sexual and racial differences strongly indicates a significant difference existing between males and females and a difference between blacks and whites. The fourth model, testing for sex, produced a Wilks' Lambda probability value of <0.001 and Univariate F probability Scores of <0.001 and 0.001 for all dependent variables. Therefor the null hypothesis of equal means between the sexes can be rejected. The test for race also produced a

Wilks' Lambda probability value of <0.001 and once again the null hypothesis can be rejected. However, the Univariate F probability statistics indicate not all dependent variables are significant in determining racial affiliation in this data set. Only foramen magnum length (<0.001) and Basilar length (<0.001) have a significant probability for the Univariate F probability scores.

To determine if the age at the time of death of the individual influences the dimension of the dependent variables within the main effects of sex and race, an estimate of effects was run on age, controlling for sex and race (refer to Appendix A.8 and A.9). The first model, age*sex, does not demonstrate a difference of dimension of the dependent variables within the sexes across age. With a predetermined α = .05 and the Wilks' Lambda probability value of .929, indicate the null hypothesis cannot be rejected. The Univariate F probability tests do not indicate any dependent variables as being significantly different between the sexes. across age The second model run on age*race suggests a slight difference occurring within the main effect of race. The Wilks' Lambda probability value of .043 enabled the rejection of the null hypothesis. In particular, the Univariate F probability tests indicate the right occipital breadth measurement as demonstrating dimensional change within the independent effect of race.

The sixth and last MANOVA analysis was run to examine change in the dimension of the dependent variables across age (refer to Appendix A.10). This model was testing to determine if the age of the individual influences the dimension of the dependent variable. For example, as the individual ages, does the dimension of width or

length of the dependent variable change. With a predetermined alpha level of .05 and a Wilks' Lambda probability values of .242, the null hypothesis of equal means is accepted. The test for the effect of age, demonstrates that the age of the individual at the time of death does not influence the dimensional measurement of the dependent variables.

Discriminant Analysis

Discriminant analysis is a term used to describe several related statistical techniques. This study will employ the discriminant analysis that performs classificatory analyses, as well principal coordinates analysis of the variables in question. Classification is a separate statistical activity in which the discriminating variables are used to predict the group to which a case most likely belongs. That is, the equations employed will combine the group characteristics in a way that will allow one to identify the group which a case most resembles (Klecka 1980). Discriminant analysis allows the simultaneous investigation of the differences between two or more groups of independent categories, with respect to several dependent variables (Klecka 1980). The ability to classify observations correctly into their constituent groups is an important performance measure governing the success or failure of a discriminant analysis (Dillion and Goldstein 1984).

Classification analysis is the comparison of the mean of the case under investigation to the position of each group's centroid ("mean"). The examination of the centroids, enables the discrimination of the

centroids and identification of which centroid minimizes the distance (D^2) of the new case. Within-group variance-covariance matrices and vectors of group means provide the necessary information for the classification of a new case.

The Mahalonobis distance of a case to each centroid is:

$$D^2=(x_i-m)' S^{-1}(x_i-m)$$

Where X_i is the vector of observations for the new case, M is a vector of means for one of the groups, and S is the pooled estimate of the variance-covariance matrix. From this, a new case will be assigned to the group against whose centroid the case has the minimal distance.

Principal coordinates analysis is a technique which computes the principal components of any Euclidean distance matrix without recourse to the original data matrix or variance-covariance matrix of the characters (Sneath and Sokal 1973). This operation is carried out upon a dissimilarity matrix **U** with individual coeffecients U_{jk}. The computation of matrix **E** with elements follows;

$$e_{jk} = -1/2U_{jk}$$

The next computation of the matrix **F** elements follows;

$$f_{jk}=e_{jk}+\frac{1}{t^2}\sum_j \sum_k e_{jk}=e_{jk}-\bar{e}_j-\bar{e}_k+\bar{\bar{e}}$$

This formula indicates that each element e_{jk} should be corrected as follows. Subtract the mean of all elements e_{jk} of its row and the mean of all elements of its column and add the mean of all the elements of matrix **E**. Then find the eigenvalues and eigenvectors of **F**. Normalize

the k th eigenvector so that its sum of squares equals the k t h eigenvalue of **F**. The matrix of normalized eigenvectors gives the coordinates of the variance-covariance matrix of the groups on their principle axes (Sneath and Sokal 1973, p248). This is related to the methods based on Mahalonobis' generalized distance and hence related to discriminant functions (Sneath and Sokal 1973, p249).

Generally, the prediction of group membership is applied for cases which have an unknown affiliation. By taking known cases and applying a classification discriminant function, the proportion of cases correctly classified indicates the accuracy of the procedure and indirectly confirms the degree of group separation (Klecka 1980). The results of the discriminant analysis are listed in a contingency table, the number misclassified and the amount classified correctly against predicted group membership, as well as the allocation error. The allocation error is the percentage of misclassified cases. The estimation of the allocation error is biased for small samples, when using reclass of the training sample.

A bootstrap technique called the 0.632 estimator was run on the data (Efron 1983). The Bootstrap is defined as a means of estimating the statistical accuracy of one or more parameters from the data in a single sample by mimicking the process of taking many samples (Diaconis and Efron 1983). The bootstrap is generated by numerously copying independent identically distributed cases. From this "new' sample, the original sample is tested and evaluated. The purpose is to find a relatively unbiased estimate of allocation error. The 0.632 is obtained by computing, 0.368 * biased estimate + 0.632 * bootstrap estimate. The 0.632 estimator is viewed to be a more

accurate represention of the ability of the discriminant functions classification (Mclachlan 1992).

A series of discriminant functions were run on the skeletal data. The skeletal sample was first separated into Hamman-Todd and University of Tennessee collections and then combined to be analyzed. The fourth test examined the overall ability to determine sex and race from four categories (white male, white female, black male and black female). The discriminant functions applied to the data produce a biased analysis of the accuracy of predicting sex and race, then the 0.632 estimator is used for prediction of an unbiased evaluation of sex and race from the data.

The first classification function was run on the Hamman-Todd collection (refer to appendix, A.11). Of the 211 crania analyzed for sex discrimination, 33 males and 32 females were misclassified. The allocation error was 30.27% for males and 31.37% for females. Overall, 30.81% of the cases were misclassifed in the Hamman-Todd collection. Conversely, the discriminant function was able to classify the correct sex in the Hamman-Todd collection for 69.80% of the males and 68.63% of the females, for an overall correct classification of sex in 69.19% of the cases. The 0.632 estimator bootstrap technique, with 1000 separate runs, produced a relatively unbiased allocation error value of 31.84% for males and 31.49% for females, with a 31.67% allocation error for both males and females. The unbiased estimates of correct prediction is therefore 68.16% for males and 68.51% for females, with correct classification of 68.33% for both males and females from the Hamman-Todd collection.

The prediction of racial affiliation was slightly less accurate than the prediction of sex (refer to appendix A.11). From a sample of 105 whites, 34 were misclassified as black, of 106 blacks, 34 were misclassified as white. The allocation error value was 32.38% for whites and 32.07% for blacks, leaving the total misclassification error rate at 32.23%. The biased racial estimate of allocation error was able to predict correctly the race from the craniometrics from the Hamman-Todd collection 67.62% for whites, 67.93% for blacks and 67.77% for both whites and blacks. The relatively unbiased 0.632 estimator predicted the allocation error value of 34.67% for whites and 31.42% for blacks, with a total allocation error rate of 33.04%. The unbiased estimates of correct prediction of race is therefore, 65.33% for whites and 68.58% for blacks. Overall, the 0.632 estimator could classify correctly 66.96% of the variable race from the Hamman-Todd collection.

The second discriminant analysis was run on the University of Tennessee collection. With a sample size of 81 cases, the results for sex discrimination in the data revealed: out of 60 males, 14 males were misclassified as females and of the 21 females, 7 were misclassified as males. The allocation error was 23.33% for males and 33.33% for females; the allocation error for both male and females was 25.92%. The discriminant function was classify sex correctly in the University of Tennessee collection for 76.67% of the males, 66.67% of the females, and 74.08% of the total sample. With only 21 females in the sample, the University of Tennessee sample consists mainly of white males. Therefore, the results of the discriminant function should be considered an unreliable estimate. According to

standard statistics, a sample of 30 or more is considered to represent a normal population distribution; the probability of gaining an accurate representation of the data is improved as the sample size increases (Ott 1988). The 0.632 estimator is a discriminant function which adjusts for bias representation and with 1000 separate bootstrap runs, estimated the unbiased allocation error to be 27.24% for males and 32.40% for females. For the total sample, the allocation error value was 28.58%. The ability to classify sex from the University of Tennessee collection was 72.76% for males and 67.6% for females. Overall, the 0.632 estimator classified correctly 71.42% of the males and females.

The University of Tennessee collection represents a small sample of modern blacks and whites (refer to appendix, A.12). From a sample of 64 whites, 17 were misclassified as black. From a sample of 17 blacks, 7 were misclassified as white. The allocation error was 26.56% for whites and 41.18% for blacks, with a total misclassification error rate of 29.63%. The racial discriminant function was able to classify correctly the race for 73.44% of the whites, 58.82% of the blacks and 70.37% for the total sample. The 0.632 estimator produced an unbiased allocation error value of 29.24% for whites and 50.61% for blacks; with a total allocation error rate of 33.73%. The 0.632 estimator classified correctly 70.76 of the whites from blacks, and 49.39% of the blacks from whites 49.39%. Overall, the 0.632 estimator could predict correctly 66.27% of the skeletal sample.

The third discriminant analysis combined the two collections to form a sample size of 292 cases with complete cranial data. The

results for sex discrimination in the data revealed: of 169 males, 41 were misclassified as females and of 123 females, 42 were classified as males. The allocation error was 24.26% for males and 34.14% for females, with a total allocation error rate of 28.42%. The discriminant function was able to classify 75.74% of the males, and 65.86% of the females correctly. Overall, 71.58% males and females were classified correctly in the combined collection. The 0.632 estimator, with a bootstrap technique containing 1000 separate runs, estimated the unbiased allocation error to be 26.45% for males and 34.83% for females. For both males and females the allocation error was 29.99%. The ability to accurately classify sex from the combined collection was 73.55% for males and 65.17% for females. Overall, the 0.632 estimator predicted correctly 70.01% of the males and females.

From a sample of 292 complete crania, representing both the Hamman-Todd and University of Tennessee collections, the results of the investigation of race are: of 169 whites, 50 were misclassified as black, of 123 blacks, 39 were misclassified as white. The allocation error was 29.59% for whites and 31.71% for blacks, leaving the total misclassification error rate at 30.48%. The racial discriminant function was able to classify correctly the race from the craniometrics from the combined sample for 70.41% of the whites, for 68.26% of the blacks and for 69.52% of both whites and blacks. The 0.632 estimator gave the unbiased allocation error of 32.07% for whites and 32.53% for blacks, with a total allocation error rate of 32.26%. The 0.632 estimator predicted correctly 67.93% of the whites from blacks, and 67.47% of the blacks from whites. Overall, the 0.632 estimator could classify correctly the racial affiliation 67.74% of the

time, establishing a more realistic evaluation of discriminating race from the combined collection.

The fourth discriminant analysis examines the ability to determine the number of misclassifications out of the actual number of each group. The analysis is performed on a four group case. The groups are race (white and black) and sex (male or female). The discriminant function is independently run on the Hamman-Todd collection, The University of Tennessee collection and then on the combination of the two collections.

Two-hundred and eleven Hamman-Todd crania were analyzed to determine the misclassification rates of four groups, white male, white female, black males and black females (refer to appendix , A.14). Of the 54 white males in the Hamman-Todd collection, 23 (44.44%) crania were misclassified as either being white female, black male or black female. Of the 51 white female crania, 23 (49.09%) were identified as either being white male, black male or black female. Of the 55 black males in the Hamman-Todd collection, 23 (50.09%) crania were misclassified as either being white male, white female or black female. Of the 51 black female crania in the collection, 24 (47.05%) were misclassified as white male, black male or white female. The 0.632 estimator of misclassification, with 1000 separate bootstrap runs, produced a more realistic estimate for the Hamman-Todd collection: 46.30% of the white males were incorrectly misclassified, 51.9% of the white females were identified incorrectly, 55.62% of the black males were misclassified and 48.60% of the black females were misidentified. The 0.632 predicted correctly 53.70% of

the white males, 48.10% of the white females, 44.38% of the black males and 51.40% of the black females.

Eighty-one University of Tennessee donated and forensic crania were analyzed for misclassifications (refer to appendix, A.15). Of the 47 white males in the Tennessee collection, 25 (53.19%) were misclassified as either being white female, black male or black female. Of the 17 white female crania, 7 (41.17%) were identified as either being white male, black male or black female. Of the 13 black males in the Tennessee collection, 6 (46.15%) were misclassified as either being white male, white female or black female. Of the 4 black female crania in the collection, none were misclassified. The 0.632 estimator of misclassification, with the 1000 separate bootstrap runs, is able to produce a relatively unbiased estimate of misclassification for the small sample size obtained from the University of Tennessee collection: 55.15%% of the white males were incorrectly identified as white female, black male or black female. 46.72% of the white females were misclassified by the 0.632 estimator, 59.90% of the black males were classified as white males, white females or black females and 9.2% of the black females were incorrectly identified. The 0.632 estimator was able to produce a more realistic evaluation of the ability to assign race from the University of Tennessee collection than the original discriminant function.

From a sample of 292 complete crania, representing both the Hamman-Todd and University of Tennessee samples, the collections were analyzed for misclassifications (refer to appendix, A.16). Of the 101 white males in the collections, 50 (49.5%) were misclassified as either being white female, black male or black female. Of the 68

white female crania, 31 (45.58%) were identified as either being white male, black male or black female. Of the 68 black male crania, 33 (48.52%) were identified as either being white male, white female or black female. Of the 55 black female crania, 25 (47.27%) were misclassified as being either white male, white female or black male. The 0.632 estimator of misclassification estimated incorrectly 51.68% of the white males, 48.04% of the white females, 53.18% of the black males and 47.11% of the black females. The 0.632 was able to correctly assign 48.32% of the white males, 51.96% of the white females, 46.82% of the black males and 52.89% of the black females. The skeletal sample is considered biased towards white males. White males are represented by 101 crania, the remaining 191 crania contain 31 white females, 33 black males and only 26 black females. Even with the bias towards white males, the ability to produce a relatively unbiased estimate by the 0.632 discriminant function still reveals a high misclassification rate of the crania.

The principal coordinates were produced for the analysis of classification of the combined collection (refer to appendix, A.17). This is a visual representation of the four groups (White male, white female, black male and black female) in a 2-d plot which is based on the Mahalonobis distance matrix (refer to appendix, A.17). The first axis represents 51.73% of the information derived from the distance matrix, the second axis represents 36.34% of the information contained in the distance matrix, the third axis contains 11.93% of the information and is not represented in the plot. The two dimensional plot visually represents the centroids of the variables, but does not depict the dispersion of the sample which would appear

as an ellipsoid centered on the centroid. The principal coordinates represented in A.17 visually demonstrate the sexual dimorphism and racial differences in the craniometrics. For example, white and black males are separated and loosely clustered above white and black females. The racial differences are not as evident as the sexual dimorphism but whites and blacks are visually distinct. The white ancestral affiliation of the skeletal sample is loosely clustered to the lower left corner of the graph and the sample of black crania is clustered in the upper right corner of the graph.

CHAPTER VI.

DISCUSSION AND CONCLUSIONS

Analysis of seven linear measurements located at the base of the cranium has been examined previously by Holland (1986) with moderate results using the Terry collection. The six regression models formulated by Holland (1986a) predicted the sex from the sample with 71-90% accuracy and predicted race of the sample with 70-86% accuracy (Holland 1986b). The present research has examined the statistical relationship between the seven linear measurements with respect to sexual dimorphism and racial affiliation using two different American samples, the Hamman-Todd (n=211) and the University of Tennessee donated and Forensic (n=81). Multivariate and discriminant analyses allowing for the discrimination of sex and race have been documented from the Hamman-Todd, University of Tennessee and for the combined sample. The results of this investigation predicted sex of the combined sample with 70.01% accuracy and predicted race with 67.74% accuracy. Secular trends and age related issues also have been documented from the Hamman-Todd, University of Tennessee and the combined sample. The multivariate and discriminant analyses based on the sample are only for white and blacks and excluded Asian ancestry.

The results of this study indicate that the craniometrics evaluated contained sexually dimorphic and racially distinct traits

within the collections. All seven craniometrics were sexually dimorphic. In contrast, only two measurements, foramen magnum length and Basilar length, were significant in determining racial assignments. The probability to classify sex and race of the cranium did not achieve similar results as Holland's published accounts. A number of issues may be involved with the discrepancies between this study and Holland's findings. The sample of 100 individuals from the Terry collection served as data for Holland's investigation. The Terry collection consists of individuals born approximately 20 years later than the individuals in the Hamman-Todd collection (Cobb 1981 and Trotter 1981). It has been established in this study that variability, due to geography or secular change, exists between the Hamman-Todd and University of Tennessee collection. It is quite possible the same variation exists between the Terry and Hamman-Todd collections, resulting in different accounts of predicting sex and race from the cranium. Another issue is the statistical methods used by Holland, which were multiple regression equations used to develop sectioning points for the determination of sex and race. In this study, the analysis of sex and race was performed together. That is, all four groups, white, black, male and female, were analyzed in respect to the craniometrics. The results of the combined discriminant analysis is a lower assignment prediction than you would estimate if sex and race were separated for the analysis. Holland's published estimates were based on regression analysis, which can only analyze two groups, sex or race, the 0.632 estimator of misclassification was not available to Holland at the time of his study. With the application of the 0.632 estimator, this discriminant

function presented a more realistic evaluation of the success rate in prediction of sex and race, due to the design of the bootstrap technique. It is therefore not surprising that the 0.632 estimator predicts a much different outcome than Holland's published assignment sex and race of the cranium, and provides a critical account of the use of these craniometrics in the identification of sex and race of an unknown cranium.

Even though recent investigations of age and its relation to changes in cranial size and shape indicate cranial changes occurring late in life (Thompson and Kendrick 1964 and Macho 1986), the results of this investigation reveal no age or sex related changes occurring within the craniometrics. Dimensional differences are, however, evident between whites and blacks with respect to age. A slight difference did occur within the main effect of race, in particular the right occipital breadth. It is not clear why the right occipital breadth shows dimensional change between whites and blacks. Especially since other avenues of research indicate cranial growth continuing through the eighth decade of life and does not seem to be population specific or sex limited (Garn et al. 1967).

Statistical evidence exists for variability between the Hamman-Todd and the University of Tennessee collections (Appendix, A.5). The Univariate F probability tests specify the right occipital length and right occipital width as being significantly different between the collections. Whether this is a result of secular trend or geographical variation between the Hamman-Todd (Cleveland) and University of Tennessee (Southeast), it could not be determined. The University of Tennessee sample should be expanded and other data sets

incorporating a wider geographical range should be included before a hypothesis concerning the variability between collections be proposed. The variability between Hamman-Todd and University of Tennessee collection suggests other vintage collections, such as the Terry collection, be used with caution when developing statistical models for the prediction of sex and race for modern crania.

The formulae available for the estimation of sex and race are numerous, including different statistical formulae employing cranial and post cranial elements (Iscan and Miller-Shaivitz 1984, Iscan 1983, DiBennardo and Taylor 1979, Kajanoja 1966). The analysis of skeletal material available should be used in order of reliability when determining sex and racial affiliation. The os coxae and complete cranium is considered the most accurate in determining sex and racial affiliation. However, the occurrence of fragmented remains does occur and the need to determine the applicability of sex and racial affiliation from these fragments makes this study valuable. It is important to have sex and race estimations using a wide variety of skeletal elements so when the complete recovery of skeletal material is not possible, the skeletal analysis may be as thorough and accurate as possible in order to make a positive identification.

It is clear this study shows the limitation of deducing sex and race from the cranial base. The statistical evaluation of sexual dimorphism predicts a 70.01% probability of assigning the correct sex from the collections. The probability of predicting race was determined by the 0.632 estimator to be 0.6696 (69.96%). With influencing factors such as geographical variation as well as secular trends, the probability of assigning the correct sex for an unknown

cranium is actually lower. Once again, this probability was developed for the Hamman-Todd and University of Tennessee collections. Geographical as well as populational variability and admixture will influence the probability of correct assignment of race for an unknown cranium. The craniometrics employed in this study do not statistically improve the probability of predicting race much beyond random guessing. The expansion of the data base, in particular the representation of modern cases, might improve the probability of classifying the correct sex and race. For this limited study, the inability to accurately classify the variables of sex and race from this data suggest this method be used only when no alternative is available.

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APPENDIX

A. 1

Summary Statistics For University of Tennesee.

47 White Males

MEANS

LFM	WFM	LB	RWOC	RLOC	LWOC	LLOC
31.13	36.36	26.68	12.42	12.18	24.00	23.94

COVARIANCE-VARIANCE MATRIX

3.65	3.27	-0.89	0.72	0.98	-0.10	-1.45
3.27	7.58	-1.40	0.44	0.73	1.74	1.48
-0.89	-1.40	4.29	-0.05	-0.42	1.41	1.81
0.72	0.44	-0.05	2.22	1.11	-0.95	-0.84
0.98	0.73	-0.42	1.11	1.46	-0.99	-1.31
-0.10	1.74	1.41	-0.95	-0.99	9.84	7.27
-1.45	1.48	1.81	-0.84	-1.31	7.27	9.38

17 White females

MEANS

LFM	WFM	LB	RWOC	RLOC	LWOC	LLOC
30.02	35.57	24.05	10.98	10.92	23.87	23.32

COVARIANCE-VARIANCE MATRIX

5.01	2.78	0.83	0.24	0.88	-0.08	0.36
2.78	5.66	-1.55	-1.23	-0.14	-2.01	-1.72
0.83	-1.55	4.21	0.87	1.21	2.59	2.45
0.24	-1.23	0.87	1.54	1.26	0.70	0.41
0.88	-0.14	1.21	1.26	2.23	0.74	0.71
-0.08	-2.01	2.59	0.70	0.74	4.78	4.57
0.36	-1.72	2.45	0.41	0.71	4.57	5.19

13 Black Males

MEANS

LFM	WFM	LB	RWOC	RLOC	LWOC	LLOC
30.48	36.92	27.90	12.21	12.13	24.32	24.66

COVARIANCE-VARIANCE MATRIX

7.16	3.36	-1.85	-1.16	1.54	2.30	1.89
3.36	6.14	0.73	-0.01	0.81	1.68	2.26
-1.85	0.73	6.50	2.71	0.85	-1.34	0.41
-1.16	-0.01	2.71	2.61	0.99	-2.12	-0.54
1.54	0.81	0.85	0.99	1.85	1.37	0.64
2.30	1.68	-1.34	-2.12	1.37	10.97	4.37
1.89	2.26	0.41	-0.54	0.64	4.37	3.33

4 Black Females

MEANS

LFM	WFM	LB	RWOC	RLOC	LWOC	LLOC
26.86	34.41	25.01	9.87	10.23	21.77	21.42

COVARIANCE-VARIANCE MATRIX

1.46	0.73	0.61	-0.12	-0.53	0.47	0.01
0.73	1.92	0.53	0.21	-0.32	-0.46	-0.14
0.61	0.53	0.33	-0.09	-0.35	0.56	0.34
-0.12	0.21	-0.09	0.19	0.25	-0.96	-0.64
-0.53	-0.32	-0.35	0.25	0.55	-1.46	-1.00
0.47	-0.46	0.56	-0.96	-1.46	5.32	3.78
0.01	-0.14	0.34	-0.64	-1.00	3.78	2.85

A. 2
Summary Statistics For Hamman-Todd.

54 White Males

MEANS

LFM	WFM	LB	RWOC	RLOC	LWOC	LLOC
31.05	36.49	25.77	12.42	12.23	25.39	25.46

COVARIANCE-VARIANCE MATRIX

5.46	3.33	-0.32	0.51	0.23	1.01	1.25
3.33	6.47	0.36	0.49	1.17	1.95	2.45
-0.32	0.36	7.32	0.87	0.44	1.84	2.45
0.51	0.49	0.87	1.63	1.21	0.19	1.05
0.23	1.17	0.44	1.21	2.44	0.77	0.95
1.01	1.95	1.84	0.19	0.77	4.63	3.70
1.25	2.45	2.45	1.05	0.95	3.70	5.95

51 White females

MEANS

LFM	WFM	LB	RWOC	RLOC	LWOC	LLOC
28.89	34.41	24.73	11.84	11.54	22.79	22.77

COVARIANCE-VARIANCE MATRIX

3.65	2.84	-0.87	0.20	0.11	0.50	0.96
2.84	6.56	0.34	-0.06	0.14	1.49	2.26
-0.87	0.34	5.60	0.52	0.59	0.91	1.80
0.20	-0.06	0.52	1.80	0.47	0.19	-0.03
0.11	0.14	0.59	0.47	1.04	0.23	-0.19
0.50	1.49	0.91	0.19	0.23	5.26	3.71
0.96	2.26	1.80	-0.03	-0.19	3.71	6.27

55 Black Males

MEANS

LFM	WFM	LB	RWOC	RLOC	LWOC	LLOC
28.93	35.60	28.00	12.77	12.32	24.27	24.51

COVARIANCE-VARIANCE MATRIX

5.84	4.53	-0.54	0.12	0.35	-0.36	0.03
4.53	10.17	-2.89	-0.22	-0.17	1.60	1.02
-0.54	-2.89	7.62	0.96	0.52	1.94	2.32
0.12	-0.22	0.96	1.90	1.04	0.62	0.48
0.35	-0.17	0.52	1.04	1.92	0.23	-0.28
-0.36	1.60	1.94	0.62	0.23	9.09	6.46
0.03	1.02	2.32	0.48	-0.28	6.46	6.81

51 Black Females

MEANS

LFM	WFM	LB	RWOC	RLOC	LWOC	LLOC
28.02	34.83	27.26	11.80	11.67	22.65	22.41

COVARIANCE-VARIANCE MATRIX

5.11	2.23	2.12	0.54	1.01	1.07	0.27
2.23	4.16	0.27	-0.21	-0.43	0.54	0.22
2.12	0.27	6.36	1.52	1.11	0.82	-0.33
0.54	-0.21	1.52	1.64	1.03	-0.26	-0.07
1.01	-0.43	1.11	1.03	1.67	0.20	-0.03
1.07	0.54	0.82	-0.26	0.20	5.51	3.07
0.27	0.22	-0.33	-0.07	-0.03	3.07	4.06

A. 3

MANOVA for Sex and Race

Univariate F tests

Variable	SS	DF	MS	F	P
LFM	5.663	1	5.663	1.151	0.284
ERROR	1412.230	287	4.921		
WFM	6.954	1	6.954	1.012	0.315
ERROR	1972.494	287	6.873		
LB	9.465	1	9.465	1.521	0.218
ERROR	1786.124	287	6.223		
RWOC	0.507	1	0.507	0.272	0.602
ERROR	535.079	287	1.864		
RLOC	0.304	1	0.304	0.173	0.678
ERROR	503.127	287	1.753		
LWOC	0.024	1	0.024	0.003	0.953
ERROR	2006.788	287	6.992		
LLOC	1.550	1	1.550	0.246	0.620
ERROR	1806.783	287	6.295		

MULTIVARIATE TEST STATISTICS

WILKS' LAMBDA = 0.980
F-STATISTIC = 0.819 DF = 7, 281 PROB = 0.573

PILLAI TRACE = 0.020
F-STATISTIC = 0.819 DF = 7, 281 PROB = 0.573

HOTELLING-LAWLEY TRACE = 0.020
F-STATISTIC = 0.819 DF = 7, 281 PROB = 0.573

A. 4

MANOVA for Sex in Collections

Univariate F tests

Variable	SS	DF	MS	F	P
LFM	0.062	1	0.062	0.013	0.911
ERROR	1417.112	286	4.955		
WFM	1.077	1	1.077	0.156	0.693
ERROR	1976.626	286	6.911		
LB	38.641	1	38.641	6.343	0.012
ERROR	1742.187	286	6.092		
RWOC	8.323	1	8.323	4.544	0.034
ERROR	523.849	286	1.832		
RLOC	6.067	1	6.067	3.495	0.063
ERROR	496.422	286	1.736		
LWOC	26.771	1	26.771	3.869	0.050
ERROR	1978.804	286	6.919		
LLOC	19.050	1	19.050	3.054	0.082
ERROR	1783.741	286	6.237		

MULTIVARIATE TEST STATISTICS

WILKS' LAMBDA = 0.945
F-STATISTIC = 2.314 DF = 7, 280 PROB = 0.026

PILLAI TRACE = 0.055
F-STATISTIC = 2.314 DF = 7, 280 PROB = 0.026

HOTELLING-LAWLEY TRACE = 0.058
F-STATISTIC = 2.314 DF = 7, 280 PROB = 0.026

A. 4a

MANOVA for Race in Collections

Univariate F tests

Variable	SS	DF	MS	F	P
LFM	0.709	1	0.709	0.143	0.706
ERROR	1417.112	286	4.955		
WFM	1.807	1	1.807	0.262	0.609
ERROR	1976.626	286	6.911		
LB	15.878	1	15.878	2.607	0.108
ERROR	1742.187	286	6.092		
RWOC	3.662	1	3.662	1.999	0.158
ERROR	523.849	286	1.832		
RLOC	1.054	1	1.054	0.607	0.436
ERROR	496.422	286	1.736		
LWOC	1.517	1	1.517	0.219	0.640
ERROR	1978.804	286	6.919		
LLOC	6.024	1	6.024	0.966	0.327
ERROR	1783.741	286	6.237		

MULTIVARIATE TEST STATISTICS

WILKS' LAMBDA = 0.979
F-STATISTIC = 0.852 DF = 7, 280 PROB = 0.545

PILLAI TRACE = 0.021
F-STATISTIC = 0.852 DF = 7, 280 PROB = 0.545

HOTELLING-LAWLEY TRACE = 0.021
F-STATISTIC = 0.852 DF = 7, 280 PROB = 0.545

A. 5

MANOVA for Collection Variability

Univariate F tests

Variable	SS	DF	MS	F	P
LFM	13.438	1	13.438	2.712	0.101
ERROR	1417.112	286	4.955		
WFM	14.369	1	14.369	2.079	0.150
ERROR	1976.626	286	6.911		
LB	9.566	1	9.566	1.570	0.211
ERROR	1742.187	286	6.092		
RWOC	21.167	1	21.167	11.556	0.001
ERROR	523.849	286	1.832		
RLOC	9.738	1	9.738	5.610	0.019
ERROR	496.422	286	1.736		
LWOC	0.266	1	0.266	0.038	0.845
ERROR	1978.804	286	6.919		
LLOC	2.055	1	2.055	0.330	0.566
ERROR	1783.741	286	6.237		

MULTIVARIATE TEST STATISTICS

WILKS' LAMBDA = 0.943
F-STATISTIC = 2.409 DF = 7, 280 PROB = 0.021

PILLAI TRACE = 0.057
F-STATISTIC = 2.409 DF = 7, 280 PROB = 0.021

HOTELLING-LAWLEY TRACE = 0.060
F-STATISTIC = 2.409 DF = 7, 280 PROB = 0.021

A. 6

MANOVA for Sex Differences in Collections

Univariate F tests

Variable	SS	DF	MS	F	P
LFM	118.151	1	118.151	23.845	0.000
ERROR	1417.112	286	4.955		
WFM	77.601	1	77.601	11.228	0.001
ERROR	1976.626	286	6.911		
LB	152.228	1	152.228	24.990	0.000
ERROR	1742.187	286	6.092		
RWOC	68.539	1	68.539	37.420	0.000
ERROR	523.849	286	1.832		
RLOC	50.584	1	50.584	29.143	0.000
ERROR	496.422	286	1.736		
LWOC	88.445	1	88.445	12.783	0.000
ERROR	1978.804	286	6.919		
LLOC	148.792	1	148.792	23.857	0.000
ERROR	1783.741	286	6.237		

MULTIVARIATE TEST STATISTICS

WILKS' LAMBDA = 0.769
F-STATISTIC = 11.998 DF = 7, 280 PROB = 0.000

PILLAI TRACE = 0.231
F-STATISTIC = 11.998 DF = 7, 280 PROB = 0.000

HOTELLING-LAWLEY TRACE = 0.300
F-STATISTIC = 11.998 DF = 7, 280 PROB = 0.000

A. 7

MANOVA for Race Differences in Collections

Univariate F tests

Variable	SS	DF	MS	F	P
LFM	81.763	1	81.763	16.501	0.000
ERROR	1417.112	286	4.955		
WFM	0.141	1	0.141	0.020	0.886
ERROR	1976.626	286	6.911		
LB	133.662	1	133.662	21.942	0.000
ERROR	1742.187	286	6.092		
RWOC	0.734	1	0.734	0.401	0.527
ERROR	523.849	286	1.832		
RLOC	0.091	1	0.091	0.053	0.819
ERROR	496.422	286	1.736		
LWOC	8.876	1	8.876	1.283	0.258
ERROR	1978.804	286	6.919		
LLOC	3.526	1	3.526	0.565	0.453
ERROR	1783.741	286	6.237		

MULTIVARIATE TEST STATISTICS

WILKS' LAMBDA = 0.833
F-STATISTIC = 8.004 DF = 7, 280 PROB = 0.000

PILLAI TRACE = 0.167
F-STATISTIC = 8.004 DF = 7, 280 PROB = 0.000

HOTELLING-LAWLEY TRACE = 0.200
F-STATISTIC = 8.004 DF = 7, 280 PROB = 0.000

A. 8

MANOVA for Age and Sex

Univariate F tests

Variable	SS	DF	MS	F	P
LFM	0.237	1	0.237	0.049	0.824
ERROR	1317.689	274	4.809		
WFM	2.949	1	2.949	0.432	0.512
ERROR	1872.482	274	6.834		
LB	0.005	1	0.005	0.001	0.979
ERROR	1741.253	274	6.355		
RWOC	1.322	1	1.322	0.706	0.401
ERROR	513.011	274	1.872		
RLOC	0.476	1	0.476	0.285	0.594
ERROR	457.847	274	1.671		
LWOC	0.181	1	0.181	0.026	0.872
ERROR	1914.469	274	6.987		
LLOC	3.934	1	3.934	0.619	0.432
ERROR	1741.265	274	6.355		

MULTIVARIATE TEST STATISTICS

WILKS' LAMBDA = .991
F-STATISTIC = .351 DF = 7, 268 PROB = 0.929

PILLAI TRACE = .009
F-STATISTIC = .351 DF = 7, 268 PROB = 0.929

HOTELLING-LAWLEY TRACE = .009
F-STATISTIC = .351 DF = 7, 268 PROB = 0.929

A. 9

MANOVA for Age and Race

Univariate F tests

Variable	SS	DF	MS	F	P
LFM	1.990	1	1.990	0.414	0.521
ERROR	1317.689	274	4.809		
WFM	6.816	1	6.816	0.997	0.319
ERROR	1872.482	274	6.834		
LB	0.134	1	0.134	0.021	0.885
ERROR	1741.253	274	6.355		
RWOC	0.275	1	0.275	0.147	0.702
ERROR	513.011	274	1.872		
RLOC	14.551	1	14.551	8.708	0.003
ERROR	457.847	274	1.671		
LWOC	0.846	1	0.846	0.121	0.728
ERROR	1914.469	274	6.987		
LLOC	0.171	1	0.171	0.027	0.870
ERROR	1741.265	274	6.355		

MULTIVARIATE TEST STATISTICS

WILKS' LAMBDA = 0.948
F-STATISTIC = 2.104 DF =7, 268 PROB = 0.043

PILLAI TRACE = 0.052
F-STATISTIC = 2.104 DF =7, 268 PROB = 0.043

HOTELLING-LAWLEY TRACE = 0.055
F-STATISTIC =2.104 DF =7, 268 PROB = 0.043

A. 10

MANOVA for Age Related Dimensional Changes

Univariate F tests

Variable	SS	DF	MS	F	P
LFM	9.769	1	9.769	0.155	2.036
ERROR	1319.115	275	4.797		
WFM	1.621	1	1.621	0.627	0.237
ERROR	1880.058	275	6.837		
LB	1.415	1	1.415	0.633	0.229
ERROR	1703.002	275	6.193		
RWOC	0.010	1	0.010	0.941	0.006
ERROR	509.259	275	1.852		
RLOC	5.699	1	5.699	0.069	3.330
ERROR	470.646	275	1.711		
LWOC	2.860	1	2.860	0.520	0.414
ERROR	1898.931	275	6.905		
LLOC	6.648	1	6.648	0.305	1.055
ERROR	1733.010	275	6.302		

MULTIVARIATE TEST STATISTICS

WILKS' LAMBDA = 0.967
F-STATISTIC = 1.318 DF = 7, 269 PROB = 0.242

PILLAI TRACE = 0.033
F-STATISTIC = 1.318 DF = 7, 269 PROB = 0.242

HOTELLING-LAWLEY TRACE = 0.034
F-STATISTIC = 1.318 DF = 7, 269 PROB = 0.242

A. 11

Hamman-Todd Sex Discrimination

Predicted

True		Male	Female	Total
	Male	76	33	109
	Female	32	70	102

0.632 Estimator

	Male	Female	Total
Male	74.29	34.71	109
Female	32.12	69.88	102
Total	106.41	104.59	211

Hamman-Todd Race Discrimination

Predicted

True		White	Black	Total
	White	71	34	105
	Black	34	72	106

0.632 Estimator

	White	Black	Total
White	68.60	36.40	109
Black	33.31	72.69	102
Total	101.90	109.10	211

A. 12

University of Tennessee Sex Discrimination

Predicted

True	Male	Female	Total
Male	46	14	60
Female	7	14	21

0.632 Estimator

	Male	Female	Total
Male	43.66	16.34	60
Female	6.80	14.20	21
Total	50.46	30.54	81

University of Tennessee Race Discrimination

Predicted

True	White	Black	Total
White	47	17	64
Black	7	10	17

0.632 Estimator

	White	Black	Total
White	45.29	18.71	64
Black	8.60	8.40	17
Total	53.89	27.11	81

A. 13

Hamman-Todd and University of Tennesee Sex Discrimination

Predicted

True	Male	Female	Total
Male	128	41	169
Female	42	81	123

0.632 Estimator

	Male	Female	Total
Male	124.30	44.70	169
Female	42.84	80.16	123
Total	167.14	124.86	292

Hamman-Todd and University of Tennessee Race Discrimination

Predicted

True	White	Black	Total
White	119	50	169
Black	39	84	123

0.632 Estimator

	White	Black	Total
White	118.99	50.01	169
Black	39.00	84.00	123
Total	158.00	134.00	211

A. 14

Misclassification Estimates for Hamman-Todd Collection

	WM	WF	BM	BF
miss	24	23	28	24
actual	54	51	55	51

Out of 1000 bootstraps

	WM	WF	BM	BF
miss	9396	10371	11807	9190
actual	19826	18564	20226	18565

missclassified (on reclass)

0.444444 0.450980 0.509090 0.470588

0.632 estimator of misclass

0.463074 0.519035 0.556277 0.486027

A. 15

Misclassification Estimates for University of Tennessee Collection

	WM	WF	BM	BF
miss	25	7	8	0
actual	47	17	13	4

out of 1000 bootstraps

	WM	WF	BM	BF
miss	9766	3075	3244	206
actual	17349	6156	4777	1400

missclassified (on reclass)

0.531914 0.411764 0.461538 0

0.632 estimator of misclass

0.551506 0.467221 0.599029 0.092994

A. 16

Misclassification Estimates for Combined Collection

	WM	WF	BM	BF
miss	50	31	33	26
actual	101	68	68	56

Out of 1000 bootstraps

	WM	WF	BM	BF
miss	19657	12308	13952	9505
actual	37117	24875	24960	20212

missclassified (on reclass)

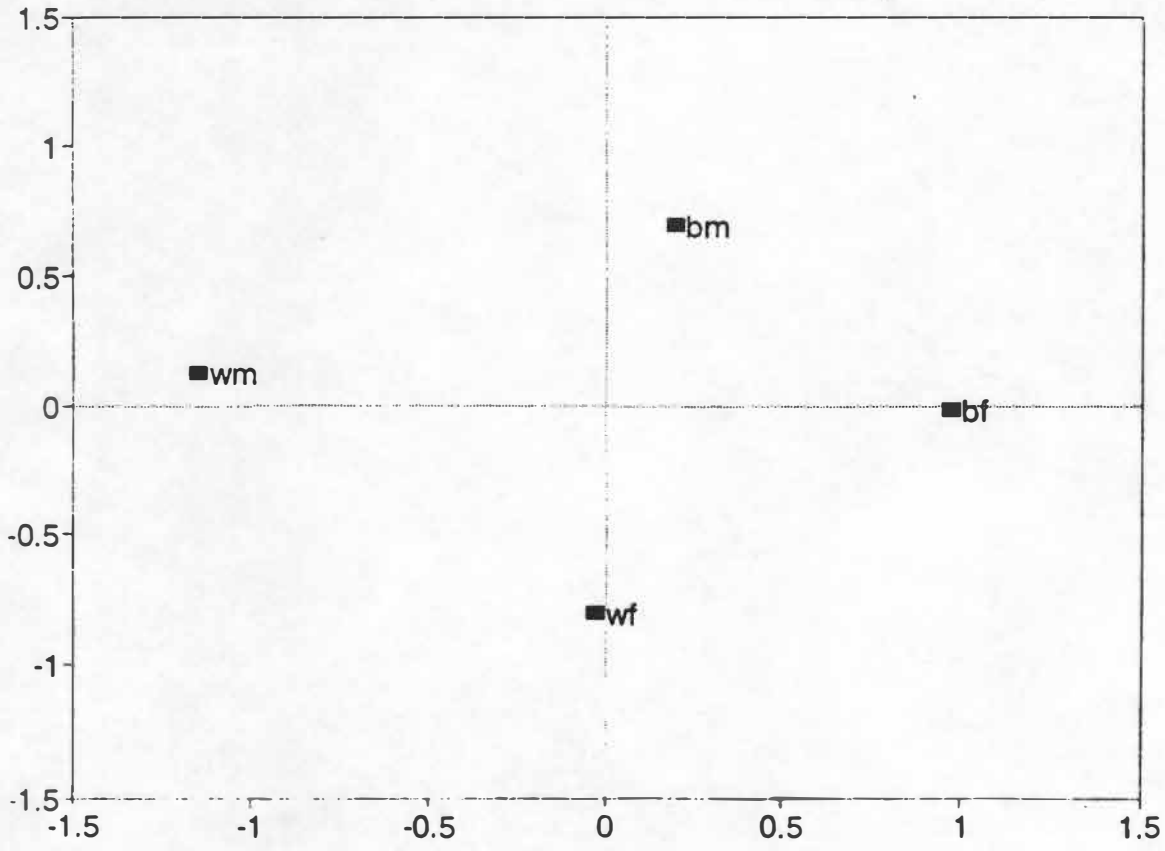
0.495049 0.455882 0.485294 0.472727

0.632 estimator of misclass

0.516882 0.480474 0.531860 0.471171

A.17

Principal Coordinates and Mahalanobis Squared Distance



	wm	wf	bm	bf
wm	0.0000000	2.1894079	2.2440045	4.5027462
wf	2.1894079	0.0000000	2.2750446	1.7283161
bm	2.2440045	2.2750446	0.0000000	1.2585813
bf	4.5027462	1.7283161	1.2585813	0.0000000

VITA

VITA

Juliet Allen Cleaves was born August 31, 1967, at Johns Hopkins Hospital, Baltimore, Maryland. She is the fourth child of Dr. Emery Taylor. and Edith Baldwin Cleaves. When she turned eight, she began to learn how to play softball, but decided it was more interesting to play with the boys. At the age of nine, she was the first girl to play little league baseball in Lutherville, Maryland. At the age of ten, Juliet discovered lacrosse at The Park School. While attending The Park School and until graduation in 1986, Juliet became involved with field hockey and basketball. These sports kept Juliet in shape for the spring and summer lacrosse leagues. However, it was not all sports and fun for Juliet. She had great difficulty with basketball and during sophmore year, managed to foul out of 20 games in a 22 game season. Her performance did improve, and Juliet was voted captain of the field hockey, basketball and lacrosse teams during her senior year. During her four year tenure at The Park School, the lacrosse team was in the championshop playoffs three times.

After an established High school sports career, Juliet attended Boston Univesity and proceeded to play lacrosse, division one of the Northeast Conference. During the fall and winter, Juliet learned to play soccer and volleyball. She graduated with her degree in archaeology, May 1990. Juliet entered graduate school at the University of Tennessee during the fall of 1991. Not able to find a women's lacrosse team, Juliet played softball with the Neanderballs, they became the champions of the 1991 fall season and she also joined the U.T cycling club. Despite her difficulties during high school,

Juliet began to play basketball again. She had finally found a group of individuals who fouled more than her.

After a two year absence, Juliet plans to make a dramatic comeback in the sport of women's lacrosse.