TESTING THE UTILITY OF CRANIAL VAULT MORPHOLOGY AS AN INDICATOR OF HEALTH: A CIVIL WAR SAMPLE

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ABSTRACT

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Most historical anthropometric research uses stature as an indication of overall health because of the influence of nutritional intake on a population's average height (Komlos 1992). Historical American population groups include soldiers, free blacks and slaves, women, and children (Fogel et al. 1982; Margo and Steckel 1983; Komlos 1987, 1992, 1996, 1998; Haines et al. 2003; Fogel 2004; Haines 2004). Auxology, or the scientific study of height, revealed cycles in average height throughout history; in particular, an apparent decline in population stature during the early years of industrialization in Europe and the United States, beginning in the late 18^{th} century in

England and the early 19th century in America (Komlos 1996; Haines et al. 2003). The paradoxical decline in health that coincided with a time of economic prosperity in America was labeled the "Antebellum Puzzle" (Komlos 1996; Haines et al. 2003). The term "Antebellum" designates that this period of health decline occurred in the years prior to the American Civil War and generally encompasses the years from the 1830's to the 1860's (Komlos 1996; Haines et al. 2003).

The current study tested the utility of cranial vault form as an indicator of population health by utilizing a sample of individuals born during the Antebellum health decline. If cranial vault form is an adequate measure of growth efficiency, the cranial vaults of individuals born during the Antebellum period should exhibit a similar pattern of stunting as found by historical stature research. Additionally, this project attempted to examine the industrialization process in America by synthesizing the stature data used in economic anthropological research with skeletal analyses of craniofacial secular change in American history. The use American Civil War casualties allowed this study to add another biological dimension to analyses of the effects of the early years of industrialization on the population of American white males. Although most Civil War remains are unidentified, research into the context of their recovery along with skeletal aging methods enabled the soldiers to be included into an adequate time series covering the entire industrialization process. This study examined cranial vault morphology, which may be a more sensitive indicator of childhood stress due to the human brain and cranium reaching adult size at a faster rate than stature.

VITA

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CHAPTER 1: INTRODUCTION

Although commonly referred to as the Industrial Revolution, the transition from preindustrial to industrial societies was in reality more of a process that spanned many years (Dubofsky 1985). Industrialization was essentially the process by which the country's main economic focus shifted from agriculture to manufacturing (Dubofsky 1985). These changes were enabled through technological innovations in sectors such as steam power and iron production and led to the largest global demographic transition since the advent of agriculture (Dubofsky 1985). These technological innovations greatly increased productive capacity by allowing mechanical assistance to manufacturing processes (Mays et al. 2008). Commercial goods were mainly produced in factories which tended to be located in urban centers. The transition from rural to urban-centered production of material goods meant that an increasing proportion of employment opportunities was located in cities (Mays et al. 2008). The transition in the job market led to dramatic changes in the demographic composition of industrialized nations.

There are several key differences between preindustrial and industrial societies that could impact the demographic composition of the population. The population concentrations during industrializing societies shifted from rural to urban, placing individuals within greater contact with one another and increasing the risk of exposure to diseases such as cholera and typhoid fever (Komlos 1996; Haines et al. 2003). Diseases were also spread through national transportations systems such as roads, railways, and canals that developed as markets expanded (Komlos 1996; Haines et al. 2003). As cities grew, larger and larger proportions of the population were removed from food sources, which were grown and harvested on rural farms. The foodstuffs had to be transported into the cities and the cost of transportation had effects on both the rural and urban populations (Komlos 1996; Haines et al. 2003). Factories were often unsafe or unsanitary with long working hours (Dubofsky 1985). With the onset of industrialization in the late 18th century, rapid changes in the disease, nutritional, and labor environments of populations appear to have had a detrimental impact on health.

The industrialization process variably affected the health of individuals. Certain segments of the population suffered more than others. In particular, laborers appeared to be smaller-bodied than middle and upper class individuals (Mays et al. 2008). The differences between individuals of differing socio-economic classes prompted researchers to conduct studies that laid the foundation for modern understanding of human growth processes and the interaction between the environment and growth.

Industrialization in England

Industrialism initiated in England during the eighteenth century and spread throughout the rest of Europe and the United States (Komlos 1990). This time was marked by an unprecedented level of growth in average income and population density (Komlos 1990). Industrialization was prompted by technological improvements in agriculture, manufacturing, mining, and transportation (Dubofsky 1985, Steinberg 1986). The economy in Great Britain underwent a transition from manual and draft-animal based labor towards machine-based manufacturing (Dubofsky 1985, Steinberg 1986).

Harnessing of steam power, water wheels, and coal led to the mechanization of textile industries and the expansion of trade led to the development of canals, roads, and railways (Dubofsky 1985, Steinberg 1986). The technological innovations in the sectors of textiles, steam power, and iron making enabled the economic expansion which characterizes the Industrial Revolution (Dubofsky 1985, Steinberg 1986).

Industrialization in America

The United States entered the industrial era after the Embargo Act of 1807 and the War of 1812. The Embargo Act limited the exportation of American goods and severely inhibited the import of goods from other nations. Relations between the United States and Great Britain deteriorated until the two nations went to war in 1812 (Dubofsky 1985). It became evident during the conflict that the United States needed to further develop the national transportation system and establish economic independence (Steinberg 1986). Key innovations in the American economy were the cotton gin, the combination of spinning and weaving in one factory, the sewing machine, and machine-produced interchangeable parts (Dubofsky 1985). An implication of these technological innovations, for example, was that clothing was now produced in factories rather than in the home. The new factory-based economy led to dramatic demographic shifts in the lifestyle of the American population (Dubofsky 1985). Industrialization led to great social change and economic development primarily through technological innovations in energy utilization and production.

Industrialization in Europe and the United States essentially changed the populations from agrarian- to industrial-oriented (Komlos 1996; Haines et al. 2003).

With increasing industrial production, Americans began to move from farms to cities. Implications of the economic shift were increased urbanization and transportation, which led human populations to come into greater contact with one another than ever before. The increased urbanization had significant impacts on the population, including overcrowding and disease (Komlos 1996; Haines et al. 2003). Although the scientific community had not yet developed an understanding of disease causes and prevention or adequate nutrition, social advocates began to notice that certain segments of the population appeared to be negatively affected by the new way of life. For example, Edwin Chadwick wrote about the deplorable conditions of the working poor in England in 1842 (Winkelstein 2009). Thus, the Industrial Revolution spawned many of the earliest studies that led to an understanding of the processes of human growth and development and the conditions which negatively affect attained adult growth (Mays et al. 2008). These studies compiled the growth measures of individuals to quantify the overall health of the population (Mays et al. 2008). The biological growth variables of a population could then be combined with demographic and economic measures to evaluate the standard of living of the population. Thus, the standard of living of any population results from the combination of individual and population health indicators.

Individual health assessment

To understand how the process of industrialization in America affected the population, one must understand the growth processes of individuals and the circumstances that lead to variations in attained adult growth. The attained adult size of individuals results from genetic and environmental factors (Komlos 1996). Thus, the variability in stature between an individual with tall parents and an individual with short parents does not necessarily indicate that the shorter individual is less healthy. It may be the case that the shorter individual reached their genetic potential while the taller one did not. Thus, the growth of any individual cannot inform much about the health of a nation; however, the growth measures of many individuals can yield insight into the overall health of a population as well as the health of certain segments within that population. Scientists evaluate growth by measuring parts of the body, a technique called anthropometrics (Komlos 1992). Anthropometric health analyses can be performed on living individuals to assess current health status and on the skeletal remains of archaeological populations to evaluate longer health trends.

Anthropometrics

Biological indicators of population health can reveal deficits that may not be identified through economic or demographic assessments. Anthropologists typically utilize anthropometrics to measure the growth efficiency of individuals and populations (Komlos 1992). Anthropometry is the scientific measurement of the size, shape, and proportions of the human body for the purpose of understanding human physical variation (American Heritage Medical Dictionary 2007). Many anthropometric measurements can be performed on living individuals as well as skeletal remains. The most commonly performed anthropometric techniques measure height for age and body mass (Komlos 1992). These indicators are measures of growth efficiency. Anthropometric measurements enable researchers to compare biological variables from different contemporaneous populations, as well as populations across time. Anthropometric research has identified phenotypic changes throughout the history of human evolution. These changes can have either genetic or environmental determinants or both (Jantz 2001, Jantz and Meadows Jantz 2000). In the short term, generational phenotypic changes are called secular changes (Jantz 2001, Jantz and Meadows Jantz 2000). Because secular changes occur over relatively short periods of time, they are believed to have environmental determinants (Jantz 2001). To understand how the environment can affect growth efficiency, it is necessary to discuss human growth processes and how these processes can be disrupted by environmental variables.

Human growth

During human growth and development, different functional systems within the body grow at different rates and reach adult size at different times (Humphrey 1998). For example, the brain and eyes grow rapidly during early development and reach adult size during childhood (Sardi and Rozzi 2005). The early rapid growth period of the brain and neurocranium is called the neural growth trajectory. Other elements such as the major organs, postcranial skeleton, and face follow a generalized growth pattern that reaches adult size around puberty (Sardi and Rozzi 2005). The differential growth periods result from differences in rate of growth and/or differences in duration of growth (Sardi and Rozzi 2005). Skeletal and facial growth is rapid at birth and then the growth velocity slows down and remains stable during childhood until just prior to maturity. In the years prior to sexual maturity, the velocity of skeletal growth increases rapidly until it attains adult size (Martinez-Abadias et al. 2009). The period of rapid skeletal growth at the end of the developmental period is called the adolescent growth spurt. Females typically reach maturity a couple of years earlier than males (Humphrey 1998). Any biological stressors that affect attained growth will be incurred during these periods; therefore studies of variation in attained growth examine the childhood developmental environments of those individuals (Martinez-Abadias et al. 2009).

When evaluating health, it is important to consider the skeletal elements as well as their soft tissue corollaries (Moss 1972). For example in living individuals, adipose, or fat, levels are evaluated alongside stature. With skeletal remains, however, soft tissue components have decomposed and leave little evidence of their values in life. Soft tissue components minimally contribute to the attained lengths of longbones, but other variables such as cranial form result directly from the growth of soft tissue components (Neubauer et al. 2010). Skeletal and soft tissue elements that grow in tandem make up functional components. Many skeletal elements can be correlated to the soft tissue counterparts of their functional unit; for example, adult cranial size and shape can provide information on brain growth (Moss 1972).

Functional Components

According to the Functional Matrix Hypothesis (Moss 1972, Humphrey 1998, Sardi and Rozzi 2005), skeletal growth is primarily a response to the requirements of associated soft tissue. Moss (1972) “introduced the term *functional matrix* to denominate all of those tissues and spaces necessary to carry out a given function, and later introduced the term *skeletal unit* to designate all those skeletal tissues (cartilage, bone, dense connective tissues) operationally involved in carrying out this same function and which serve to protect and support their related matrices” (Moss 1972:86). Thus, skeletal indicators of health can be potentially used as proxies for the soft tissue components of their functional matrix. The implication of the functional matrix hypothesis for cranial growth is that variation in cranial vault form may indirectly reflect environmental insults suffered during critical periods of brain development. To understand how the environment might affect the growth of the brain and cranium, it is important to understand how environmental factors influence growth and development.

Environmental stressors

While children are endowed with a genetic potential for growth from their parents, environmental insults during developmental periods can prevent an individual from maximizing their genetic capacity. Environmental stressors that can negatively affect attained growth are chronic malnutrition, disease prevalence, and heavy physical labor (Prentice et al. 2006). When an individual experiences such stressors during ontogeny, insufficient calories are devoted to normal bone growth and development (Prentice et al. 2006). Environmental stress experienced during childhood can affect both the quantity and quality of bone growth. Quantitative decreases in longbone growth lead to shorter individuals, while qualitative growth deficits, such as those caused by diseases such as scurvy and rickets lead to characteristic bone malformations. Qualitative bone deficiencies caused by diseases can generally be distinguished from quantitative and qualitative growth deficits resulting from malnutrition.

Nutrition

Individuals who suffer from chronic childhood stress lack adequate raw materials for skeletal growth. In humans these raw materials are the macronutrients protein, carbohydrates, and fats, and micronutrients such as minerals which are consumed as food. Proteins are the building blocks for somatic development and are the most vital for studies of growth (Illich and Kersetter 2000). Carbohydrates are essential for energy, but do not contribute directly to body size. Vitamins are essential for organ growth (Illich and Kersetter 2000). Chronic malnutrition results from insufficient amount of proteins, carbohydrates, fats, and minerals for growth. Chronic protein deficiencies typically result in smaller, or stunted, individuals (Illich and Kersetter 2000). Because proteins are vital for skeletal growth, individuals with diminished levels will not have as much energy to devote to skeletal growth (Illich and Kersetter 2000). Malnutrition can manifest both quantitatively and qualitatively in the skeleton.

Poor nutrition affects skeletal health in ways such as stunting, rickets and osteomalacia, and osteoporosis and fragility (Prentice et al. 2006). Stunting refers to "chronic growth retardation and is defined as a height- or length-for-age that is <2 SD below the mean for reference children" (de Onis and Blossner 2006). Rickets and osteomalacia are abnormalities due to low bone mineral and collagen content (Prentice et al. 2006). Osteoporotic bone is normal in composition but lacks normal density; thus leading to fragile bones that are more prone to fracture (Prentice et al. 2006). My study attempts to detect stunting in cranial vault growth that may be attributed to nutritional deficiencies during the early industrial years. Stunting results in increased mortality and delayed mental development (Prentice et al. 2006). In 2006, the World Health Organization estimated that 30% of children under the age of five are stunted (Prentice et al. 2006).

Disease

Disease also places a cost on potential growth. Energy must be diverted to fighting infection and maximum growth cannot be achieved (Humphrey 1998). Disease generally affects the quality of bone growth. Many diseases leave their mark on the skeleton and their frequencies in populations are used to assess health. There are problems, however, with using skeletal remains to assess health in archaeological populations. First of all, not all diseases leave their mark on bone. Diseases such as small pox that could have been prevalent in an archaeological population and negatively affected the developmental environment may not be detected through skeletal analyses (Wood et al. 1992). Disease also differentially affects members of a population. It is not known whether individuals in a skeletal series had elevated levels of frailty, or were more susceptible to disease and death. These unknown variables related that complicate inferring health from skeletal series is referred to as the osteological paradox (Wood et al. 1992).

Physical labor

As industrialism rapidly expanded in the United States, children often went to work in factories with deplorable conditions. At that time, children were considered "little adults" (Bogin 1997). It was not known at that the time that children underwent a complex period of growth and development that can be disrupted by stressors such as heavy physical labor. Similar to the effects of malnutrition and disease, heavy physical labor can drain vital resources that would be otherwise directed towards growth. Although populations grew and infant mortality declined throughout the industrialization process, the chances of surviving childhood did not increase (Bar and Leukhina 2010). Educational opportunities were limited during this time; therefore, children were expected to work. Because children could be paid less despite comparable productivity, could operate industrial machinery, and industrial experience was limited across the board, child workers were the preferable form of labor (Bar and Leukhina 2010).

Intense childhood labor, exposure to disease, and malnutrition are all factors that lead to variation in anthropometric measures and, therefore, variation in the health of the individuals within a nation. To assess the overall health of a nation, anthropometric variables are often combined with economic variables that measure a nation's productivity (e.g., Komlos 1996; Haines et al. 2003).

Standards of living

Population anthropometric variation is often correlated with economic variables such as Gross Domestic Product (GDP) and average wages to evaluate the wellness of a nation. Many times economic variables do not indicate the quality of life of its constituents. National level financial statistics do not take into consideration the cost of food to workers, the type of food available, access to medicine and disease, and the negative effects of heavy labor on growth in the health of the population (Komlos 1992, Steckel 2005). By combining economic with biological data, information can be gained regarding the distribution of wealth as well as the overall health of a society.

Material standards of living

The most often utilized material standard of living is GDP per capita (Komlos 1992, Steckel 2005). GDP is generally adjusted for inflation or deflation to obtain real

GDP per capita, which reflects economic activities that flow through markets (Komlos 1992, Steckel 2005). Real GDP omits expenses that are not recorded in market exchanges, such as food preparation and home maintenance. GDP also overlooks the amount of physical labor required to produce income and other conditions in the work place that may affect health and safety (Komlos 1992, Steckel 2005). Despite these limitations, economists generally agree that GDP per capita reveals information on the average availability of goods and services (Komlos 1992, Steckel 2005).

Real GDP per capita data are available for the United States beginning in 1820. During these years, real GDP per capita in America increased 21.7 fold, averaging about 1.73 percent per year (Steckel 2005). Analyses of the trends in real GDP per capita from 1820-1998 revealed that economic progress has been uneven over time. Business cycles are common since the beginning of industrialization. The worst downturn of real GDP per capita in America occurred during the Great Depression, where GDP declined by one-third and unemployment levels rose to 25 percent (Steckel 2005). National real GDP per capita measures do not take into account regional differences in the standard of living. For example, personal income was twice as high in the Northeast as in North Central States in 1840, and the South Atlantic became the nation's poorest region after the Civil War (Steckel 2005).

Biological health indicators

Economic historians generally use two biological measures of health: life expectancy at birth and average height. Life expectancy measures the average length of life while stature measures nutritional conditions during the growing years (Komlos

1992, Steckel 2005). The average life expectancy in 1850's America was 38.3 years of age. By 1998, the average life expectancy in America had risen to 76.7 years (Steckel 2005). Where depressions and recessions have negative effects on the material standard of living, epidemics were a major cause of health declines in the past (Steckel 2005). Although average life expectancy has fluctuated throughout American history, these growth rates in health are less volatile than GDP (Steckel 2005).

Life expectancy. Average life expectancy is greatly affected by childhood mortality. Life expectancy was low in the mid-19th century because approximately one child in five born in 1850 did not survive to the age of one (Steckel 2005). Throughout American history deaths have shifted from early childhood to old age (Steckel 2005). The major cause of deaths has also shifted from infectious diseases to degenerative processes that are affected by life-style choices such as diet, smoking, and exercise (Steckel 2005). The first half of the twentieth century saw the largest increases in average life expectancy, increasing from 47.8 years in 1900 to 68.2 years in 1950 (Steckel 2005).

Auxology. Auxology is the scientific study of stature. Height data are abundant throughout American history, obtained from military muster rolls, slave manifests, registrations of free blacks, advertisements for runaway slaves and servants, and long bone lengths from skeletal remains (Margo and Steckel 1983; Komlos 1987, 1992, 1996, 1998; Fogel 2004; Fogel et al. 1982; Haines 2004; Haines et al. 2003). Prior to the widespread use of photography, personal characteristics such as height, age, hair color, and skin complexion were used for identification purposes (Steckel 1998, 1999). Military organizations used height during the mustering process, to track deserters, to assess the fighting abilities of regiments, and to determine the manufacture of uniform sizes and standard food rations (Steckel 1998, 1999). These procedures were extended to military preparatory schools, such as West Point, and to ship cargo manifests to prevent illegal smuggling of African slaves. During the Civil War, the Union Army recorded height as part of identifying information for contraband slaves (Steckel 1998, 1999). In the late 1800's, several urban school districts began to measure students as part of public health programs.

Research indicated that native born white American males achieved modern stature early in the colonial period (Steckel 1998, 1999). Soldiers in the 1700's were almost as tall as those in the 1850's. Colonial American soldiers were also taller than their European contemporaries. Swedish and British soldiers did not reach the heights of colonial Americans until the late 1800's. Plotting average height against birth year revealed that population heights have fluctuated throughout American history (Steckel 1998, 1999). The average height for native-born white males was 171cm from 1720-1740. Average height increased by 1.5 cm for those born in the mid 1750's. By 1830, the average height of the American white male reached 174 cm. Height declined to around 169cm by the late 1800's and then rapidly rose during the beginning of the 20th century (Steckel 1998, 1999). These trends are interpreted as fluctuations in health throughout the years. The decline in stature that began in the 1830's and lasted until the late 1800's was labeled the "Antebellum puzzle." The term "Antebellum" refers to the years prior to the American Civil War and the puzzle is the paradoxical decline in health that occurred during a time of economical prosperity.

Antebellum Puzzle

The Antebellum puzzle describes the phenomenon in which the physical stature of white and free black Americans declined from 1830 to around 1880 (Haines 2004). The decline was first detected in white Union Army recruits (Margo and Steckel 1983) and substantiated in New York and Pennsylvania Civil War soldiers, West Point cadets, free blacks in Maryland and Virginia, Georgia convicts, Amherst students, and Ohio National Guardsmen (Komlos 1998). The decline in stature occurred during a period of significant economic growth and rapid economic change and development (Haines 2004). These trends are believed to be related to the industrialization process because similar declines in health were detected in the early industrial years of Britain, Sweden, the Hapsburg Monarchy, France, and Bavaria (Haines et al. 2003, Haines 2004).

Komlos (1996) proposed several reasons for the Antebellum health decline. First, the cost of food rose dramatically during this period. From the 1820's to the 1830's, relative prices of food rose by 30 percent, 11 percent in the 1840's, and 37 percent in the 1850's (Komlos 1996). Meat and dairy products were more expensive than grains and, given the rising food costs, Komlos (1996) argues that people may have rearranged their consumption bundles and substituted grains for meat. The lack of dietary protein may have resulted in suboptimal growth (Komlos 1996). With increased urbanization, much of the population was removed from primary food sources; meat and dairy products had to be transported into the cities. The Antebellum health decline occurred before the advent of mechanical refrigeration (Komlos 1996). The consequences were that many meat and dairy products could not be transported over long distances. It stands to reason that many of the urban poor would not have been able to acquire sufficient nutrients for optimal growth.

Komlos (1996) points out that not all segments of society were affected by the Antebellum health decline. Neither the heights of middle-class West Point cadets nor adult African slaves diminished during this time (Margo and Steckel 1982; Steckel 1986). The families of the cadets were most likely able to offset food prices while slaves were believed to be well nourished during this period because of the value placed on slave productivity. Lower-class white and free black family heads, on the other hand, were able to change the type of food consumed according to changes in relative food costs (Komlos 1996). The decline in stature may have been the result of increased consumption of cheaper grains to satiate family members and decreases in the amount of protein consumed.

Another possible explanation for the Antebellum health decline is the disease environment encountered with increased urbanization. Although Komlos (1996) dismisses disease as a cause of the health decline because disease "would not have discriminated to the same extent by social status (Komlos 1996:208)," diseases were certainly more prevalent in the urban squalor. For example, the cholera outbreak in New York in 1832 was caused by the water-born bacterium *Vibro cholera* (Larsen 1969). The upper class citizens may not have been exposed to the disease-infested water and may have been spared from the epidemic. The Germ Theory of Disease had not yet been accepted in Antebellum America. Few doctors of the era understood that diseases were caused by microorganisms (Gilchrist 1998). Louis Pasteur was conducting experiments with fermentation while Americans were fighting the Civil War. Joseph Lister did not develop aseptic surgery until 1867 and Robert Koch did not isolate bacteria until 1876 (Gilcrist 1998). The implications were that there was little public effort to clean garbage from the streets or emphasize clean water. Disease may have been a factor in the health decline because people were living in close proximity and little was known about the ways in which diseases spread (Mays et al. 2008).

These auxological research projects suggest that the early years of industrialization in America may have had negative consequences on the health of certain portions of the population. However, data obtained from historical records may only be available for certain segments of society, such as men, or may be inaccurate due to height and birth year rounding (Meadows Jantz and Jantz 1999). It is for these reasons that skeletal analyses of secular change may be more appropriate for examining changes over time.

Skeletal secular change

Meadows Jantz and Jantz (1999) identified several advantages for using skeletal analyses of secular change over data obtained from historical records. First, data are generally available for both sexes; whereas, historical records of stature typically include only males. Historical records of stature are often approximations; however, skeletal measurements can be taken directly and accurately (Meadows Jantz and Jantz 1999). Because human remains may extend longer into history than historical records, skeletal analyses are capable of examining changes over longer periods of time. It is also possible to examine shape differences over time with skeletal remains (Meadows Jantz and Jantz 1999). While size examinations are appropriate for detecting stunting, improvements in health that occurred around the beginning of the 20th century led to shape changes in skeletal elements that differ according to sex and ancestry.

Meadows Jantz and Jantz (1999) utilized documented skeletal remains dating from the mid-19th century to examine changes in bone length and proportions over time through American history. Changes were first investigated by Trotter and Gleser (1951) on World War II casualties. Trotter and Gleser's (1951) work along with the research of Meadows Jantz and Jantz (1999) detected allometric changes in longbone lengths and proportions of blacks and whites in the United States from the mid-1800's to 1970. This means that different bones changed at different rates and in different amounts over time. A key aspect of the Meadows Jantz and Jantz (1999) study was that the authors used specimens from the Huntington Collection, Terry Collection, World War II casualties, and the Forensic Anthropology Data Bank. The known documentation of birth year, ancestry, and sex in these collections enabled a continuous time series over a period of 150 years.

The results of the Meadows Jantz and Jantz (1999) study largely corroborated the pattern detected by economic anthropological research over the past 150 years. The lower limbs reflected the "trough" of the mid-19th century, followed by a period of recovery in the early 20th century and continued increases in length through the 1960's and 1970's (Meadows Jantz and Jantz 1999:64). Their research demonstrated that lower limb bones can be used as a proxy for stature and can be used where stature data are not available (Meadows Jantz and Jantz 1999). While the researchers demonstrated several advantages for using skeletal analyses to supplement historical data, the use of any form of stature to assess population health is problematic due to the potential for catch up growth.

Meadows Jantz and Jantz (1999) noted; “It is likely that influences acting early in development have been underestimated in the discussion of secular changes in adult height” (Meadows Jantz and Jantz 1999:66). The reason for the conclusion was that the greatest impact of environmental influences occurs between 6 months to 3 years and may therefore be erased by subsequent catch up growth (Meadows Jantz and Jantz, 1999). Economic research on the height per age of African slaves (Margo and Steckel 1983; Steckel 1986) demonstrated that catch up growth in stature has the ability to erase some forms of evidence of childhood developmental stress. The researchers found that African slave children in America exhibited a net nutrition level “that approximated those of the slowest growing population ever studied by auxologists” (Steckel 1986:729). Subsequent catch up growth “eventually brought slaves to approximately the twenty-eighth centile of modern height standards (Steckel 1986). The research of Margo and Steckel exemplifies the difficulties of using only adult stature to assess population health. Despite improvements over historical stature data, skeletal stature analyses of health are still problematic because nutritional deficiencies must be maintained throughout a long period of time to manifest in the adult form. Studies of stature from living or skeletal specimens also only examine one aspect of the human growth process. Further research has focused on secular changes in the craniofacial region throughout American history.

Craniofacial secular change

Angel (1976) first analyzed cranial skeletal changes for Colonial to modern times for blacks and white Americans with birth years ranging from 1675 to the late 20th century. Angel's goal was to test popular myths of "a major increase in body size, shown by smaller Colonial clothing, furniture and houses, and a radical change in physical makeup and appearance, shown by portraits, and resulting from the melting pot effect of immigration of later nineteenth and twentieth centuries" (Angel 1976:723). In other words, Angel examined size and shape changes throughout American history. He compared the skeletons of 82 modern middle-class blacks and whites to assess changes over the time period. Both populations exhibited increases in vault height and decreases in vault breadth (Angel 1976). Angel (1976) attributed these changes to improvements in diet, a reduction in disease, and 19th century immigration. Angel grouped his cohorts so that the colonial period included individuals who died between 1675 and 1879, with the modern period consisting of those born between 1950 and 1975. Although Angel's (1976) research indicated increases in stature as well as cranial vault height, the grouping of his cohorts does not allow the research to be compared with the stature research that detected a decline in health beginning in the 1830's.

Angel (1982) also explored the potential use of variation in skull height to measure growth efficiency. Angel tested the hypothesis that because the skull base supports the weight of the head and brain and a lack of dietary protein inhibits growth, skull base height should be sensitive to nutritional deficiencies. He tested his hypothesis by comparing individuals with known differences in childhood nutrition and illness, derived from the Robert J. Terry osteological collection along with skeletons obtained from the FBI and other law enforcement agencies (Angel 1982). Angel (1982) found that nutritional stress depressed the overall height of the skull vault, particularly in the basilar region. Angel's (1982) research suggested that the cranial base may be responsible for the differences in skull height observed in populations of differential nutritional status.

Contrary to the results of Angel (1982), Moore-Jansen (1989) concluded that the changes in vault height over time were the result of an increase in the superior vault rather than the cranial base. Wescott and Jantz (2005) further investigated this discrepancy by using two-dimensional Cartesian coordinate data to detect the anatomical regions which were responsible for the secular trends observed in American blacks and whites. The researchers divided individuals by sex and ancestry and grouped them into 25-year birth cohorts, beginning in 1850. Wescott and Jantz (2005) found that "the secular change in American crania is concentrated on the base and posterior aspects of the skull" (Wescott and Jantz 2005:236). Their research indicated that much of the growth in height witnessed in the cranial vault was due to growth in the cranial base region, primarily the posterior cranial base (Wescott and Jantz 2005).

Jantz and Meadows Jantz (2000) also examined craniofacial variables of black and white Americans of both sexes from the mid-19th century to the early 20th century, utilizing the Terry and Hamann-Todd collections for 19th century data and the Forensic Anthropology Data Bank for the modern 20th century sample. The goal of their study was to systematically examine the magnitude and pattern of the observed secular changes. The Jantz and Meadows Jantz (2000) study examined change over a period from the 1840's to 1975. The authors found changes in the size and shape of the neurocranium and facial skeleton. Although changes in the face were less pronounced than changes to the vault, the authors noted that the face had become narrower and higher (Jantz and Meadows Jantz 2000). These findings supported those of Angel (1976) and supported the trend of increased height and decreased breadth in the craniofacial region of Americans since the 1840's (Meadows Jantz and Jantz 1999).

The trend for heightening and narrowing of the craniofacial region gained further support from Jantz (2001). He examined changes in cranial morphology among American blacks and whites from 1850-1975. The results indicated that cranial vaults became higher and narrower and faces narrowed over the 125 year time span. Jantz (2001) attributed the changes in cranial morphology primarily to growth in the cranial base due to improved environmental conditions. Both genetic and environmental components affect cranial morphology and the changes identified in this study most likely resulted from a combination of genetics and phenotypic plasticity over time (Jantz 2001). Any attempt to discern between genetic and environmental causes for these changes requires an understanding of how the human cranium grows and develops into adulthood.

Cranial growth and form

Interpreting changes in the craniofacial region over time requires an understanding of several growth mechanisms that work towards obtaining the adult form. The functional importance of the brain and its rapid neural growth trajectory make cranial vault form an ideal indicator of childhood health in skeletal remains. The human cranium consists of three distinct regions: the basicranium, the neurocranium, and the splanchnocranium, or face (Lieberman et al. 2000). The regions differ in development type with both the facial skeleton and neurocranium developing intramembranously from neural crest cells; the basicranium, on the other hand, exhibits endochondral ossification from cartilaginous precursors originating in the mesoderm (Lieberman et al. 2000). These precursors, called the chondocranium, develop *in utero* and are postnatally replaced by bone (Lieberman et al. 2000).

As dictated by the Functional Matrix Hypothesis, the bony brain case exists to protect and support the brain. As a consequence, cranial vault form directly relates to brain form. Variations in cranial vault form, therefore, can be used as proxies for variations in brain form. There is a potential for catch up growth because cranial sutures do not fully fuse until adolescence, but because the brain and cranium reach near adult size early in childhood, the effects of biological stress have a better chance of being preserved in the adult form (Humphrey 1998; Martinez-Abadias et al. 2009). The energy demands of the brain also make it particularly susceptible to environmental insults.

The Expensive Brain

The Expensive Brain Hypothesis (Isler and van Schaik 2009) “claims that the costs of a relatively large brain must be met by any combination of increased total energy turnover or reduced energy allocation to another expensive function such as digestion, locomotion, or production (growth and reproduction)” (Isler and van Schaik 2009:392). In order to devote the energy necessary for skeletal growth, the brain and cranium must reach maturity at an earlier age. Therefore, the basicranium and neurocranium exhibit a neural growth trajectory and reach adult size earlier than the face and remainder of the skeleton. It follows that any stunting in body growth is likely the result of the percentage of the nutrients being directed towards brain growth. The rapidly growing brain is highly sensitive to nutritional insults (Georgieff 2007). Nutrients are needed for neurological processes such as synapse formation and myelination (Georgieff 2007). Although the young brain is able to repair itself after nutrient depletion, on the whole the brain's vulnerability to insults outweighs its plasticity (Georgieff 2007). Nutrients that have significant impacts on brain development are protein, energy, fats, iron, zinc, copper, iodine, selenium, vitamin A, choline, and folate (Georgieff 2007). Because protein malnutrition is a main cause of stunting, the effects of these deficiencies can possibly be detected in the cranial vault.

Limitations of previous research

Economic anthropological research into the effects of the early years of industrialization revealed a decline in health, detected through mean stature, for certain segments of societies in Europe and America. There are several issues with stature data obtained from historical records. Analyses of skeletal secular change alleviate some of these issues; however, using elements that growth according to the skeletal growth trajectory will always have long periods in which catch up growth may erase evidence of childhood nutritional stress. Because of the neural growth trajectory of the cranium and the central role of the functional brain matrix, cranial vault morphology may provide a better indicator of childhood nutritional stress. The existing craniofacial research does not have as much time depth in the series as in the historical stature data. Obtaining cranial vault data for individuals born or developing during the health decline that began in the 1830's will shed valuable light on the relationship between cranial form and stature as well as synthesize and add another biological dimension to the economic anthropological research that detected the period of health decline. Although exact birth years may not be known, skeletal analyses of American Civil War casualties can provide abundant information on the health status of individuals born during the Antebellum health decline.

Civil War soldiers

The American Civil War was one of the most significant periods in the development of the United States. Aside from the 625,000 casualties from the war, there were innumerable hardships such as malnutrition and disease that affected the nation as a whole (Faust 2008). The Civil War was fought from 1861-1865, but the subsequent Reconstruction period in the South lasted until 1878. Based on what is known about the timing of growth mechanisms in the human body and the ages of the average Civil War soldier, it can be reasonably concluded that most soldiers killed during Civil War battles would have been born during the Antebellum health decline, which originated in the 1830's. An individual who was born in 1830 and died during the Civil War would have been 31-35 years of age at death. Although some would have been older and many younger, Civil War casualties were treated in the current study as a cohort representing the Antebellum period.

Current study

The current study examined the reported Antebellum health decline and subsequent periods in American history associated with improvements in terms of overall health. My research aims to provide depth to the economic stature studies by incorporating additional biological data as well as increasing the time depth for the series used in Jantz and Meadows Jantz's (2001) secular change study. The current research builds on that of Jantz and Meadows Jantz (2001) by adding larger samples sizes to a time period that saw significant changes in the nation's history. The time period from 1830-1850 is underrepresented in the Jantz and Meadows Jantz (2001) study. The researchers had only four white males with birth years from 1840-1849 and none born before 1840. Consequently, the Jantz and Meadows Jantz (2001) study began with individuals born or developing during the American Civil War.

The combination of the Jantz and Meadows Jantz (2001) skeletal study and the economic research of Steckel et al. revealed a pattern of fluctuating health in American history with which to test the method proposed by the current study. If cranial vault form is an acceptable health indicator, then cranial vault dimensions over the time period of the study should demonstrate a decline in health coincident with the Antebellum period, followed by the reported health improvements Jantz and Meadows Jantz (2001) observed from the 1840's to the 1970's. If the results reveal that cranial vault morphology can be used to assess growth efficiency, then the methodology employed in the current research will provide another tool for assessing health in historical populations.

CHAPTER 2: METHODS

Samples

Craniometric data were collected or collated from the skeletal remains of 754 American white males with birth years ranging from the 1830s-1970s. The samples used in the current study were obtained from four sources. Data were collated from three osteological collections, the Robert J. Terry Collection (n=75), the Hamann-Todd Collection (n=37), and William M. Bass Donated Collection (n=600). These data were collected by Dr. Richard Jantz and used with his permission. I collected the remaining data from the American Civil War Collection housed at the National Museum of Health and Medicine, Armed Forces Institute of Pathology (n=45) via a Microscribe G2 digitizer. Table 1 summarizes the sources of skeletal material and sample sizes.

Table 1. Sources of Skeletal Specimens and Sample Sizes.

Source	Collection	Location	Sample size
Jantz	Robert J. Terry Osteological Collection	Washington, D.C.	n=75
Jantz	Hamann-Todd Osteological Collection	Cleveland, OH	n=37
Jantz	William M. Bass Donated Collection	Knoxville, TN	n=600
Stott	National Museum of Health and Medicine, Armed Forces Institute of Pathology-	Washington, D.C.	n=45

Known collections

This study utilizes three collections with known constituents, meaning that sex, ancestry, date of birth, and age-at-death are known for the individuals that comprise the collection. The Terry Collection represents individuals from the St. Louis, Missouri area. The majority of these individuals were cadavers of unclaimed bodies and donations and ranged in birth years from the mid-1800's to early 1900's (Hunt 1999). The Hamann-Todd Collection is also comprised of unclaimed and donated cadavers from the mid 19th century to early 20th century, but represents the Cleveland, Ohio area. The William M. Bass Collection was started in 1981 to provide a modern sample for the development of skeletal identification methods and currently consists of nearly 650 known individuals (The University of Tennessee-Knoxville).

NMHM, AFIP collection.

The fourth source of individuals in the current study was the collection of American Civil War soldiers housed at the National Museum of Health and Medicine, Armed Forces Institute of Pathology (NMHM, AFIP) in Washington, D.C. This collection is considered "contextually" documented to oppose the known nature of the specimens in the other collections. The individuals in the NMHM, AFIP collection were collected from Civil War battlefields; therefore, little demographic information is available. Only three individuals in the collection were positively identified, with known name, birth year, and date of death. Because the remaining individuals in the NMHM, AFIP collection were not positively identified, information such as birth year was not available. The only information known about these individuals was their date of death, which was derived from the battle in which they were killed. Although the collection does not have the strength of a known collection, valuable information was gleaned from the context in which the specimens were obtained. The contextual information pertaining to the Civil War collection was obtained through archival research and skeletal analysis. Sex and ancestry estimations were obtained from osteological analyses in museum records.

Years of birth are essential for subjects included in studies of secular change. Because the birth years of the individuals in the NMHM, AFIP collection were not known, their inclusion required assignment to a decade of birth. To obtain a birth decade for each individual, the individual's estimated age, derived from skeletal analysis, was subtracted from their known date of death, obtained from the date of the battle in which they were killed.

Age-at-death. I estimated the age-at-death of each individual in the NMHM, AFIP using the method outlined in Meindl and Lovejoy (1985). This method examines the degree of ectocranial suture closure. The degree of closure for several suture locations were scored on a scale of 0-3, with 0 meaning no closure at all and 3 meaning complete obliteration of the suture. The scores of the individual landmarks were compiled into a composite score that was associated with an age-at-death range (Buikstra and Ubelaker 1994). Meindl and Lovejoy's (1985) method is not an ideal method for estimating age-at-death in a medicolegal context because degree of suture closure is highly variable; however, because the NMHM, AFIP collection is comprised of only crania, this method was the only one available. Adult status for each individual was confirmed by third molar eruption.

Because there is high variability in suture closure with age, the Meindl and Lovejoy (1985) output has a large age range. The contribution of archival literature regarding the average age of the Civil War soldiers along with their status as enlisted soldiers inferred from their treatment at death allowed the age range obtained from Meindl and Lovejoy (1985) to be reduced to the younger portion. For example, according to the Meindl and Lovejoy (1985) method, individual AFIP 1000184 had an age range of 27-51, with a mean of 40 years of age. Based on the age range obtained from Meindl and Lovejoy's (1985) method and the fact that the average age of Civil War soldiers was 18-29 (Faust 2008), the age of AFIP 1000184 was estimated to be 27 years of age. To assess the accuracy of the age estimations, the same treatment was given to the three individuals with known ages at death. Using the methods of the current study, the age-at-death of AFIP 1000627 was estimated at 35 years of age, when it is known from the records that the individual was 30 years old when he died. The other two individuals with known ages-at-death were similarly overestimated. AFIP 1000628 was estimated to be 35 when he was in fact 28, and AFIP 1002807 was estimated to be 35 when he was in fact 29. These age estimations were intended to approximate a reasonable decade of birth distribution for Civil War soldiers. With only three known ages at death, the reliability of individual birth years is suspect. It is for this reason that individuals were assigned to an estimated birth decade rather than birth year.

Decade of Birth. Analyses of secular change require some sort of time component to assess any change. In order to contribute to the current analysis of secular changes in cranial vault morphology, the individuals in the NMHM collection needed to be assigned to a decade of birth. Because the actual birth years of the individuals in the collection were not known, any assignment of these individuals into a decade of birth needed to be done conservatively. In order to accomplish this end, the estimated age for each individual was subtracted from their known date of birth to obtain an estimated birth year. Because the Meindl and Lovejoy (1985) consistently overestimated actual age by five years, each individual's estimated birth year was rounded up to the next five or zero ending year. The individual was then assigned to a cohort based on decade of birth. For example, if an individual's birth year was 1843, that individual's estimated birth year would be rounded up to 1845, and the individual would be assigned to the 1840s cohort. Likewise, if an individual's estimated birth year was 1848, that individual's birth year would be rounded up to 1850 and the individual would be assigned to the 1850s cohort. The conservative assignment of individuals into their decade of birth cohorts allowed for an age distribution similar to what one might expect to see in a Civil War battle.

Cohorts

In addition to decade of birth cohorts, individuals were also arranged according to birth years that coincided with particular historical periods in American history.

Antebellum cohort (1830-1855, n=56). The Antebellum cohort includes individuals whose cranial vaults reached adult size before the beginning of the American Civil War. This cohort acted as a baseline from which to judge the effects of the conflict. Individuals born during this time experienced a negative trend in stature described as the "Antebellum Puzzle."

Civil War Era cohort (1856-1878, n=53). This cohort covers individuals born or developing during the American Civil War and subsequent period of Reconstruction in the South. The American Civil War Era was a period of widespread disease and nutritional deficiencies (Faust 2008).

Early Progressive Era cohort (1879-1899, n=34), Late Progressive Era cohort (1900-1928, n=105). The Progressive Era in American history roughly spanned the time from the end of Reconstruction in the South until the 1920's. This period was characterized by responses to the "social, economic, and political problems attending rapid and brutal industrialization at the turn of the (19th) century" (Lorenzi McDonagh 1992). Many social and economic ills were associated with unrestricted capitalist market expansion (Lorenzi McDonagh 1992). During the Progressive Era, government authority was restructured institute controls over areas such as food and drugs, sanitation, and labor. The Progressive Era marked the beginning of health improvements in the United States and coincided with the timing of the improvements in craniofacial morphology noted by Jantz (2001), Jantz and Meadows Jantz (2000), and Wescott and Jantz (2005). For the purposes of the current study, the Progressive Era was divided into two cohorts, an Early Progressive Era cohort and a Late Progressive Era cohort to distinguish individuals with birth years in the 19th century from individuals born during the 20th century.

Great Depression cohort (1929-1941, n=157). A cohort was created to contain individuals born during the Great Depression because this was another period of wide spread biological stress throughout American history. The Great Depression was a period of economic "catastrophe," with one in five Americans unemployed (Cutler et al. 2007). Associated with this time was "The Dust Bowl," a termed used to signify the severe drought and wind erosion that afflicted the Great Plains (Cutler et al. 2007).

Modern Era cohort (1942-1978, n=349). The Modern Era cohort began with those born at the beginning of World War I and included the remaining individuals in the study. This cohort was designed to assess the current status for cranial vault measures. Table 2 summarizes the period cohorts and sample sizes.

Table 2. Period Cohorts and Sample Sizes.

Period cohorts	Birth years	Sample sizes
1. Antebellum	1830-1855	n=56
2. Civil War Era	1856-1878	n=53
3. Early Progressive Era	1879-1899	n=34
4. Late Progressive Era	1900-1928	n=105
5. Great Depression	1929-1941	n=157
6. Modern Era	1942-1978	n=349

Variables

Variables representing cranial vault dimensions were selected for analysis. In general, these variables describe the height, length, and breadth of the vault. Neurocranial variables were distinguished from basicranial variables. The values obtained from these variables were straight line inter-landmark distances and instrument-determined maximums and minimums, see Figure 1. Variable definitions were obtained from the W.W. Howell's data set (Howells 1973, 1989).

Neurocranial variables

Height. Basion-bregma height (BBH), Figure 1-B, represents cranial vault height. The measurement is defined as the distance from the anterior border of the foramen magnum in the midline (basion), to the juncture of the frontal and parietal bones, in the midline (bregma).

Breadth. Cranial vault breadth was measured from the minimum the overall maximum breadth (XCB), Figure 1-C, which is instrument determined. XCB is defined as the maximum cranial breadth perpendicular to the median sagittal plane.

Length. The length of the cranial vault, Figure 1-B, was obtained from glabello-occipital length (GOL), or the greatest length from the glabellar to occipital regions, in the median sagittal plane.

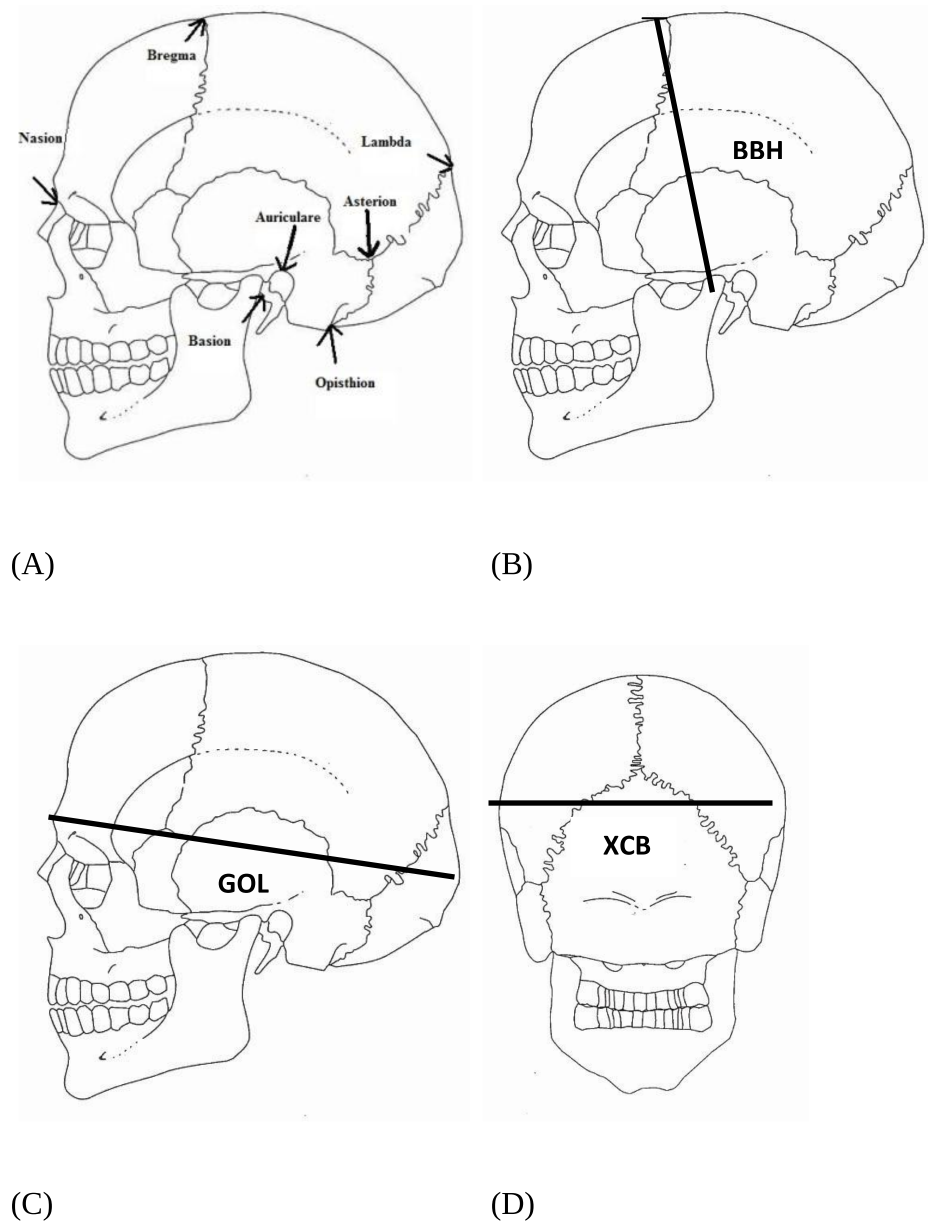

Figure 1. Diagrams of landmarks and neurocranial variables. (A) denotes landmarks used for cranial vault measures; (B) BBH represents cranial vault height; (C) GOL represents cranial vault length; (D) XCB represents maximum cranial breadth.

Basicranial variables

Height. Cranial base height, figure 2-A, was obtained from basion-radius (BAR), or the distance perpendicular to the transmeatal axis.

Breadth. Basicranial breadth was represented by biauricular breadth (AUB), Figure 2-B, and biasterionic breadth (ASB), Figure 2-D. AUB is the least exterior breadth across the roots of zygomatics processes (auriculare), wherever found. ASB is defined as the direct measurement from the common meeting point of the temporal, parietal, and occipital bones on each side (asterion).

Length. Basion-nasion length (BNL), Figure 2-C, serves as the length of the cranial base. BNL is the distance from the anterior border of the foramen magnum, in the midline (basion), to the intersection of the fronto-nasal suture and the median plane (nasion). Table 4 lists the variables used in this study along with abbreviations.

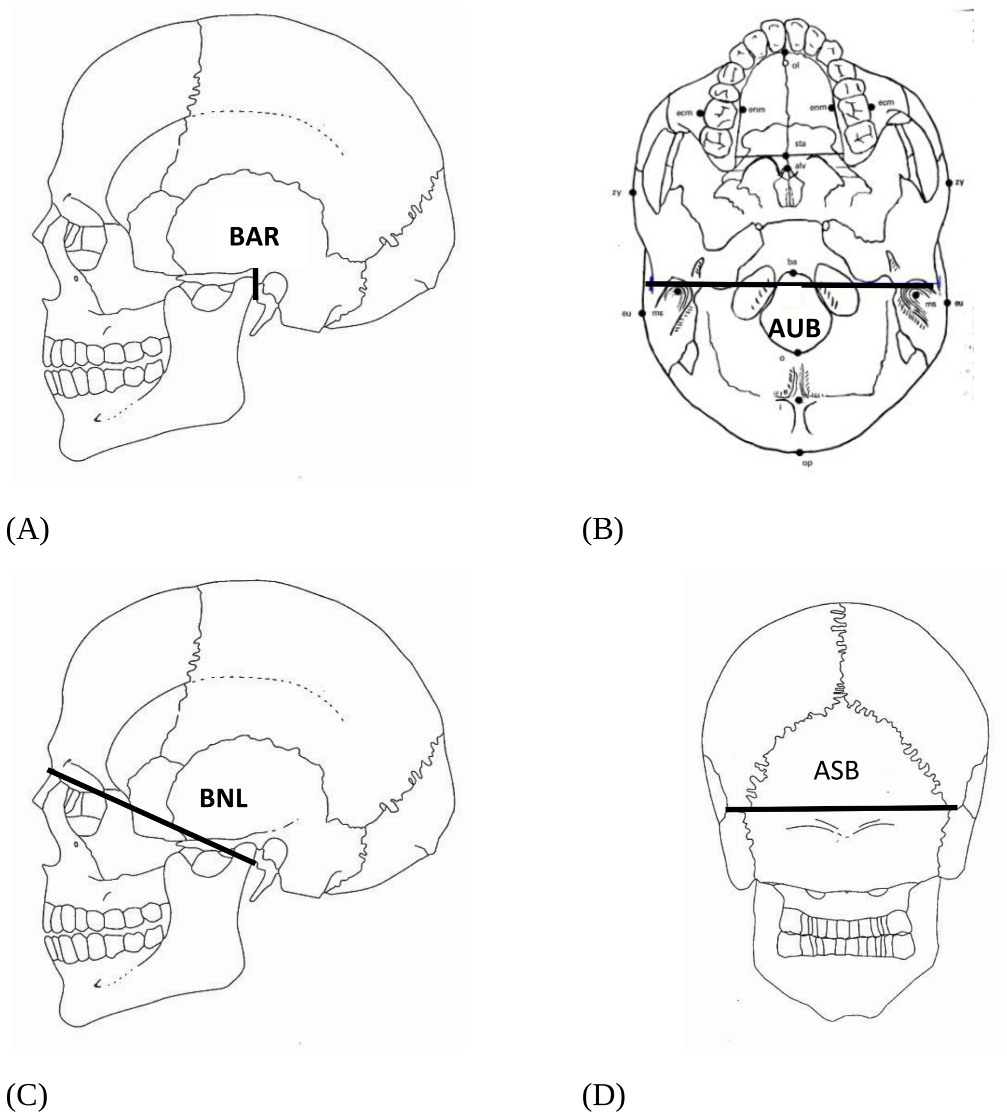

Figure 2. Diagrams of basicranial variables. (A) BAR represents basicranial height; (B) AUB represents basicranial breadth; (C) BNL represents basicranial length; (D) ASB represents the breadth of the posterior occiput.

Table 3. Variables and Abbreviations.

Variable	Abbreviation
Neurocranium	
Cranial vault height	BBH
Cranial vault length	GOL
Maximum cranial vault breadth	XCB
Basicranium	
Cranial base height	BAR
Cranial base length	BNL
Biauricular breadth	AUB
Biasterionic breadth	ASB

Statistics

The current study tested the utility of cranial vault morphology as an indicator of health by performing a model I, one-way ANOVA on six cohorts obtained from birth years that coincided with particular American historical periods. ANOVA on the "period cohorts" was carried out in SPSS Student Version 16.0 and results interpreted according to guidelines found in Madrigal (1998). The null hypothesis of a model I ANOVA states that all samples were obtained from the same population (Madrigal 1998). The H0 for the ANOVA stated that the means of period cohorts would not significantly differ from one another. The H0 was rejected if sample means differed significantly at the $p<.05$ level. The first step in testing the H0 was to estimate the total variation in the sample without regard to cohort membership. The total sum of squares (SStotal) was then partitioned into the amount of variation within the cohorts (SSwithin) and the amount of variation among the cohorts (SSamong). Sum of squares (SS) was then divided by the degrees of freedom (n-1) to obtain the mean squares (MS). Mean squares within (MSwithin) and mean squares among (MSamong) were computed in order to perform the ANOVA.

The H0 was tested by dividing MSamong by MSwithin. To reject the null hypothesis, individuals in cohorts must be more morphologically similar to one another than to individuals in other cohorts. When the null hypothesis is correct, MSamong will not differ from MSwithin (Madrigal 1998). The *F* ratio obtained by dividing MSamong by MSwithin was the statistic used to decide whether or not to reject H0. Where the ANOVA found significant differences, a post hoc Scheffé test was performed to compare all cohorts. The Scheffé post hoc test was chosen because it is the most conservative test and is therefore the least likely to produce type I errors (Madrigal 1998). Additionally, the Scheffé test can be used with unequal samples size, as is the case in the current study.

CHAPTER 3: RESULTS

Visual inspection of variables plotted against decade of birth revealed trends toward increases in neurocranial height and length, decreases in neurocranial breadth, increases in basicranial height and length, relative stability of cranial base breadth in the transmeatal dimension, and increases in the breadth of the inferior occipital bone. Arranging individuals into birth decade cohorts revealed episodic fluctuations in group means for nearly all of the measurements. Significance testing consistently revealed that these fluctuations resulted in significant differences for those born before 1900 and those born after. The results suggest a decline in health in the 1800's followed by a period of rapid health improvements right around the turn of the 20th century. Cranial height and length measures showed a decrease in size in the late 1800's followed by a rapid increase in size and subsequent leveling off in the 1920's. Vault breadth seemed to exhibit a pattern that was the inverse of that observed in height and length.

Birth Decade Cohorts

Neurocranium

Plots of birth decade cohorts detected trends in the relative increases and decreases in vault dimensions. Cranial vault height (BBH) showed a decrease in size from the 1840's until the 1860's, a slight increase during the 1860's, followed by a rapid decrease that reached its lowest value around the 1880's. The period from 1890's to

1900's saw a rapid increase in vault height that leveled off around the 1910's and has remained consistent since. Cranial vault height for decade of birth is represented by Figure 3-A.

Cranial vault length (GOL) showed a similar trend to vault height. GOL increased from the 1840's to 1860's, rapidly decreased from the 1860's until reaching its lowest value in the 1880's. Vault length then rapidly increased from the 1880's until the 1920's, declined from the 1920's to the 1950's, and has been increasing since the 1950's. The trend for cranial vault length for decade of birth is depicted in Figure 3-B.

Maximum vault breadth (XCB) exhibited an inverse trend to those of vault height and length. XCB increased steadily from the 1840's to the 1860's, and then declined in the 1880's. Vault breadth rapidly increased to its maximum level between 1890 and 1900, rapidly decreased from then 1900's to 1910's, and has steadily decreased since the 1910's. Cranial vault breadth by decade is represented by Figure 3-C.

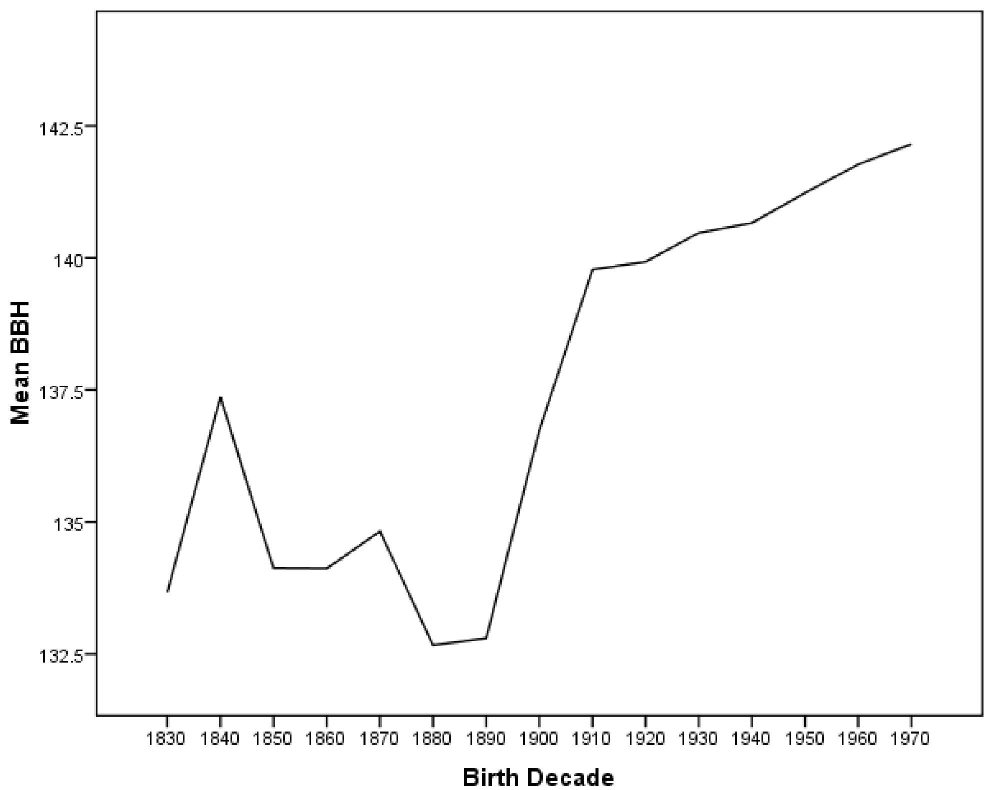

Figure 3: Plots of mean neurocranial dimensions against decade of birth
(A) Plot of basion-bregma height against decade of birth

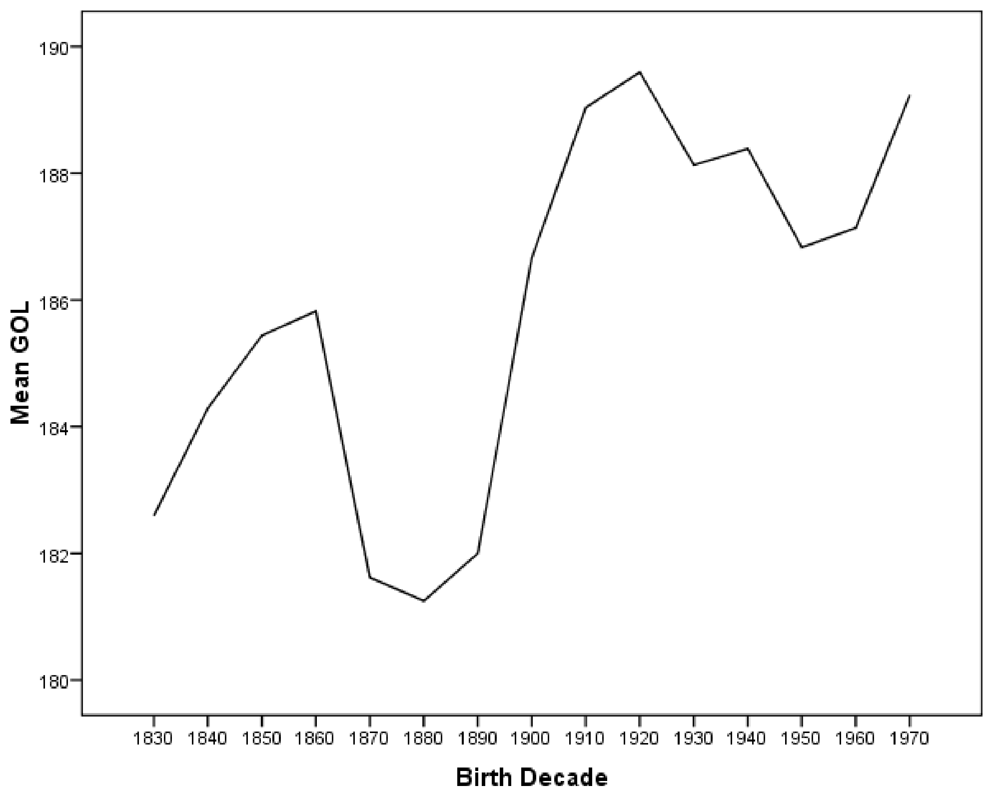

Figure 3: Plots of mean neurocranial dimensions against decade of birth
(B) Plot of maximum cranial length against decade of birth

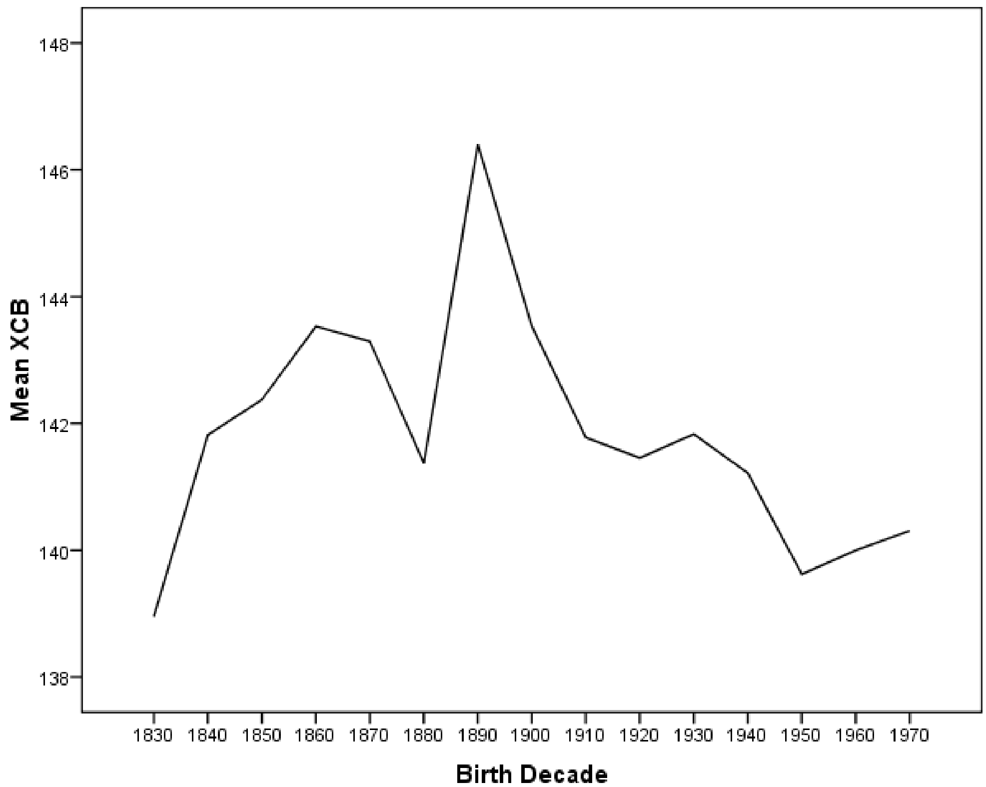

Figure 3: Plots of mean neurocranial dimensions against decade of birth
(C) Plot of maximum cranial breadth against decade of birth.

Figure 3. Plots of mean cranial dimensions against decade of birth. (A) cranial vault height (BBH); (B) cranial vault length (GOL); (C) maximum cranial breadth (XCB).

Basicranium

Cranial base height (BAR), Figure 4-A, presented a pattern similar to the ones observed in vault height and length. BAR was relatively stable from the 1840's to the 1870's, rapidly decreased from the 1870's to its minimum value in the 1890's, rapidly increased from the 1890's until the 1920's, and has moderately increased since the 1920's.

Cranial base length (BNL), Figure 4-B, increased from the 1840's to the 1850's, steadily decreased to a minimum in the 1890's, rapidly increased from the 1890's to 1920's, and has steadily increased since the 1920's.

Cranial base breadth in the trans-meatal dimension (AUB), Figure 4-C presented a pattern of rapid fluctuations throughout the time period studies. AUB decreased from the 1850's the 1880's, increased from the 1880's to 1900's, decrease from 1900's to 1910's, increased from the 1910's to 1920's, decreased from the 1920's to the 1960's, and has increased since the 1960's.

The breadth of the cranial base at the inferior occiput (ASB), Figure 4-D, showed a pattern more closely aligned with the height and breadth variables than with the other breadth variables. ASB decreased from the 1840's to the 1850's, decreased from the 1860's to its minimum value in the 1880's, rapidly increased from the 1880's to its maximum value in the 1910's, decreased from the 1910's to 1950's, and has increased since the 1950's.

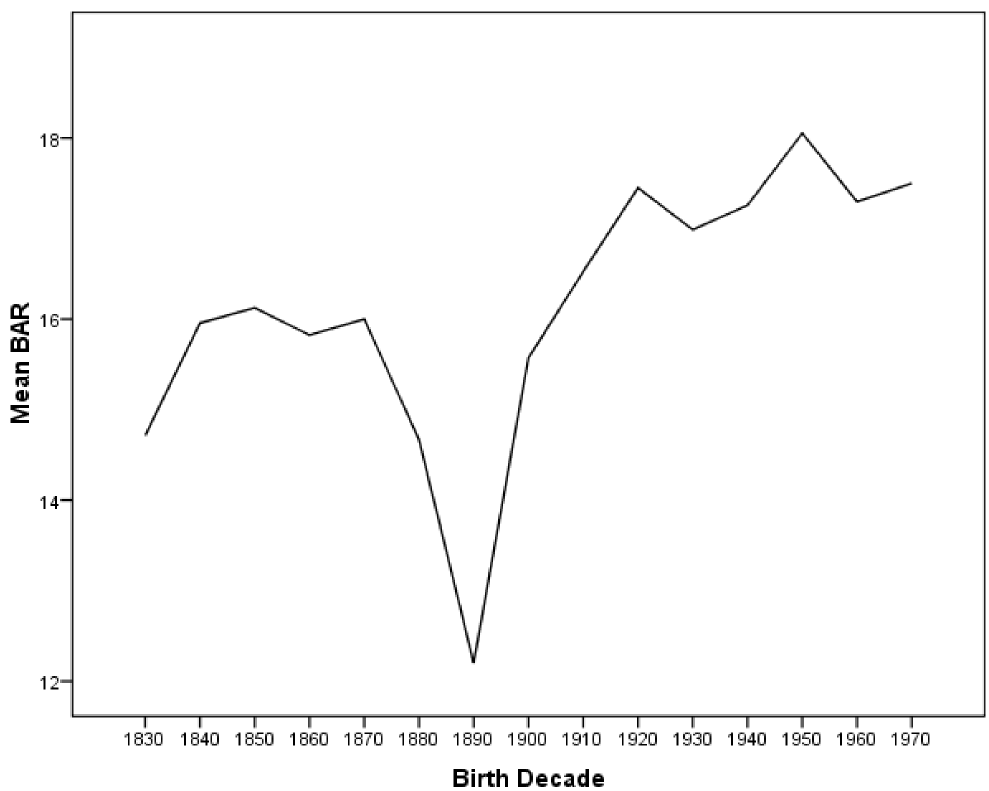

Figure 4: Plots of mean basicranial dimensions against decade of birth
(A) Plot of basion radius against decade of birth

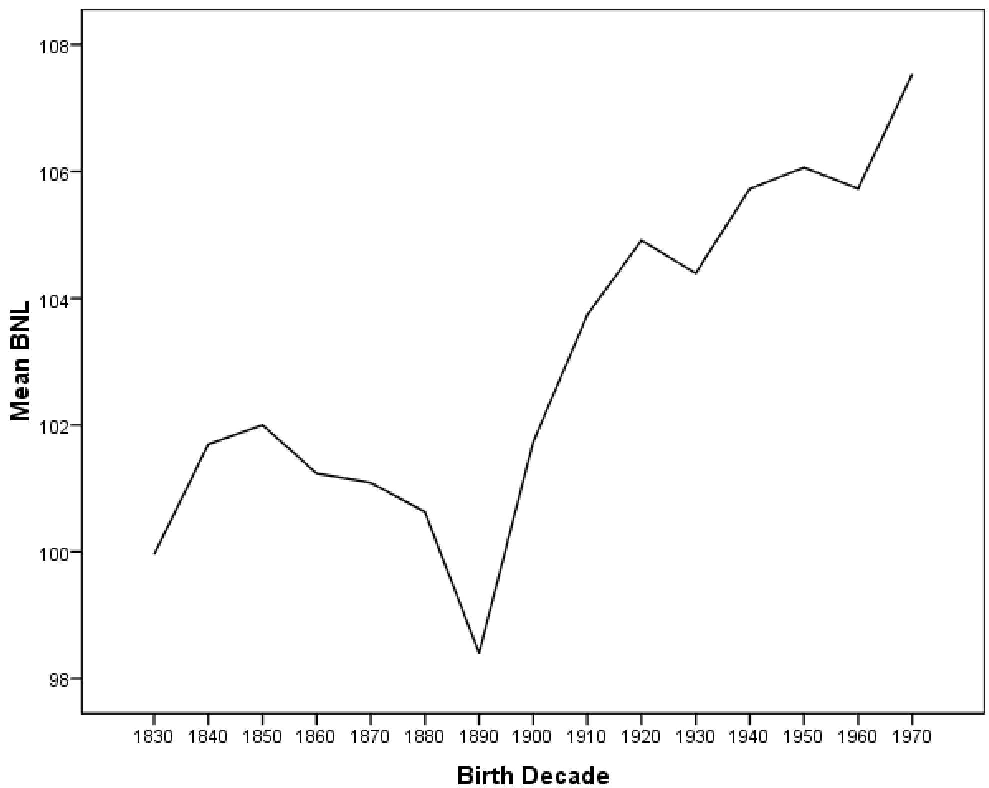

Figure 4: Plots of mean basicranial dimensions against decade of birth
(B) Plot of basion-nasion length against decade of birth.

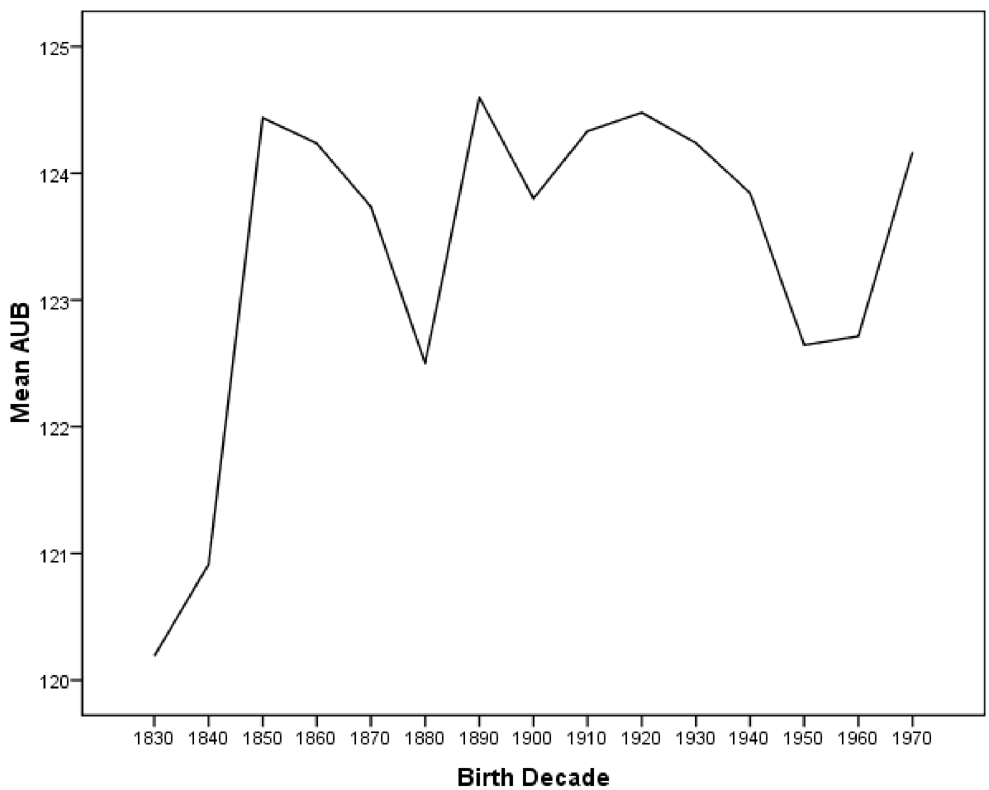

Figure 4: Plots of mean basicranial dimensions against decade of birth
(C) Plot of bi-auricular breadth against decade of birth.

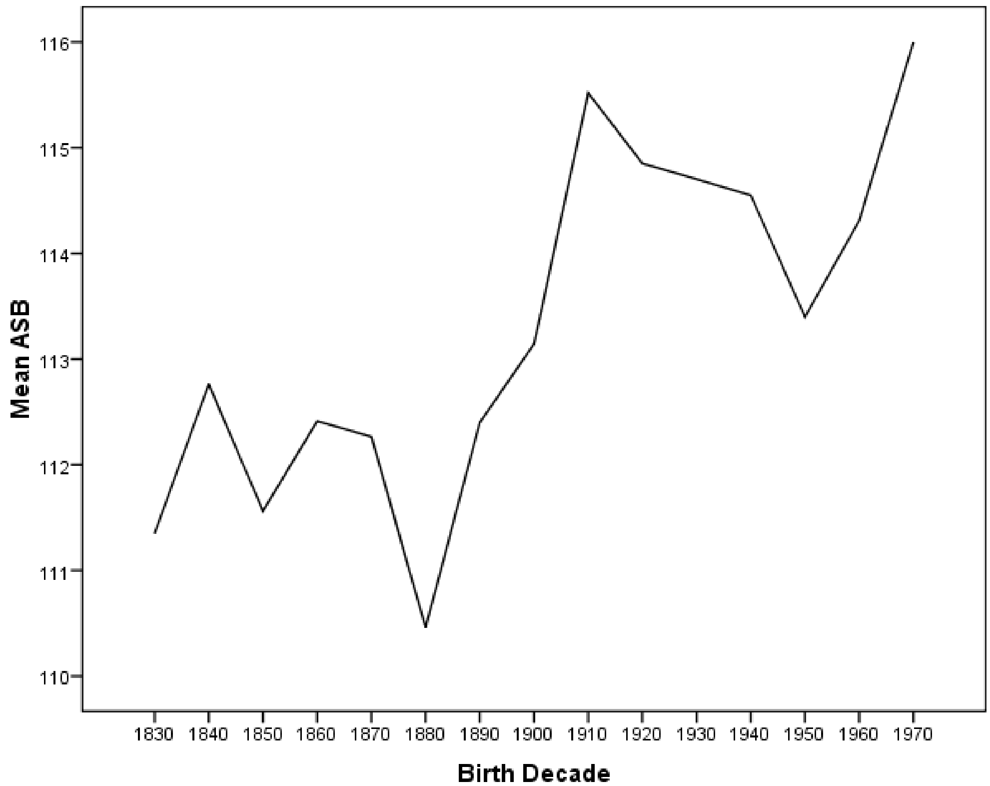

Figure 4: Plots of mean basicranial dimensions against decade of birth
(D) Plot of bi-asterionic breadth against decade of birth.

Figure 4. Plots of mean cranial dimensions against decade of birth. (A) cranial base height (BAR); (B) cranial base length (GOL); (C) cranial base breadth; (D) posterior occipital breadth (AUB).

ANOVA

Analysis of Variance indicated significant differences at the $p<0.05$ level for every variable used in the study. Table 5 depicts the ANOVA results for the neurocranial measurements: BBH (F=31.207, df=741), GOL (F=11.316, df=747), XCB (F=4.602, df=742); basicranial measurements: BAR (F=7.124, df=521), BNL (F=24.375, df=746), AUB (F=4.493, df=730), ASB (F=6.145, df=555).

Table 4. Results for Period Cohort ANOVA

Variable	*F* ratio	df
BBH	31.207	741
GOL	11.316	747
XCB	4.602	742
BAR	7.124	521
BNL	24.375	746
AUB	4.493	730
ASB	6.145	555

Scheffé test

Neurocranium. The post hoc Scheffé test detected significant differences between cohorts. For vault height, the Scheffé test revealed two clusters between temporally related cohorts. The first three cohorts (Antebellum, Civil War Era, and Early Progressive Age) were significantly different from the last three cohorts (Late Progressive Era, Great Depression, and Modern Era). Essentially, individuals born during the 19th century differed significantly from those born in the 20th century. Cranial vault length exhibited the same patterns as vault height with cohorts 1, 2, and 3 each differing significantly from cohorts 4, 5, and 6. For maximum cranial breadth, the only significant differences were found between the Civil War Era cohort and the Great Depression cohort. Error bars for the neurocranial ANOVA are presented in Figure 5.

Basicranium. Cranial base height (BAR) did not reflect the same pattern as vault height. For BAR, the only significant differences were between cohorts 1 and 6, the two most temporally different cohorts. Cranial base length, however, displayed the same temporal clustering as vault height and length with the 19th century cohorts significantly differing from the 20th century cohorts. The only significant differences for auricular breadth (AUB) were between the Antebellum cohort and the Late Progressive Age and Great Depression cohorts, while the Early Progressive Age cohort differed from the Late Progressive Age cohort and the Great Depression cohort in inferior occipital bone breadth (ASB). Error bars for the basicranial ANOVA are presented in Figure 6.

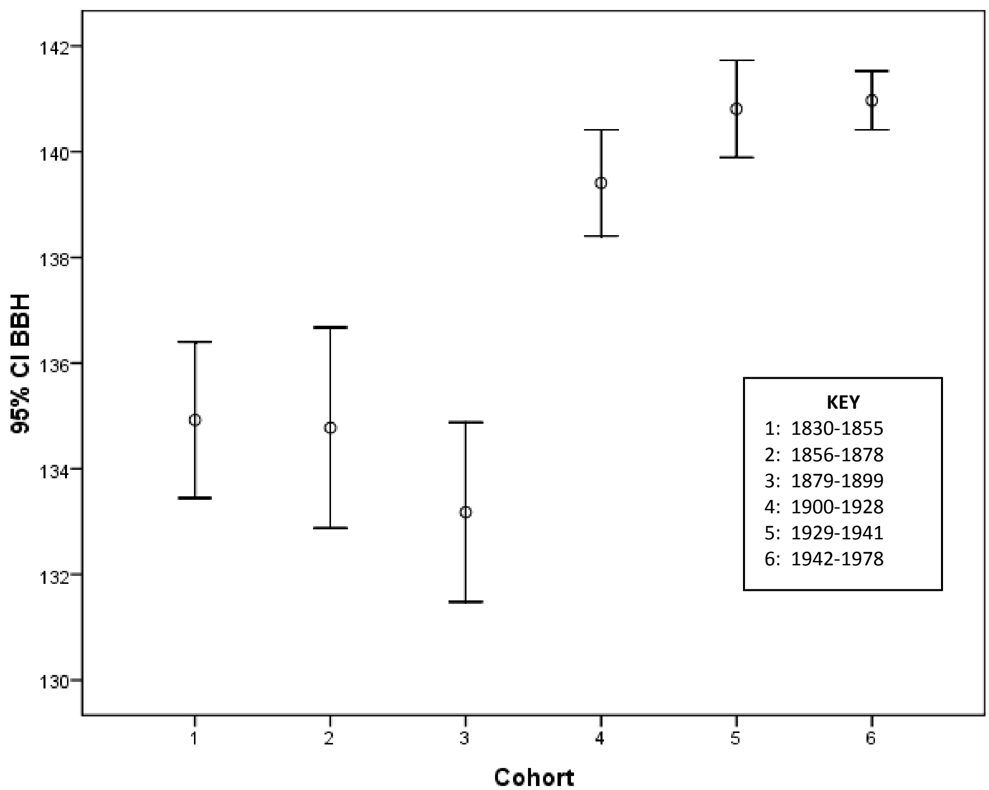

Figure 5: Error bars for neurocranial dimensions
(A) Error bars for cohort ANOVA for basion-bregma height.

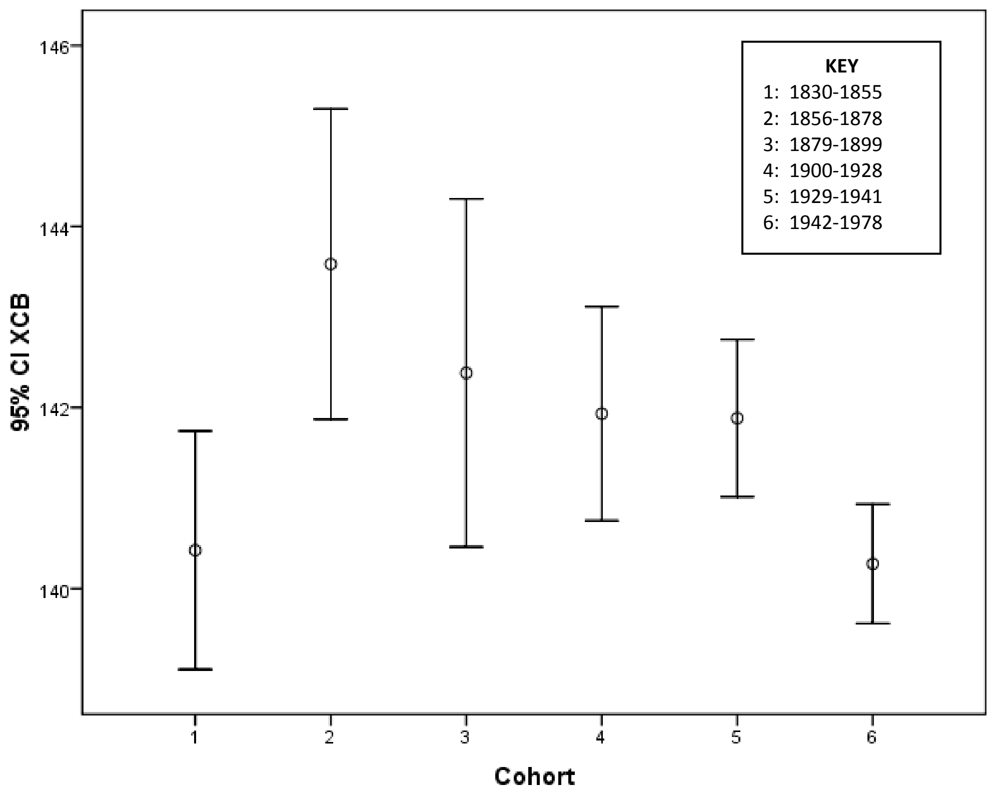

Figure 5: Error bars for neurocranial dimensions
(B) Error bars for cohort ANOVA for maximum cranial breadth.

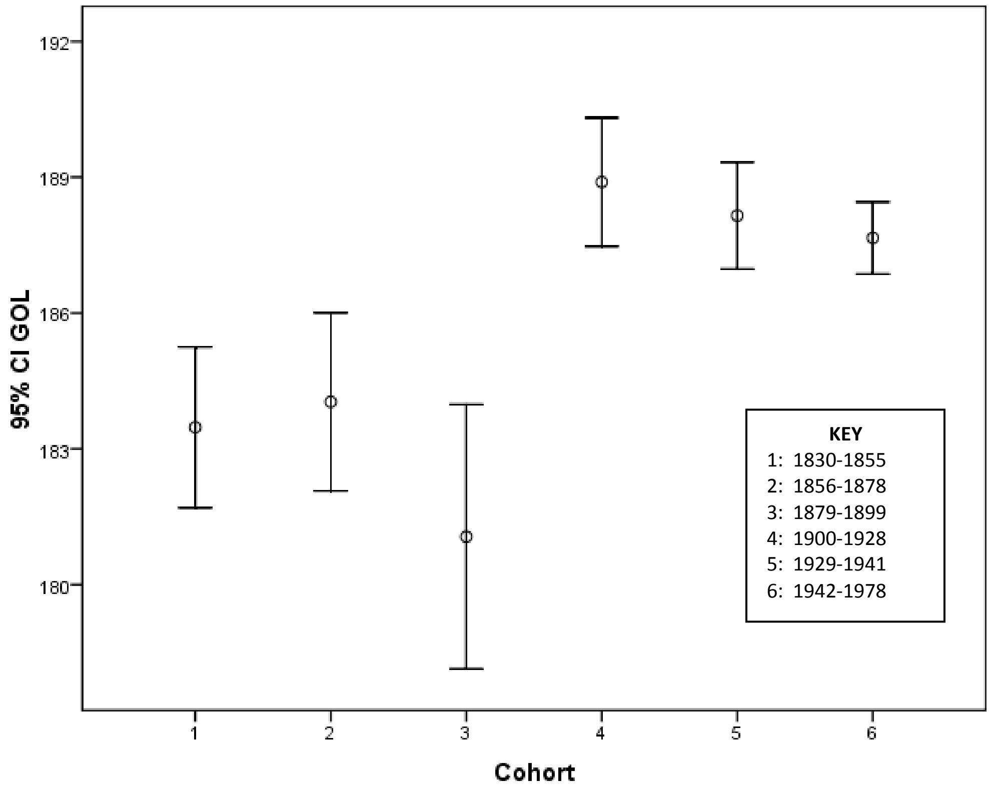

Figure 5: Error bars for neurocranial dimensions
(C) Error bars for cohort ANOVA for maximum cranial length.

Figure 5. Error bars for cranial dimensions. (A) basion-bregma height (BBH); (B) maximum cranial breadth (XCB); (C) maximum cranial length (GOL).

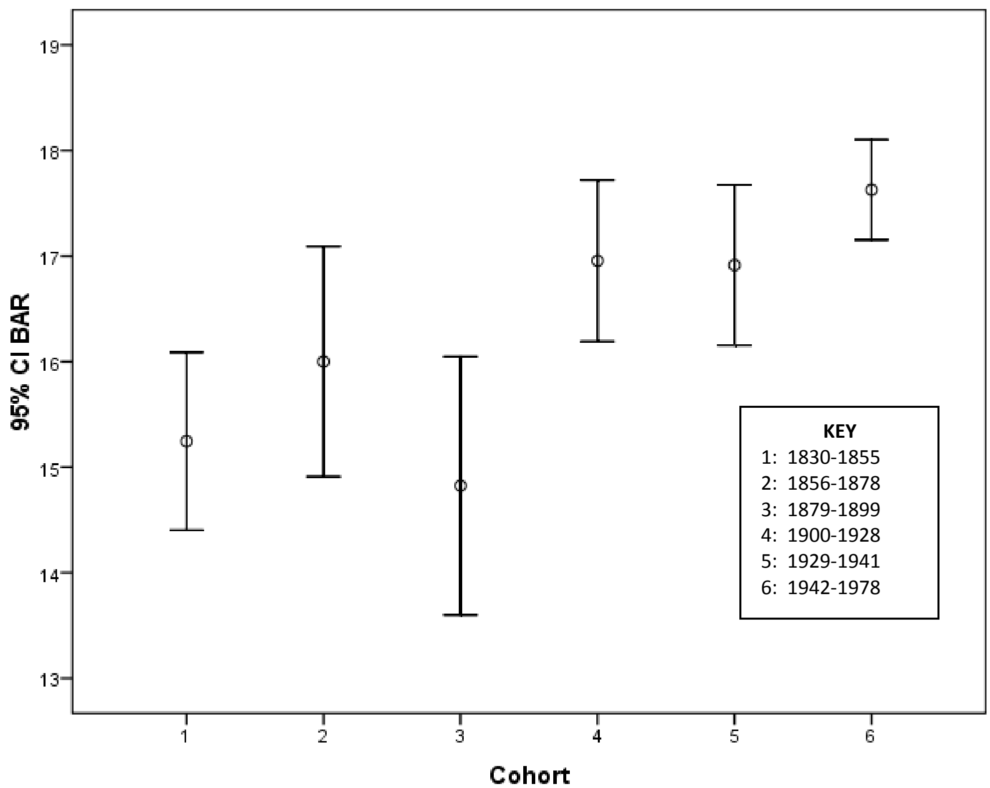

Figure 6: Error bars for basicranial dimensions.
(A) Error bars for cohort ANOVA for basion radius.

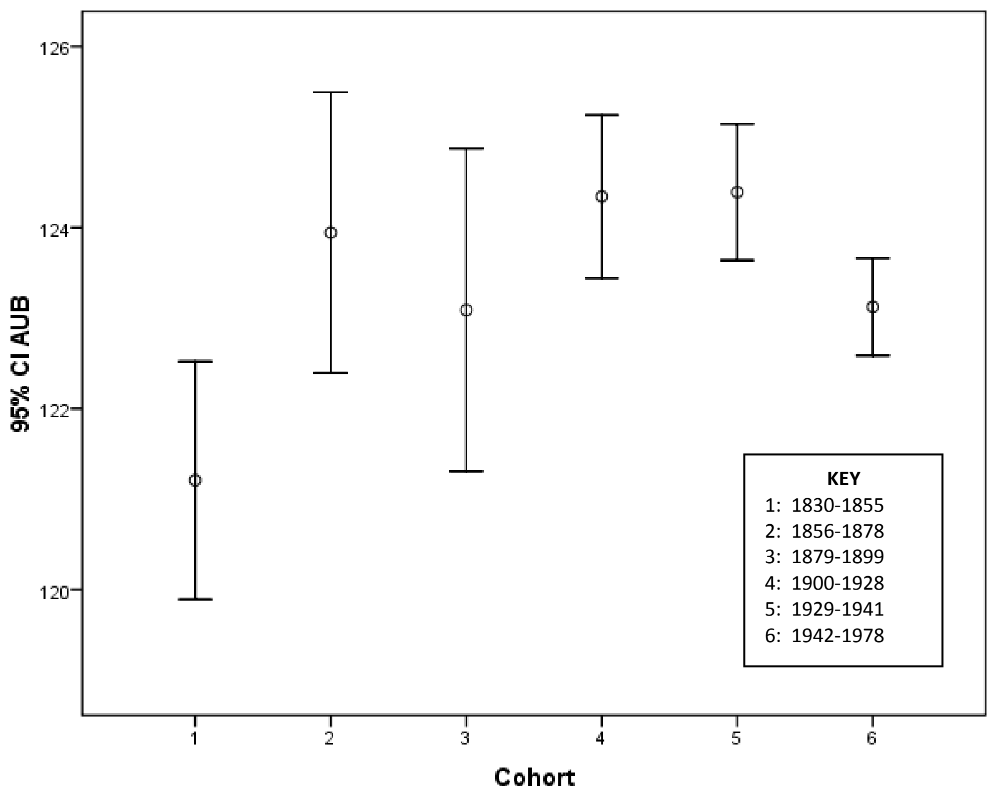

Figure 6: Error bars for basicranial dimensions.
(B) Error bars for cohort ANOVA for bi-auricular breadth.

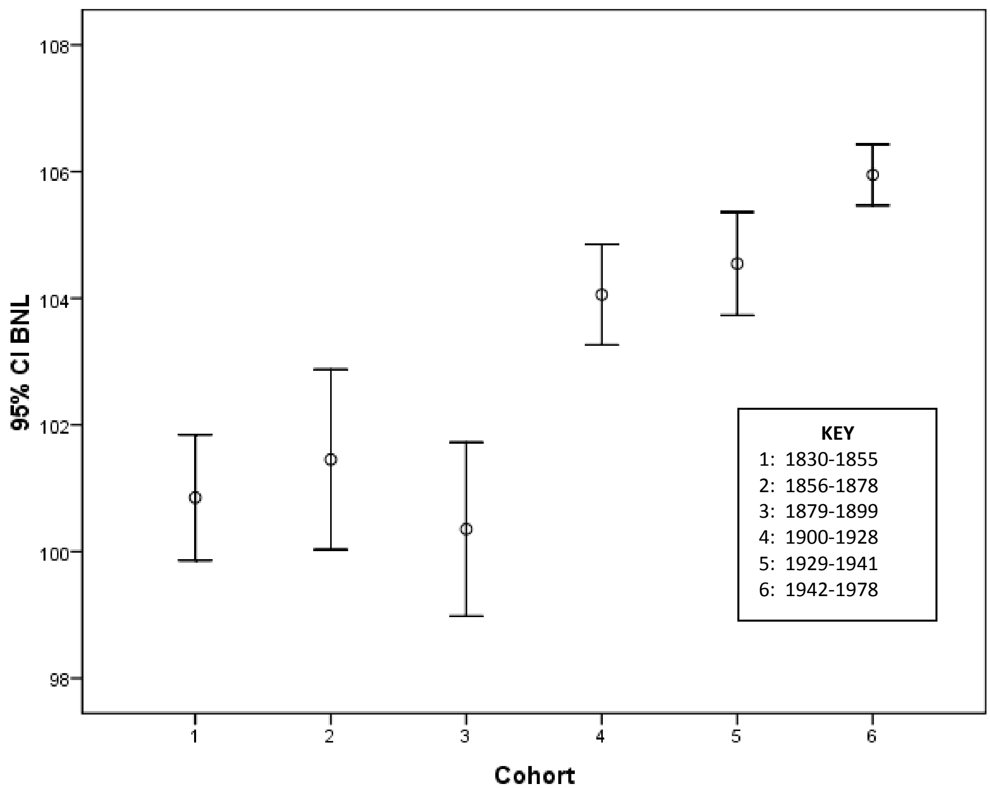

Figure 6: Error bars for basicranial dimensions.
(C) Error bars for cohort ANOVA for basion-nasion length.

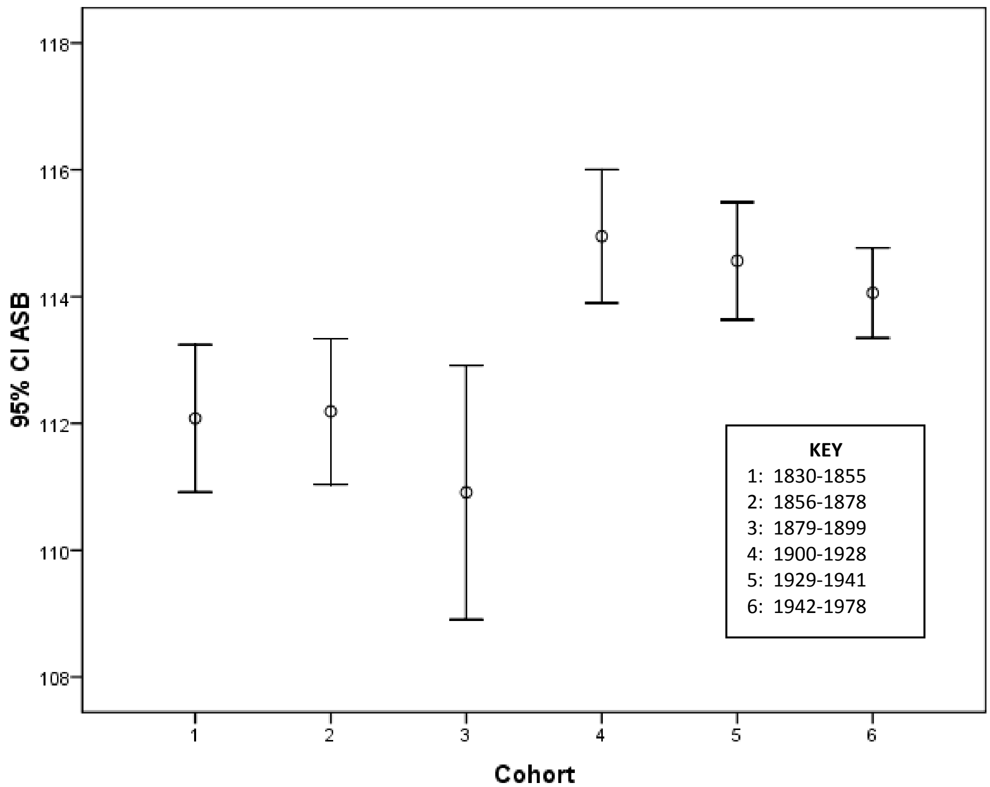

Figure 6: Error bars for basicranial dimensions.
(D) Error bars for cohort ANOVA for bi-asterionic breadth.

Figure 6. Error bars for cohort ANOVA for cranial dimensions. (A)basion radius(BAR); (B) bi-auricular breadth (AUB); (C) basion-nasion length (BNL); (D) bi-auricular breadth (AUB).

CHAPTER 4: DISCUSSION

The purpose of this study was to test the utility of cranial vault morphology as an indicator of population health. This project probed secular changes in the cranial vaults of white American males to detect periods of stunting due to nutritional deficiencies. The use of Civil War casualties enabled assessment of the cranial vault forms of individuals born during the Antebellum Period. The study was unable to detect a decline in health during the Antebellum Period because there was no record of cranial vault form prior to the 'Antebellum' period for reference. Future analyses spanning the Colonial period in American history will reveal whether or not cranial vaults decreased in volume during the early years of industrialization or whether the increases experienced during the Progressive Era were unlike any seen in American history. The fact that average stature appeared to decline from Colonial to Antebellum America suggests that members of the Antebellum cohort were indeed stunted. The case for stunting during the early years of industrialization was strengthened by comparison to the Civil War Era cohort. The values for each cranial vault dimension were similar between the Antebellum cohort and the Civil War Era cohort. The deleterious conditions of the American Civil War Era are thoroughly documented and the lack of significant differences between the two cohorts implies that adverse environmental conditions were also present during the early years of the industrialization process in America. That the changes in vault morphology during the Progressive Era of the current study were similar to those reported by Jantz an

Meadows Jantz (2000) further supports the utility of cranial vault form as an indicator of health.

Many changes in cranial form occurred during the time period of this study. Over the past 180 years, the quality of nutrition increased, disease and mortality decreased, and activity levels decreased, enabling additional resources to be directed towards growth and development (Jantz 2000). The effects that these factors had on growth are evident when comparing the Progressive Era to the Antebellum Period, in which little was known about nutrition, disease transmission, and the degree to which child labor negatively affects growth. Most of the changes observed in this study came between 1879-1928, after a period of health decline from the 1830's to the end of Reconstruction in the South in 1878. The results suggest recovery growth characterized by size changes immediately after Reconstruction followed by a period of growth characterized by shape changes. This study corroborated prior research that detected a decline in stature beginning in the 1830's. The similar trajectories discovered in cranial form suggest an actual decline in health rather than results altered by catch up growth. Explanations for the decline must involve the environmental conditions existing from the 1830's to the end of the Civil War Era in the late-1870's. Because this study included only American born males of European ancestry, genetic variation is an unlikely cause for the health decline. The differences between the Antebellum Period and the Progressive Era must be explained in terms of nutrition, disease, and labor. After discussion of the biological changes incurred during this time, explanations for the changes will be expressed in terms of each factor's potential impact.

Biological data

Antebellum Period. The results of the skeletal analyses of the cranial vaults of those born during the Antebellum period suggest that growth was stunted during this time. The neurocranium decreased in value in every dimension. This means that the neurocranium decreased in height, length, and breadth. This pattern holds true for dimensions of the basicranium as well. The results of previous literature along with the current study show an overall decrease in cranial vault size and stature from the 1830's to the 1880's.

Civil War Era. Although not significantly different from the Antebellum cohort, individuals born between 1855-1878 continued the trend of health decline initiated in the 1830's. The Civil War Era served as "trough" for the Antebellum decline in health with each variable reaching its lowest value over the trend. By the end of Reconstruction in the South, cranial vault height, length, and breadth were at the smallest values since the initiation of the Antebellum decline in health. This pattern hold true for the neurocranium as well as the basicranium.

Early Progressive Era. Dramatic changes occurred to the Progressive Era in American history. The current study divided the time period into cohorts of individuals born prior to 1900 and those born in the 20th century. Although not significantly different from the Civil War Era cohort, every cranial vault dimension increased in quantity during the Early Progressive Era to levels prior to the Antebellum decline. These increases were detected in both the neuro- and basicranium. The results suggest an improvement in health conditions after Antebellum period and subsequent Reconstruction periods.

Late Progressive Era. Every significant difference found in the current study occurred between the Early and Late Progressive Era cohorts. These results suggest dramatic improvements in the health of white American males right around the turn of the 20th Century. The changes that occurred around the beginning of the 20th century differ from previous trends because they appear to be changes in cranial vault form. Cranial vault form includes both size and shape dimensions. Vault height and length dimensions continued the trend of increasing, but vault breadth showed a more complex pattern.

Beginning around the year 1900, cranial vault breadth began to decrease. These results are similar to those of Jantz and Meadows Jantz (2001). Maximum breadth of the neurocranium decreased significantly between the Early and Late Progressive Era cohorts. The basicranial dimensions also exhibited different growth trajectories than in the previous cohorts. Cranial base height and length followed the same trends as neurocranial dimensions, but the decrease in neurocranial breadth did not result in decreases to either of the basicranial breadth measures. Basicranial breadth in the coronal plane remained stable, which would be expected considering that the auricular breadth was found to be a genetically stable cranial variable (Martinez-Abadias et al. 2009).

The results of the current study reveal that the individuals born during the Antebellum health decline had smaller heads than individuals born during the Progressive Era, and not just bodies. It is much easier to explain the stunting during the Antebellum period and the subsequent size increases following Reconstruction than it is to explain the changes in cranial vault form experienced at the turn of the 20th century. The change in form may be the result of the interaction between the basicranium and the brain.

Interrelation of cranial components

The basicranium serves as the platform for the brain. The cranial base provides the protective foramina through which the brain connects to the face and the rest of the body (Lieberman et al. 2000). The neurocranium essentially floats on top of the brain and its adult size is almost completely determined by brain size. The bones grow by sutural deposition until brain growth ceases and then fuse to form the completed cranial vault. Rather than being completely dependent on brain growth, the basicranial platform exerts some constraints on brain growth (Lieberman et al. 2000). To be an adequate platform for a rapidly expanding brain, the cranial base must be stable early on. It is reasonable to believe that brain growth will be affected in some way be platform upon which it rests.

The globular nature of the brain means that growth occurs in essentially all directions. Because the cranial base is the first region to reach adult size (Lieberman et al. 2000), it is essentially one fixed point among moving parts. It then becomes more efficient for the brain to direct growth energy in a manner similar to an inflating balloon. It follows that the dimensions of the basicranium (length, width, height) should be correlated with brain shape. Cranial vault height, length, and breadth are highly dependent upon, but not perfectly correlated with brain size because they are taken on the ectocranial surface and do not account for cortical thickness. However, the minimal error does not prevent variation in vault dimensions to serve as a proxy for variation in brain form.

The breadth of the basicranium also influences overall cranial vault length. Populations with genetically narrow cranial bases tend to have longer crania (Jantz 2000). The narrow base “bowl” produces resistance that inhibits inferior expansion and promotes growth in the anterior-posterior and vertical dimensions. The basicranium provides resistance, but does not prevent inferior-directed brain growth. Cranial base flexion is an adaptation to the pressures of an enlarging brain; therefore, cranial base height is component of cranial vault height (Lieberman et al. 2000).

Ecological explanations

There is no doubt that many factors contributed to the Antebellum health decline. Rising urban populations along with the development of railroads, canals, and steamboats increased exposure to disease. High food prices and growing social inequality could have led to malnutrition. However, these conditions were only exacerbated during the Progressive Era in which the health of the population dramatically improved. Even more so, there were no noticeable declines in the stature of individuals born during the Great Depression. The explanation for the differences in health between the mid-19th century and early 20th century lies in the different attitudes towards nutrition, sanitation, and disease between the two periods. The industrialization process in American reorganized the population from a primarily rural-based to a primarily urban-based nation. These demographic changes brought people in closer contact with one another and had numerous implications for the health of the populous. The Industrial Revolution in America occurred at a time when little was known about nutrition, disease transmission, and the effects of child labor on growth.

Nutrition

While economic explanations claim that rises in food costs led to the Antebellum health decline, American attitudes towards diet and nutrition most likely contributed to their decreasing stature. Food abundance diminished with a more urbanized and sedentary population (Roth 2000). Whereas in the 18th century food was produced and consumed primarily within local areas, industrial America transported food over long distances. Many food items, such as bread, were processed to aid in preservation (Roth 2000). The Antebellum decline occurred before such concepts as calories, protein, fat, carbohydrates, and vitamins were known (Roth 2000). The Progressive Era began during the age of the "groaning table" (Roth 2000). After the Civil War Era, Americans consumed food on a grand scale. Corpulence was considered a sign of success and well-being (Roth 2000). Conditions did not improve for the working classes, however. Millions of immigrants were paid wages that barely covered the costs of basic needs. In the late 1880's nutritionists began to understand the components of food: fat, protein, and carbohydrates (Roth 2000). These discoveries led to knowledge such as the fact that beans and meats shared similar amounts of protein that enabled the poor to provide better nourishment for their families (Roth 2000). Aside from substituting beans for meats, progressive reformers encouraged government legislation to prevent the tampering of food products. The Pure Food and Drug Act of 1906, for example, gave federal authority over interstate trade of food and drugs (Law and Libecap 2004).

Disease and sanitation

Prior to the late 19th century, little was understood about sanitation and the transmission of disease. Disease pandemics were a part of life and significant nutritional resources were spent combating infection. The increased urbanization associated with the early years of industrialization placed people in close contact another and increased the risk of exposure to disease. New modes of transportation brought diseases from across the globe and reached rural areas that would not have otherwise been at risk. The devastating effects of disease were most acutely felt during the Civil War. Nearly 63% (224,586) of Union casualties were caused by disease versus 12% (43.012) due to wounds (Gilchrist 1998). It is also estimated that more than 160,000 of the Confederacy's 250,000 casualties were the result of disease (Gilchrist 1998). It was the prevalence of disease and lack of treatment that designated infectious disease at the "Third Army" of the Civil War (Sartin 1993).

Sanitation was directly related to urbanization and disease. The population growth of large cities generated large amounts of garbage and waste. Larsen (1969) characterized the study of 19th century street sanitation a "study of filth and frustration (Larsen 1969). These were years prior to the invention of the automobile so most transportation was done via horse. While cities worked on plans to remove their garbage, horse manure and urine "created an almost unsolvable situation" (Larsen 1969). In 1880's St. Paul, Minnesota only one of the city's 325 miles of streets received regular cleaning (Larsen 1969). The same situation occurred all over the country, with the main goal of local officials to keep the roads passable. An interesting indicator of the dire nature of 19th century street sanitation, many cities enlisted pigs in the 1840's to eliminate the waste (Larsen 1969). It was not uncommon to see herds of pigs wandering the streets of New York, Louisville, and Cincinnati (Larsen 1969).

Understanding the germ theory of disease had tremendous impacts of the health of the nation. By the end of the 19th century germ theory was widely accepted throughout the country (Tomes 1997). The main aspects of the germ theory that led to health improvements were preventive and hygienic (Tomes 1997). Hand washing was now encouraged. Efforts were made to clean water supplies. Rather than disease treatment, disease prevention most likely allowed calories to be used more efficiently for growth and enabled the Progressive Era health improvements.

Child labor

Child labor laws were enacted beginning in the 1890's (Dubofsky 1985). In 1892 John Altgeld, governor of Illinois, persuaded the state legislature to pass a law limiting the work day to eight hours for women and children (Dubofsky 1985). The National Child Labor Committee was formed in 1904 (Dubofsky 1985). Throughout the 20th century legislation was passed that restricted the working conditions of children until the use of children as laborers all but disappeared during the 1930's (Dubofsky 1985). Other factors that contributed to the Progressive Era health improvements may not be as obvious as the changes in nutrition, disease, and child labor laws.

It is no coincidence that the upward turn in population occurred after the adoption of large scale mechanical refrigeration in the 1890s (Craig et al. 2004). Prior to refrigeration, meat, poultry, fruit, and dairy products spoiled very quickly. Craig et al. (2004) cite butter production as a prime mover in the increase in stature that occurred during the Progressive Era. The authors claim that "the annual contribution of refrigeration equaled 30% of one day's caloric needs for an average adult worker and thus more than 30% of a day's caloric needs for the population as a whole" (Craig et al.

2004). The authors also pointed out that the antebellum puzzle ended with stature increases in post-refrigeration cohorts (Craig et al. 2004). The findings of the current study are consistent with the claims of Craig et al. (2004).

The late 19th century and early 20th century was characterized by efforts to reform government, education, medicine, and industry. Muckrakers, such as Upton Sinclair, called attention to the exploitation of child labor, corruption in city governments, and the ruthless business practices of robber barons. Reformists wanted government intervention and federal regulation to combat the exploitation of people and resources. Thus, the Progressive Era began the age of American regulatory government (Law and Libecap 2004). The Progressives sought to break up business trusts and political machines, improve conditions in cities, improve working conditions for females and end child labor, protect consumers and voters, and reform banking. Progressive Era movements were essentially motivated towards the health of the population. These improvements were most apparent in legislation designed to regulate to food industry, combat sanitation and disease-related issues, and halt child labor. There can be no doubt that improvements in health experienced during the Progressive Era were the direct result improvements in the nutrition-disease-labor environment brought about by outcries against the conditions of the Antebellum Period.

CHAPTER 5: CONCLUSIONS

The addition of the skeletal remains of American Civil War casualties provided another biological aspect to prior research that detected negative trends in health during the Antebellum period as well as the improvements in health after the turn of the 20th century. The results of this study support the finding of previous literature that American health began to decline around the 1830's and reached its lowest levels around the end of Reconstruction in the South. The population then experienced a period of rapid growth which most likely resulted from the combination of size changes due to recovery from the Antebellum Period and Civil War Era and shape changes resulting from improvements in nutrition and medical sanitation. The results of the current study indicate a promising potential for using cranial vault morphology as an indicator of health in archaeological populations.

Some information regarding the demographics of the population is necessary, however, for the technique to be applicable. First, there must be enough population history to track changes in health over time. The historical period in American history was thoroughly documented, enabling health to be tracked almost to the year. These kinds of data may not be available for archaeological populations. Second, the methodology is population specific. Although stunting results in smaller crania for all populations, the observed secular shape changes in this study were due to the interaction of improvements in health with the genetically narrow cranial base of white American males. Craniometric analyses of health fluctuations in other populations will likely have different phenotypic fluctuations.

The health improvements associated with the Progressive Era in American history demonstrate that the health deficits experienced during the early years of industrialization may be overcome. The fact that health did not decline during the Great Depression suggests that proper medical sanitation may overcome disruptions in the nutritional environment associated with demographic transitions. These results have implications for countries that are currently industrializing. By examining the biological impact of the industrialization process in America, it may be possible to prevent the negative effects of industrialization in living populations.

Future research

Future should research should focus on the health of other populations during the early years of the industrial process. It is uncertain whether the detrimental effects experienced by white American males were uniform for both sexes and across populations of different ancestries. Future research on secular changes in populations with genetically broad cranial bases will shed further light on the interaction of brain growth, cranial form, and the effects of nutrition on growth. Additional research into secular change in the brain over the past 180 years will reveal which brain regions are changing and if those changes correspond to the changes in cranial vault morphology.

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