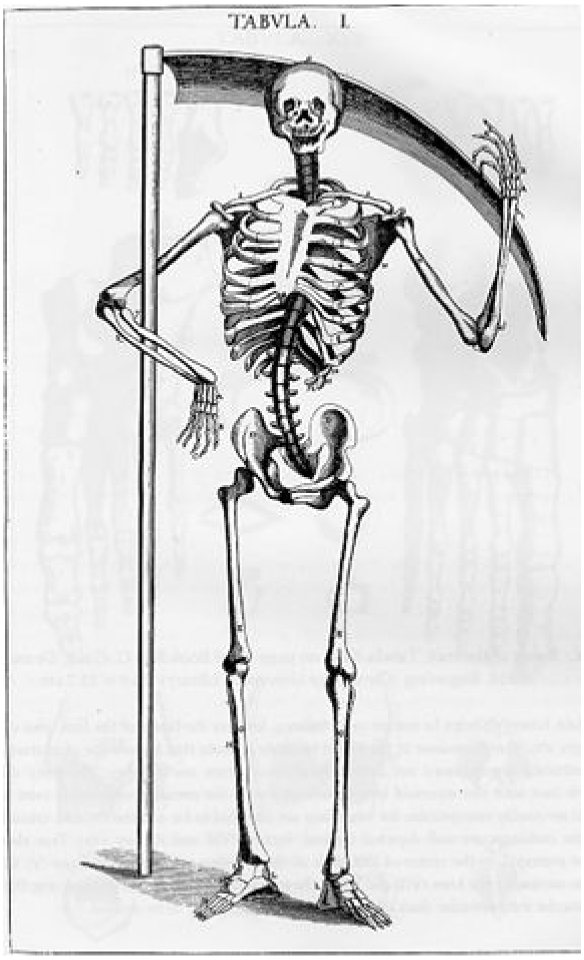
Human Adaptation to Climate: A Study of Human Adaptation to Humidity and Temperature in Three Populations



Elena Sandoval

Cover Image:

https://web.stanford.edu/class/history13/earlysciencelab/body/skeletonpages/241.gif

Human Adaptation to Climate: A Study of Human Adaptation to Humidity and Temperature in Three Populations

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Table of Contents

Table of Contents: Images

Table of Contents: Tables

Acknowledgements

Firstly I would like to thank my thesis advisors, Dr. Sarah Schrader and Dr. Carla Burrell. Dr. Schrader was instrumental in the formation of my thesis topic and in the choice behind the populations studied in this research. I am extremely grateful for her allowing me to use her Abu Fatima collection as my third population. Dr. Burrell was significant in the elevation of this research from a paper to a thesis. Her feedback was always extremely detailed and valuable.

I would also like to thank my housemate, Selina K., for her computation lessons in R and SPSS. Her consideration and patience in this matter allowed me to gain the understanding I needed to complete my statistical analysis.

I would also like to thank my mom for her support and patience during my academic career. This research would not have been possible without her encouragement.

Thank you

Elena Sandoval

1 Introduction

Darwin’s theory of evolution via natural selection relies on minute changes in organisms that become more pronounced over time, if the adaptations are more suitable to the environment (Darwin 1859). Due to constant environmental pressure, species in differing environments often have phenotypic, or physical, differences within the same species. Humans are not exempt from environmental pressures or evolutionary changes, and therefore should exhibit phenotypic differences depending on the environment.

Phenotypic differences have been studied in humans, but earlier iterations of these studies tended to draw incomplete conclusions, or only reported data conducive to their desired results in order to support the racist ideologies of the times. Modern studies of phenotypic differences in human populations have proven that these differences have arisen due to environmental differences, and have no relationship to intelligence or any fabricated superiority. Environmental changes should invoke an evolutionary response in regards to human physiology, as adaptation to environmental stressors is the basic building block of evolution.

Due to the process of natural selection, environments that differ in humidity and temperature should produce a response in the physiology of humans located in these differing climates. The shape of the nose and differences in body shape, such as the ratio of the upper leg to the lower leg, as a response to these climatic changes are the most commonly reported in scientific resources. However, these resources are often clouded by the racial divisions of the time. This is not to say that the data that was recorded during times of racial inequality is inaccurate, but rather the conclusions drawn from the data are often marred by racial insensitivities. The shape of different populations noses and the shape and size of their bodies should differ, but this is based on climate and the purpose of these anatomical structures.

This study will look at the size and shape of both the nose and the body in three different populations from differing locations; Suriname, Nubia, and the Netherlands. Using statistical analysis of specific skeletal measurements, this study will research the correlations behind the differences in body size and shape looking specifically at climate as the factor behind these differences.

1.1 Nasal structure

Body structure should suit the environment. The structure of the body is used to survive in the environment it lives in and should therefore change in regards to the influences of the environment. The structure of the nose in particular, should be variable based on changes in climate and temperature as the function of the nose is twofold; one: to increase the temperature of the inhaled air to the same temperature of the internal core of the body and two: to ensure the air that is inhaled is of the proper humidity to be used by the lungs. Inhaled air is required to reach a certain temperature and humidity level before it can be successfully used by the lungs. Without reaching this specific temperature and humidity, at the very least the lungs will not be able to operate at the optimum, and at the worst, detrimental body shock will occur (Zaide 2017).

While the nasopharynx plays a role in the warming of inhaled air, the nose is considered to be the most important part of this system as it is estimated that 90% of the necessary temperature is reached before the air enters the nasopharynx, pictured in Image 1 (Zaidi 2017). Due to the majority of inhaled air reaching the desired temperature inside the cavity of the nose, it would be plausible that the nose shape, and in turn the nasal indices, will change in regards to the climate and temperature of the outside world. The size of the nose should correlate to the climate the population lives in as the nose is a finely tuned tool that specializes in adapting inhaled air to a delicate balance of warmth and humidity. This tool should change depending on the needs of the population after centuries of natural selection.

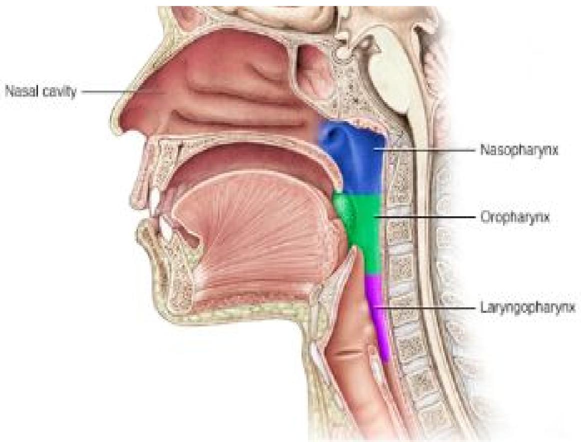


Image 1: The structure of the nasal cavity and the nasopharynx

https://www.mayoclinic.org/diseases-conditions/nasopharyngeal-carcinoma/symptoms-causes/syc-20375529

The nasal index is the ratio of nasal breadth to nasal length. This index creates an accurate representation of whether the cartilaginous portion of the nose of the individual was narrow, wide, or somewhere in-between. The narrower nasal indices are usually assumed to be from cold and arid climates, while wide nasal indices are usually assumed to be from humid and warm climates due to the rule of Thomson’s Nose (Thomson 1923). Arthur Thomson proposed this rule as the adaption of a narrower nose in cold and arid climates would insure that the air is warmed and moistened to the proper degrees before entering the nasopharynx due to the forced contact with the warm nasal walls. According to Thomson's rule, nasal indices that are found in warm and humid areas would be wider and shorter, as it is less vital for the nose to warm and humidify the inhaled air, as the outside temperature and humidity of the air is already near the necessary requirements of the lungs. This research prompted him to develop the concept of populations that live closer to the equator having wider noses, and the populations further from the equator have narrower noses (Thomson 1923).

1.2 Body structure

The crural index should also be related to environmental factors as these indices are an important factor in determining body shape. Crural indices measure the relationship between the length of the tibia and the length of the femur. This relationship is displayed in a single number. Differences in body shape and form should affect the crural index due to the needs of energy conservation for thermal regulation (Salewski 2017). Individuals who are located in warmer areas do not need to produce as much energy for thermoregulation as the climate itself keeps the body at its necessary core temperature, or at least ensures less energy is needed to maintain the necessary temperature. Colder temperatures would result in a greater amount of energy needed to maintain core temperature (Salewski 2017). The humidity of the area also plays a role in thermoregulation as it affects the way the body can regulate heat. As the tibia is the most distal skeletal element in the leg besides the feet, pictured in image 2, it would be expected to be correlated to environmental factors as the shape of the body would be affected by distal elements in a greater way than proximal elements (Allen 1877).

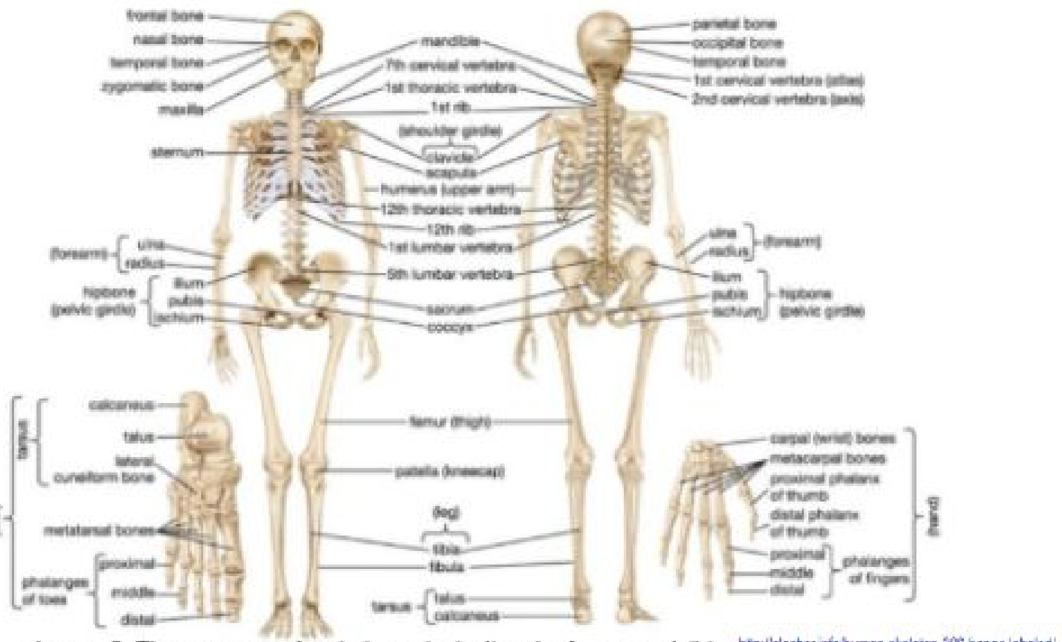


Image 2: The anatomy of a skeleton including the femur and tibia. http://glasber.info/human-skeleton-206-bones-labeled/

The crural index represents the ratio of the femur to the tibia. If the tibia is affected by environmental factors, the crural index will reflect these changes. According to the rules set forth by Carl Bergmann and Joel Asaph Allen, the tibia should be shorter in colder regions and longer in warmer locations (Bergmann 1847 in Meiri 2003, Allen 1877). A larger tibia will result in a larger crural index. If the temperature is the largest factor affecting the length of the distal skeleton, then the crural index would increase in warm locations and decrease the colder the region.

The suitability of the body to the environment is the backbone of the theory of evolution due to natural selection (Darwin 1859). The suitability of body shape and size should cause phenotypic differences among human populations that live in different climates. Certain body shapes and sizes should be more suited to certain climates due to the need for the human body to regulate internal temperature and the effect the outside temperature has on the time it takes to lose the generated heat. A more compact and spherical body shape with short distal limbs would be the most ideal body for an endothermic animal in a cold environment (Bergmann 1847 in Meiri 2003, Allen 1877). If this is applicable to the human body, the adaptations should be measurable through the crural index. The crural index will change according to the size of the tibia, a distal long bone, which allows for a measurement of the change in body shape and size in different populations.

1.3 Research questions

While current anthropological research suggests that there is a strong relationship between the environment and changes in the crural and nasal indices, this correlation has yet to be completely proven. This research will add to the literature on this subject using three separate populations that have yet to be compared under this topic. The impact of the environment on human physiology will give anthropologists a greater understanding of our ancestors' physiology and possible reasoning behind certain phenotypes. With the increasing globalization of our world, this research is also important as it not only dispels lingering thoughts on the racist theories of the early twentieth century, but it is important for scientific fields such as medicine to have a full understanding of how certain ancestries can have traits that support the environments of past populations, and may not be as adapted to other environments which could lead to health problems, such as the environmental adaptability of retaining fat in cold areas. This study will delve into the following questions:

- Is the nasal index correlated with sex?
  - If so, is sex more of an influence than climate?
- Is the nasal index correlated with humidity or temperature?
  - If the nasal index is correlated with both, is one of these climate factors more of an influence than the other?
- Is the crural index correlated with sex?
  - If so, is sex more of an influence than climate?
- Is the crural index correlated with humidity or temperature?
  - If the crural index is correlated with both, which is more of an influence?

These questions are formed to create a determination of whether climate is correlated with body shape and size, and if sex is a factor in these measurements.

1.4 Thesis structure

This thesis contains six chapters. This chapter provides an introduction to the research topic of study. The background of this research will be presented in Chapter 2 and will explain the complex origin of using metrics to determine information about human evolution and how the methods and reasoning changed over time. Chapter 3 will present the materials and methods of this research. In Chapter 3, the methods used to determine which measurements were taken will be discussed. An overview and explanation on which skeletal collections were included in this study will also be examined. Alongside this, a historical background on each of the three populations under study will be provided. Following the materials and methods chapter, the results chapter (Chapter 4) will provide the data that was collected and the statistical analysis that was used on the data set. Chapter 5 will present a discussion of the results and will explain the meaning behind the statistical analysis and how this affects the study of human adaptation to the environment. The discussion chapter, Chapter 5, will also go over the limitations of the study and how the results either supported or contradicted my hypotheses. Chapter 6 will present the conclusions of my study. Aspects of further research in this area of study will also be approached in this chapter.

2 Background

This chapter will provide a detailed history behind the use of skeletal measurements, known as anthropometrics, as instruments of science. The genesis of anthropomorphics and its use as a pseudoscientific tool will be discussed, as well as the turning point in which anthropometrics began to be used to discuss scientific queries. The formulation of the nasal and crural index and how these were used in both pseudoscientific ways and for scientific means will be explored. An overview of climatology and the classifications of certain aspects of temperature and humidity will also be discussed.

2.1 Natural selection and its tie to anthropometrics

In November 1859, Charles Darwin published his book on evolution titled *On the Origin of Species* and changed both the scientific community and the public sphere (Darwin 1859). In this book, he detailed that the driving force behind evolution was a process he called natural selection. Natural selection relies on environmental pressures acting on individuals of a species, with each individual containing some measure of variability. Heritable traits are randomly passed down from parent to offspring and overtime, selective environmental pressures cause the genes that are more adapted to the environment to become more pronounced. The individuals who are less suited to the environment have a smaller chance at survival and reproduction, and therefore will eventually become extinct. Over time Darwin's theory of evolution by natural selection displaced other evolutionary theories as it gained more supporting evidence through the discovery of genes and meiosis. The gathering support for Darwin's theory brought it into the public eye, which caused a new focus on the variability among humans. As human variability rose to the forefront of scientific and public thought, new ways to understand and measure this variability were invented and tested. It was during this time that the idea of anthropometrics was invented.

2.2 Anthropometric history

Anthropometrics has a long and complex history when it comes to studying human variation due to its adoption in the late eighteenth century, the era of the escalation of the eugenics movement in scientific circles (Ulijaszek 2009). The creation of anthropometrics stemmed from a need to identify criminals in Paris in order to punish them to the fullest extent of the law and deport them to French colonies (Ferrari 2016). A member of the criminal records office in Paris, Alphonse Bertillon, son of Louis-Adolphe Bertillon the founder of the Society of Anthropology of Paris, brought attention to a flaw in the identification process of repeat offenders (Ferrari 2016). Prior to anthropometrics, repeat offenders were identified through their names or any unique features, such as tattoos. The obvious issue with this identification method is the use of an alias. Bertillon bypassed this issue by measuring specific locations on individual's bodies, such as height, width, shoe size, and included this information in their criminal record (Ferrari 2016). Bertillon used the idea of variability among individuals from the theory of natural selection to argue each individual would have a distinctive and non-repeated set of measurements (Ferrari 2016). The logic behind this was, if an individual was suspected of being a repeat offender, these measurements could be taken again and the appropriate file on past criminal activities could be found as the measurements would act as a unique identifier. The ethics of deportation as a punishment notwithstanding, Bertillon had discovered that measurements of various areas of the body varied between individuals (Ferrari 2016).

Unfortunately, the use of anthropometrics took an even darker turn during the later years of the nineteenth century and the beginning of the twentieth century. With increasing globalization, anthropometrics soon morphed into a tool for xenophobia and eugenics. The beginning of race theory intertwining with eugenics theory begins as far back as 1869, when Francis Galton, the father of eugenics, published a 'scientific' book on eugenics theory (Galton 1869). In Galton's book, *Hereditary Genius*, Galton focuses an entire chapter on "The Comparative Worth of Different Races" (Galton 1869). In this chapter, Galton (1989) introduces the idea that races compete against each other in the struggle for survival and only the most suited will survive. Galton (1989) states, "the nomadic disposition found in most barbarians becomes unsuitable in these conditions (the conditions being what Galton considered a true civilization, a European society) (Galton 1869)". The purpose of this study was to create a socially acceptable way of promoting racist ideals that were sanctioned by 'scientific[1]' research.

To this end, Galton opened a laboratory that was used to measure over 9,000 individuals in an attempt to categorize races by physical means (Lombardo 2016). Each race was categorized by physical traits which were immutable. An individual was designated a single race based on these fixed physical characteristics. Craniometrics, measurements taken on

[1] This was actually a pseudo-scientific approach to the theory of evolution via natural selection which used elitist, racist views and cherry-picked data in an attempt to legitimize racism and elitism.

the cranium, in particular was used as a tool to further ‘scientific’ proof that certain races were more ‘pure’ than others, while ‘less pure’ races were more prone to qualities such as alcoholism, laziness, and criminality. Galton based his ideas on a heavily biased concept that nature and heritability was the driving force behind undesirable traits and actions, which not only disregarded nurture, but also assumed that European traits were more desirable. Galton also tended to ignore female traits altogether as he believed intelligence and the ability to inherit talent and ability belonged solely to males (Kron 2005).

Early anthropometric studies were not always used for abhorrent reasons. Early studies of stature comparing populations of various socioeconomic classes proved the lack of access to proper nutrition that plagued the lower classes of industrializing countries (Kron 2005). Initial studies of nutritional disparities in differing social classes were based on anecdotal evidence, which was usually ignored or accused of being biased. Anthropometric studies of stature allowed an objective and scientific approach to these studies, by providing measurable evidence of the lack of nutrition of the urban working class. Studies conducted in France and England in the late 19th century and early 20th century on the stunted growth of industrial labourers helped shed light on the poor working environments and nutrition of the working classes (Kron 2005). The process behind anthropometrics was not inherently flawed and its use was not always grounded in racist undertones. Anthropometrics had the potential to be used to better society, such as the studies on the link between height and poor nutrition, and to unlock scientific discoveries, but for the first several decades of its inception, anthropometrics was dominated by pseudoscience that was used to promote the sexist and racist ideas of the time.

A turning point in anthropometric research was conducted and published by E. A. Hooton, who studied skeletal collections to create a classification of morphological types, which are detailed in Edward Hunt’s 1959 publication on the history of anthropometry (Hunt 1959). A combination of measurements and shape of certain attributes, such as the cranium, was used as the basis of this classification which created racial groups called primary groups and various subgroups. The difference between Hooton and Galton’s work, was Hooton’s studies dissolved the link between mental prowess and race stating, “There are no racial monopolies either of human virtues or of vices (Hooton 1936)”. However, as many scientists of the early twentieth century, Hooton still advocated for sterilization of criminals and those deemed insane (Hooton 1936).

The separation of anthropometrics from mental and behavioral profiling was an important step towards understanding phenotypic differences across human populations were caused by differences in environment and had nothing to do with a hierarchical racial plan. By stepping away from the assumption that differing phenotypes must be related to racial and mental differences, scientists were able to broaden their hypotheses on the reasoning behind phenotypic phenomenons. This paved the way for Arthur Thomson's work on the changes of the nasal index in populations of differing climates (Thomson 1923).

2.2.1 Nasal index history

In 1923, Arthur Thomson and L. H. Dudley Buxton published their research on nasal indices titled *Man's Nasal Index in Relation to Certain Climatic Conditions* (Thomson 1923). This research separates nasal index size from any correlations with mental ability or the nature of an individual and focuses instead on the forces of temperature and climate acting upon human populations. Thomson and Buxton developed a formula to describe the way humidity and temperature acts on the nasal index. According to their formula, each 2 degree fahrenheit change in temperature produces a 1 millimeter change in the nasal index (Thomson 1923). Humidity on the other hand, requires a 5% change in the relative humidity to produce a 1 millimeter change in the index. If humidity and temperature are not acting independently on the nasal index, then temperature will be a stronger factor than humidity (Thomson 1923). However on average, their research shows that nasal indices in the Eastern Hemisphere have a correlation with climate of a .721, where 1 is a perfect correlation (Thomson 1923).

Thomson and Buxton did not create a perfect formula to find the nasal indices of populations based on temperature and humidity, but they did show that there was an obvious correlation between the climate of the population and the size of the nasal index (Thomson 1923). Thomson and Buxton admits their formula had exceptions to the rule (Thomson 1923), but the list of exceptions is longer than it should be for a working formula. The exceptions to the rule as put forward by Thomson and Buxton are populations from tropical areas, populations from the center of continents, and populations from towns. The caveats to this formula are more widespread than desirable, which questions the validity and applicable nature of Thomson and Buxton's conclusions to continuing research on nasal indices. Thomson and Buxton do mention two compounding factors that might have influenced their data and conclusions. Firstly, is the lack of accurate meteorological data from all of the regions studied and secondly, the increased globalization and migration of different populations. As the amount of time it is needed for the nasal aperture to be influenced by selective pressures is unknown, any migratory groups that were included in the study would have skewed the data as they would not be representative of the climate they are currently living in.

Further research into the nasal index indicates a separate climate correlation between nasal height and nasal breadth. Due to the role of the nose in moisture retention, humidity was considered next in the factors surrounding changes in the nasal index. Milford Wolpoff studied the components of the nasal index separately and extrapolated from his data that nasal height has a higher correlation to temperature, while nasal breadth has a higher correlation to humidity (Wolpoff 1968). This indicates that climatic pressures outside of temperature affect the nasal index. However, nasal height is the most variable component of the nasal index worldwide, which suggests that temperature is still the most substantial factor affecting nasal index variation, unless there are other factors involved in this variation.

2.2.2 Crural index history

A discussion on the history of the crural index in regards to its use in the field of biology, anthropology, and archaeology cannot be conducted without first introducing Bergmann's and Allen's rules. Both of these rules were developed in the 19th century to describe ecogeographical rules that endothermic animals follow. Ecogeographical rules are trends in morphology that are directly correlated with the environment (Nudds 2007) and tend to be applicable to humans. Bergmann's rule, published in 1847 by German biologist Carl Bergmann, posits that endothermic species in colder climates will have larger body masses in order retain heat due to a reduced surface area (Meiri 2003). Allen's rule, developed by Joel Asaph Allen in 1877, broadly states that colder environments will produce animals with shorter distal appendages and a rounder form (Nudds 2007). The logic behind this rule was the reduced surface area of short appendages and a round form will save energy as there will be less heat loss and therefore the animal will be able to keep their temperature regulated easier (Nudds 2007). The similarities between these two rules tends to link them together as one rule, but there are key differences between them.

Allen's rule focuses specifically on the shape of the form and on the appendages and is therefore more applicable to studies focusing on crural indices. The focus of Allen's rule is on the energy needed to maintain the necessary body temperature. In colder climates, this energy is greater, so less surface area to volume would be a more effective body shape for maintaining temperature. In this way, the distal appendages should be shorter in colder climates to create this ratio of surface area to volume. The crural index, which is measured using the femur and the tibia, should be affected by climate in such a way that the tibia shrinks in size in colder climates according to Allen's rule. The populations from warmer climates should have smaller crural indices as the tibiae should increase in size as it takes less energy to maintain thermoregulation in warmer climates.

Bergmann's rule, like Allen's rule, focuses on energy production and energy retention. This law is based on the mass to surface area ratio, in which a greater mass will produce a larger amount of energy, which regulates the temperature of the organism, but in order to retain this energy a smaller surface area is needed which is illustrated in image 3 (Kurki 2008). The larger the surface area is on an organism, the greater the loss of energy through convection and evaporation (Kurki 2008). Thus a smaller surface area would conserve energy by retaining heat and moisture. The colder the climate, and the further away from the equator an organism lives, according to Bergmann's Law the most functional form for thermoregulation purposes is a high body mass with a low surface area, which results in a rounder form. This should influence the crural indices as the form shape and mass of the form is altered from areas with higher temperatures. Bergmann's rule of a larger body mass in colder climates would suggest a longer femur in lower temperatures as the femur supports much of the weight of the body while walking, and therefore should be affected by a larger body mass.

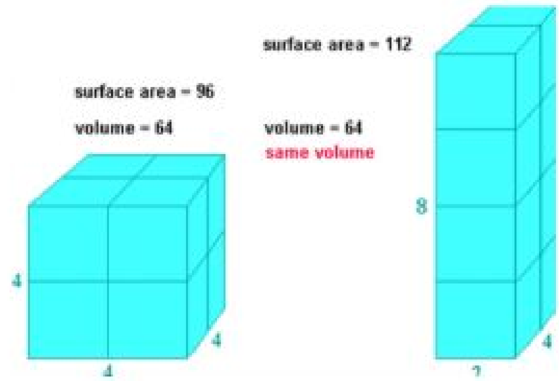


Image 3: An illustration of how differing shapes can create different surface areas with the same volume

The crural index was not developed until decades after Bergmann's and Allen's rules were established. C. B. Davenport invented the crural index in 1933 to study locomotion of primates (Davenport 1933). Davenport compared the tibia and femur to levers, which are pulled on by muscles to produce movement. The use of the leg in different ways throughout primates, such as running versus tree climbing, would necessitate a change in the proportion of these levers to create the most functional propulsion method (Davenport 1933). While the crural index was developed to research locomotion, its components are the two main skeletal elements in the leg. Therefore, these components should be affected by climate based on Bergmann's and Allen's rules, as the legs are the majority of the human form.

While the measurements of the leg should be affected by thermoregulation as Bergmann's and Allen's rules state, there is also evidence that the measurement of the leg is correlated with stature, which is correlated with sex (Krishan 2016). If this is true, then the crural index might be affected more from the sex of the individual than the climate of the population.

Many of the variations involving differences in measurements have been assumed to have been correlated to sex. Sexual dimorphism is not as obvious in human populations, but it is present. The shape of the pelvis and skull, and the stature of an individual have been shown to have correlations to the sex (Buikstra and Ubelaker 1994). If the size and shape of these skeletal elements affect the calculated measurements of the crural and nasal indices, then it is possible that the differences in these measurements are more correlated to sex than climate. If there is a correlation to sex, then climate may not be the defining factor behind the differences in these two indices which would complicate the rules set forth by Thomson, Allen, and Bergmann.

2.3 Climate

The climate of the earth follows certain trends based on the distance from the equator, with the greater distance forming a colder climate. Other aspects of climate including weather patterns and ocean currents affect the broad latitudinal climate patterns. Latitudinal climate patterns splits the earth into three separate climate zones based on the location to the equator (Reisa 2006). The Arctic Zone encompasses the area from the North Pole to 66.5°N and 66.5°S to the South Pole (Reisa 2006). The Tropic Zone is the closest to the equator and includes the points between 23.5°S and 23.5°N (Reisa 2006). The Temperate Zone is in-between the Tropic and Arctic and experiences the most diverse weather landscape of the three zones (Reisa 2006).

The three zone climate categories are based on an idea of three cells of earth's atmospheric circulation (Reisa 2006) which simplifies the atmospheric processes of the earth, but gives a good generalization of how the temperature of the earth should decrease the further away from the poles. While this three cell model is a good indicator of temperature, it is not an accurate model of humidity differences due to changes in ocean currents, sea levels, and precipitation in differing areas. These areas are classified through an aridity index.

As humidity is the measurement of the saturation of the air with water vapor, the aridity index measures this saturation, or lack of saturation. The formation of this classification of climate areas began in 1905 with a publication on the effectiveness of precipitation levels on forest growth (Thornthwaite 1948). This was modified to be an aridity index after it was discovered that the level of precipitation does not account for the amount of water in the air itself. Following the transition to an aridity index, modifications on the calculations used to determine the aridity of a region were made until 1958. In 1958, Mikhail Budyko published a new set of calculations to determine aridity which are explained in detail in Robert Cahalan's research, *The Works of M Budyko*. This calculation used the mean annual net radiation, the mean annual precipitation, and the latent heat for the vaporization of water (Cahalan 2004). This calculation accounts for the amount of evaporation that is occurring in each region, as well as precipitation. These two variables are multiplied together and the resulting number is used to divide the mean annual net radiation, which is the balance of energy in the atmosphere. The net radiation of the atmosphere keeps the atmospheric cycles in a continuous motion as it is the amount of energy that is received via the sun and the amount of energy that exits the system through reflection (Cahalan 2004). As water moves from a liquid to a gas state, it stores potential energy. This energy cannot be stored for long so as soon as it is released, the energy it releases causes the water vapor to change back into a liquid. Thus the net radiation affects the humidity of a region by forcing water to leave the atmosphere and return to the liquid state, no longer a part of the moisture in the air (Cahalan 2004).

Budyko's calculations for determining aridity of an area take into consideration all the factors surrounding the saturation of the air with water vapor. This calculation results in a number between 0 and 1, with five separate categories for aridity. These categories range from a hyper-arid climate with an aridity index of less than .05 to a humid climate with an aridity index of over .65. These different aridity categories shows how humid a region is, which also affects the temperature (Cahalan 2004).

While most of the earth's regions follow the trend of an increasing temperature the closer to the equator, humidity affects how this temperature is regulated by endothermic animals. Endothermic animals, such as humans, cool their body systems in areas of high temperature through evaporative cooling (Boyles 2011). This system uses the release of energy to lower the core temperatures of endothermic bodies. The water that is formed when sweat evaporates, releasing stored energy from the body, the loss of this energy cools the skin which in turn lowers the temperature of the core. However in areas of high humidity, the use of evaporative cooling to lower body temperatures is hindered, due to the constant saturation of the air (Boyles 2011). Therefore, the higher the humidity of a region, the hotter the temperature feels to an endothermic animal as the temperature regulation system is restricted. The false increase in temperature could invoke a physiological change to evolve a body form that can regulate heat.

The populations chosen for this study are diverse in their temperature and humidity in order to have a comparable statistical analysis. Image 4 shows the locations of the three populations that will be used in this study; the Netherlands, Nubia, and Suriname. Each location is on a different latitude and there is variability in the distance from the equator, which creates variation in the temperatures of these regions. Two of these samples have locations that are of a high temperature, while one sample has a more moderate average temperature. These locations also differ in their average humidity, with two of the populations coming from areas of high humidity. Due to the differences in temperature and

Image 4: A world map indicating in red the different locations of the populations used in this study

http://hashtag-bg.com/world-map-no-label/

humidity

between these populations, if there is a correlation between the size of the nasal index and the crural index and climate, then there should be a difference in the nasal indices and crural indices between these three populations.

The variation in the locations of the populations covers different temperature and humidity zones, which will allow for the study of nasal and crural indices in regards to their correlations to climate. To successfully test Thomson's Nose Rule, a wide range of populations from differing temperatures and humidities is needed. This range of climate differences is also needed to test Bergmann and Allen's Rule and its applicability to humans. In order to test these rules, the nasal and crural indices must be measured accurately for accurate statistical analysis. Measuring differences in the crural and nasal indices between these populations require certain methods to obtain accurate results.

3 Materials and Methods

This chapter will introduce the three separate collections of human skeletal remains that are used in this study and the methods that will be used to analyze each individual, as well as an overview of the statistical analysis that will be used to discern any climatic and physiological connections. Each population will have a brief historical background, a background of the climate, the location of the burial grounds, and an overview of the sample size. The methods used in this study will be discussed and there will be a general summary of human skeletal biological profile analysis, skeletal measurements, and the statistical analysis that will be used on these populations and climate components.

3.1 Study materials

This section will review the materials used in this thesis. These materials involve the different skeletal collections that data was collected from. The three separate populations used in this study, Suriname, Nubia, and Suriname will be discussed, along with a historical background of the collections and a discussion of the climate of the location will be examined.

3.1.1 Suriname collection

Suriname is the modern name for an area on the northeast coast of South America that was colonized by the Dutch. Prior to colonization, the area was a diverse landscape of several different distinct societies. The collection that is used in this study is a pre-Columbian population, and is therefore not influenced by colonialism or gene flow[2] from across the Atlantic. The most probable date for these individuals is the Arauquinoid period, which dates from AD 700 to AD 1530 and is characterized by its distinctive pottery (Giesso 2018, van Duijvenbode 2017). The collection was excavated by Dutch archaeologist, D. C. Geijskes in the 1960’s and extends through multiple sites and burial grounds. Only individuals from the Tingiholo site and the Okrodam site were used in this analysis and for the sake of this thesis were combined into a single population called Suriname.

[2] Gene flow is the introduction of genes outside of the original gene pool through interbreeding between individuals outside the original gene pool

3.1.1.1 Tingiholo

The Tingiholo site is located on the central coast of Suriname and was excavated by Geijskes from November 1961 to January 1962 (van Duijvenbode 2017). Initial analysis by Geijskes estimated that there were 18 individuals excavated. Further analysis of the human remains in the following decades, by J. Tacoma, also a Dutch archaeologist, revealed that the collection was comprised of 25 individuals. The reexamination and subsequent change in the amount of individuals suggests that the initial excavation was not as methodical as modern excavations. Added to the possible mismanagement of the skeletal remains was an attempt to piece together the broken skeletal elements and fix the pieces together with glue, epoxy, and plastic. The attempted reconstruction of the skulls was hindered by possible cranial modification as well as warping of the skeleton due to taphonomic pressures. This caused several of the skulls to be omitted from measurements as the measurements would have been inaccurate, and therefore would create an inaccurate nasal index. The axial skeleton suffered from the same attempted reconstruction as the skulls, but due to the strength of the femur and tibia, several of these elements were still intact. The reconstructed femurs and tibias were only analyzed if the reconstruction appeared to place the shattered remnants flush together. Due to the above mentioned preservational issues, only one individual from the Tingoholo site, shown in image 5, could be analyzed for a nasal index, but seven of the individuals could be measured for crural indices.

3.1.1.2 Okrodam

The Okrodam site, as seen in image 5, consisted of only 4 individuals and was excavated in 1959 by Geijskes (van Duijvenbode 2017). This site faced similar taphonomic problems as the Tingiholo site, but less reconstructive attempts. Unfortunately, the extent of the

Image 5: A map of the coast of Suriname with the locations of the sites used in this study Edens, E. 2015

taphonomic pressures on the four individuals present did not allow for much analysis. Only one of the skulls from this site contained a complete nasal index and only one individual contained the tibia and femur necessary to measure a crural index.

As both of these sites are from a similar location with the same climate, for the sake of this study both of these sites will be treated as a single population. The measurements that were taken to calculate the nasal and crural indices were taken from the most well preserved and accurate skeletal remains from this population. Due to this, most of the measurements were taken from individuals without an estimated sex. Only two crural indices were calculated from measurements taken from individuals whose sex could not be accurately estimated as the only surviving skeletal elements were the femur, tibia, and fibula. The issues regarding using these two measurements in this study will be covered in detail in the discussion section of this study.

As Suriname is located at the latitude of 3.° N, it falls under the category of a tropical climate. It follows the trend of the tropical climate with high precipitation and high temperatures. Each year there is an average of 2,200 mm of rainfall, falling under the category of humid on the aridity index. Between the high amount of rainfall and the high temperatures of the nearby ocean, the annual humidity averages around 75%.The mean temperature per year is 27.4°C. The temperature does not shift during the year, with a range of 3°C temperature changes.

3.1.2 Nubia collection

Located in modern day south Egypt and Sudan, Nubia was situated directly below the powerful Egyptian empire (Buzon 2007). Throughout their neighboring times, Nubia and Egypt were involved in almost continuous power struggles that resulted in Nubian colonization of Egypt and Egyptian colonization of Nubia at various times in their history. The specimens that are used in this project were excavated from the Abu Fatima site. Abu Fatima is located at the Third Cataract of the Nile River, around 10 km from Kerma, the capital city of Nubia (Schrader 2017) as can be seen in image 6. The cemetery at Abu Fatima is

Image 6: A map indicating the location of Abu Fatima in relation to modern day Egypt and Sudan Schrader, S, 2017

associated with the Kerma culture of ancient Nubia and was utilized during the Ancient Kerma (2500–2050 BCE), Middle Kerma (2050–1750 BCE), and Classic Kerma (1750–1500 BCE) periods (Schrader 2017). The Kerma culture rose from indigenous nomadic peoples (Thomson 2008), and is the earliest state power in Upper Nubia (Judd 2005). While this culture clashed heavily with the Egyptian kingdom above it, there was also a large amount of trade occurring between the two cultures, as well as migration of people. The migration of people from Egypt into Nubia is evident in the burial practices, as Nubian burial practice involved the body lying in a flexed position facing north, while Egyptians were buried lying flat with their arms folded across their chests. The migration of Egyptians into Abu Fatima most likely was caused by the colonization of Nubia by Egypt during this time.

The oldest burials in this site date from around 2,500 BCE (Schrader 2017). During this time Nubia was settled into the hyper-arid climate that it has today. Following 3,500 BCE, there was no continuous rainfall in Nubia as is evident by the desiccation of predynastic individuals who were buried with no mummifying agent (Murray 1951). Since these bodies were buried in sand, a permeable substance, any moisture that fell would have seeped through to the body below, halting desiccation. As this did not occur, it may be assumed that there was very little to no rainfall following 3,500 BCE (Murray 1951). This lack of rainfall can be traced back to the mid-Holocene when the aridification of the Sahara began (Pennington 2019). Prior to the aridification of the Sahara, this region followed a more tropical climate with a monsoon season that was strengthened by the presence of the Tethys Sea (Zhang 2014). The shrinkage and eventual disappearance of this sea disrupted the monsoon season and allowed for the spread of a desert climate through the Sahara. This aridification climaxed around 3,000 BCE (Pennington 2019), which is well before the start of the cemetery in Abu Fatima.

While there was definite gene flow between Nubian and Egyptian populations due to the constant colonization strategies from both sides, the environment that both cultures lived in is extremely similar in terms of aridity, landscape, and access to the Nile River, so the gene intermixing will not compromise this study. The climate in Nubia, modern day Sudan, has been stable for around 6,000 years, with little fluctuation in temperature or humidity due to the aridity of the area and the lack of rainfall. The aridity of the area not only protects the validity of environmental analysis on this population, but also caused natural mummification via desiccation throughout the cemetery. This mummification occurred at varying rates between individuals. In some individuals this mummification caused skeletal elements necessary to this study to stay encased in the overlying tissue. As removal of this tissue would harm the integrity of the collection, but measuring these elements would result in inaccurate data, these elements were excluded from measurements. Since the mummification of these elements was natural, as opposed to artificially mummified cadavers purposefully created by humans, the preservation of skin and muscle tissue was sporadic allowing for most of the necessary measurements to be collected.

The collection used contained 23 individuals of various usability. Unfortunately, this cemetery not only had mummification that hindered measurements, but it was also plagued by grave robbers and damage from mining, so many of the skulls were missing (Schrader 2017). Despite the mummification and grave robbing, the skeletal remains from this collection were of excellent condition. Of these individuals, only five nasal indices were able to be calculated due to the frequency of missing skulls. The higher availability of the femur and tibia provided ten crural indices to be calculated from this collection. However, only one individual contained the necessary skeletal elements to calculate both the nasal index and the crural index on the same skeleton.

Nubia is located at 12°N, which also places it in the latitudinal category of tropical. However, due to the aridification of the Sahara region, the Sahara no longer follows the latitudinal trend of a tropical climate. The area the individuals were excavated from falls under a desert climate with less than .05 mm of rainfall per year. The aridity index for this area classifies it as a hyper-arid region. Due to the aridity of the area and the lack of rainfall, the average humidity per year is 11.5%. The average temperature is 20.9°C, with a summer high of 33.8°C and a winter low of 17.9°C.

3.1.3 Middenbeemster collection

The third collection that was used in this study is from a site in Middenbeemster in the Netherlands. It was excavated in 2011 under the supervision of Professor Menno Hoogland (van Spelde and Hoogland 2018). During the excavations, 450 individuals of varying sex and age were excavated (Griffioen 2011). The village of Middenbeemster is located on the middle of the Beemster polder which was formed out of the Beemster Lake, which is shown in image 7 (van Spelde and Hoogland 2018). The lake was drained during 1609 to 1612 and then divided into pastoral land for cattle (De Jong 1998). Due to the manmade quality of Middenbeemster, the land is completely flat, broken only by a few canals filled with water. Despite the majority of Middenbeemster consisting of made of pasture land, manorial estates were also a part of the settlement. These estates housed wealthy merchants and governors who were profiting from the the Dutch Golden Age and the later Industrial Revolution. The mixture of socioeconomic status in Middenbeemster is also reflected in the cemetery, but this should not influence the results of this study as there is no recorded correlation between socioeconomic status and nasal and crural indices.

The cemetery site is located at a Protestant church called Keyserkerk which was built in 1623 (van Spelde and Hoogland 2018). This cemetery was used during the time period of 1617 to 1866 A.D, but due to reuse of the cemetery overtime most of the remains are from the 1800's (Griffioen 2011). These burials date to 1829, the year the older burials were exhumed, to 1867, the year a new cemetery outside Middenbeemster began to be used (van Spelde and Hoogland 2018). The burial ritual of the area followed the Christian burial strategy of the bodies placed in a supine position. The arms had three methods of placement; folded on the chest, crossed on the pelvis, or placed alongside their body (van Spelde and Hoogland 2018). The graves were positioned northwest to southwest with the bodies matching this orientation. The bodies were also interred in wooden coffins, which protected the remains from weathering and allowed for a clear outline of the individual during excavation. As this site was excavated with a mixture of Dutch archaeologists and volunteers, the clearly delineated graves meant less skeletal elements were lost to excavation practices done by the volunteers.

Image 7: A map indicating the location of Beemser in relation to modern day Holland Vikatou. I, 2017

The preservation of these specimens was excellent, which allowed for most of the necessary measurements to be recorded for a majority of the skeletal remains analyzed. Most of the necessary skeletal elements for both nasal and crural indices were present on each individual that was measured, and the skeletal elements were very rarely damaged. A total of 50 individuals from this site was used in the study; 25 of which were female and 25 of which were male. The individuals were chosen by random for data collection, but no subadults were included in the sampling. Due to the preservation status, this collection has a greater amount of data than the other two collections in this study.

The climate of this area falls under the Temperate Zone which has a latitudinal point of 52°N. As the temperate zone encompasses many different regions, the average temperature and humidity must be calculated to have an accurate representation of the climate of Middenbeemster. The current average temperature of Middenbeemster is an annual 10°C (Schier 2010). It has relatively moderate winters with a summer low of around 2°C and a summer high of 17°C (Schier 2010). However during the era this cemetery was used Europe was experiencing what is known as the "Little Ice Age." This age of colder temperatures began in 1,450 C.E. and lasted until 1,850 CE (Degroot 2018) causing a drop in annual mean temperature of 1.7°C (Labrijn 1945). Thus the corrected annual mean of Middenbeemster for the years of 1633 CE to 1866 CE is 8.3°C. The humidity of this area has not fluctuated considerably since the first use of the Keyserkerk cemetery. The aridity index of this area is calculated at greater than .65, which places it in the humid category. Due to the average annual rainfall of 700 millimeters, the high moisture content in the air is unsurprising. The annual mean humidity for the Middenbeemster area is 83%.

3.2 Methods

This section will discuss the methods used in analyzing the skeletal remains. For each individual a biological profile was created for use in the statistical analysis and to determine inclusion in this study. The measurements taken on each individual followed a precise method to reduce human error and to produce the most accurate data possible for these collections.

3.2.1 Biological profile

The biological profile of each individual is the sex and age estimation. As the individual is deceased, these aspects must be estimated through the skeletal remains using specific methodology that has been tested for accuracy. The age estimation of each individual will divide the populations into either adults or subadults, individuals whose skeletal elements have not yet completed fusing. This will help with the exclusion criteria of study. The estimation of sex will be important to this study as it is necessary to test for correlations between the measurements of the indices and sexual dimorphism. If there is a significant correlation between either indices and the sex of the individual, then each population must be split into males and females to get accurate statistical results on climate correlations. However, it is important to note that the skeletal remains can only give an estimate of the biological sex. Gender cannot be estimated from remains as gender is culturally defined.

3.2.1.1 Sex Estimation

For each individual that was included in this study their sex was estimated via the morphology of the pelvis when it was available (Buikstra and Ubelaker 1994). When the pelvis was not available, the morphology of the skull was used as a sex indicator (Buikstra and Ubelaker 1994). Individuals that contained neither of these elements did not receive a sex estimate. The os coxae, commonly known as the pelvic bones, are the most reliable method of sexing a human skeleton, as during adolescence the hormonal and growth changes in the body leads to sexual dimorphism in the pelvis (Buikstra and Ubelaker 1994). The areas of the most sexual dimorphism are the greater sciatic notch, the shape of the ventral arc, and the subpubic concavity (Buikstra and Ubelaker 1994). The greater sciatic notch is broader in females, resembling more of a right angle, while the males tend to be narrower, resembling an acute angle (Buikstra and Ubelaker 1994). If the greater sciatic notch is in-between a broad female angle and a narrow male angle, it is noted as an indeterminable sex (Buikstra and Ubelaker 1994). Image 8 shows the variability of the greater sciatic notch with the female labeled as a 1, the indeterminate as a 3, and the male as a 5. If the angle is between a definite sex and indeterminant, it is written as probable. In Image 8, a 2 is a probable female while a 4 is a probable male.

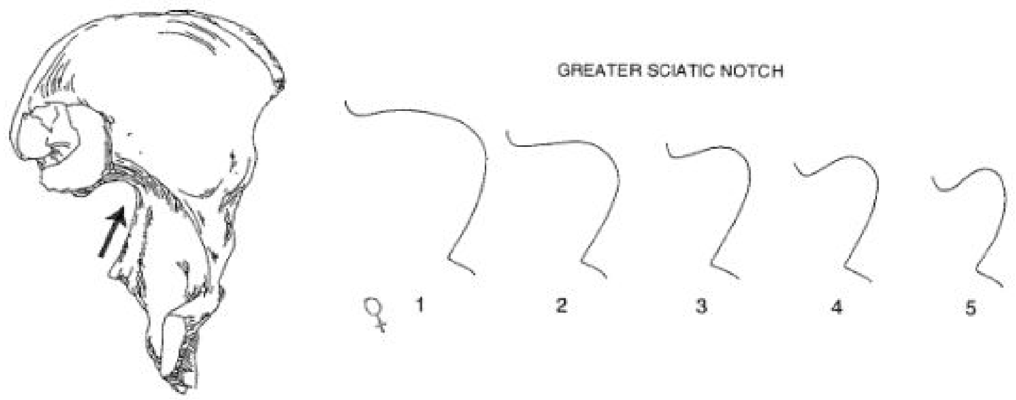


Image 8: An illustration showing the location of the sciatic notch and how it is scored
Buikstra, J. E, 1994

The ventral arc shape and subpubic concavity are noted as either present or absent (Buikstra and Ubelaker 1994). The ventral arc is located on the ventral side of the pubis bone (Buikstra and Ubelaker 1994). A typical male ventral arc will have a more gradual curve, while a typical female ventral arc has more of a right angle (Buikstra and Ubelaker 1994). This is illustrated in image 9. The subpubic concavity can be viewed from the dorsal side of the pubis bone (Buikstra and Ubelaker 1994). A female subpubic concavity will be concave, while the male subpubic concavity will be convex with a more robust inferior pubic ramus (Buikstra and Ubelaker 1994).

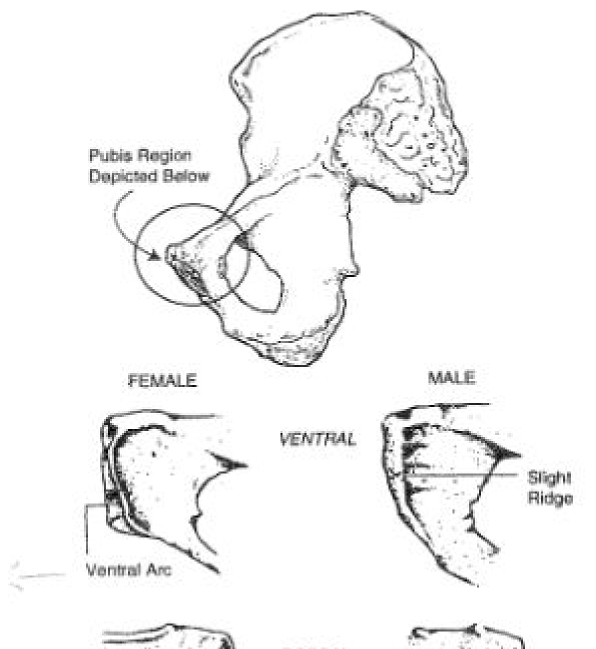


Image 9: An illustration showing the location of the ventral arc and subpubic concavity on the os coxis

These three sexually dimorphic features are all considered while estimating a sex for each individual (Buikstra and Ubelaker 1994). If most of the features are female, then the sex estimation is female. If the features are a mix of female and indeterminate, then the sex estimation will be a probable female. If the features are an equal mix of male and female determinations, then a sex of indeterminate is assigned for the individual (Buikstra and Ubelaker 1994).

The skull is the next most accurate skeletal element for estimating the sex of an individual. The skeletal features of the nuchal crest, mastoid process, supraorbital ridge, and mental eminence are calculated on a score of 1 to 5 with 1 being an estimate of female and 5 being an estimate of male, much like the greater sciatic notch is scored in the pelvis (Buikstra and

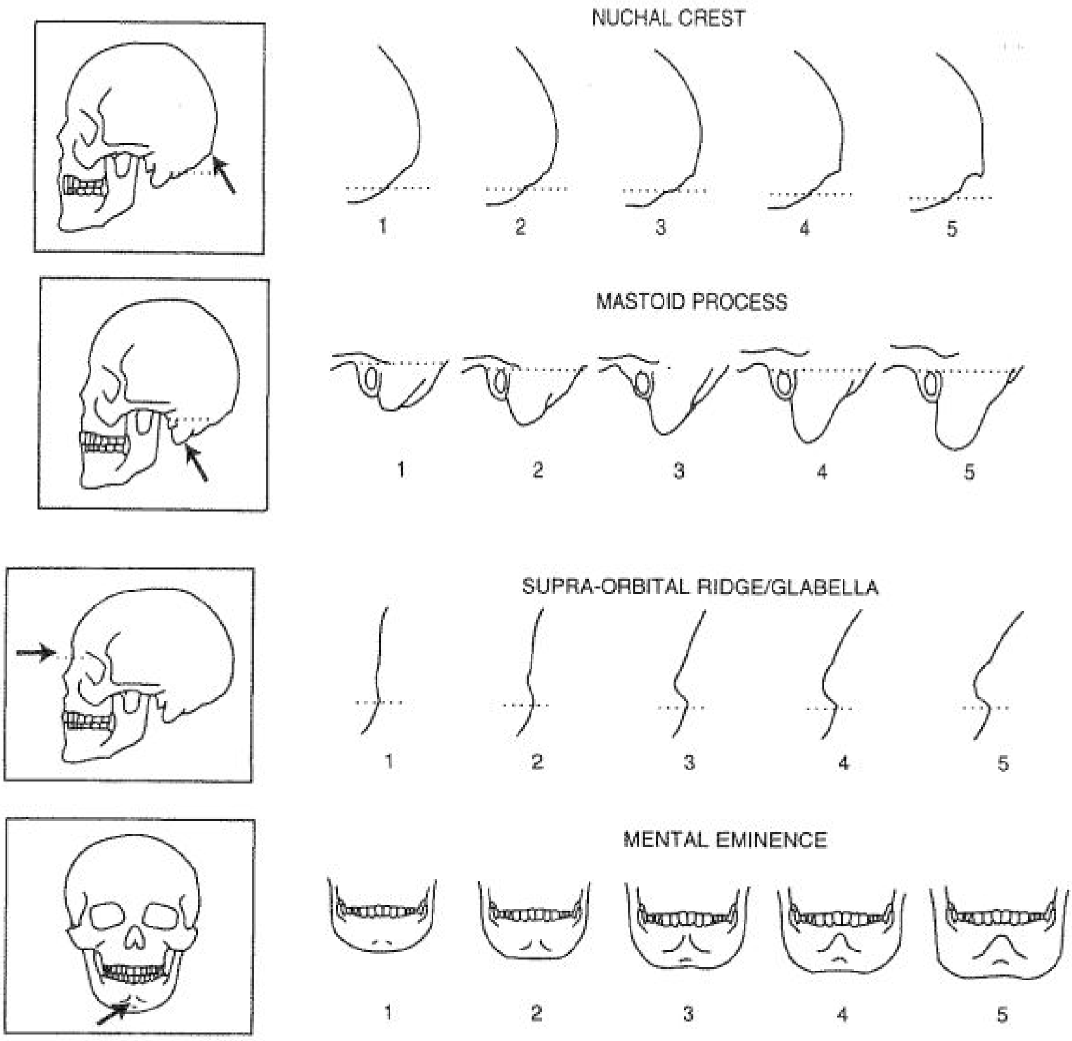


Image 10: This illustration shows the key skeletal elements that are used in sex estimation on a skull

Buikstra, J. E, 1994

Ubelaker 1994). The nuchal crest is located on the occipital bone of the skull. The skull should be viewed in a lateral profile to view the robustness of the nuchal crest. A more robust nuchal crest is more indicative of a male scoring (Buikstra and Ubelaker 1994). The mastoid process is located on the posterior portion of the temporal bone and should be observed for size (Buikstra and Ubelaker 1994). A broader and longer mastoid process is more indicative of a male (Buikstra and Ubelaker 1994). The supraorbital ridge is located superior to the eye orbits. A more robust projection of the supraorbital ridge when the skull is viewed in lateral profile is indicative of a male scoring (Buikstra and Ubelaker 1994). The mental eminence is located on anterior portion of the mandible. The eminence should be viewed anteriorly and is in the shape of a rough triangle. A more robust and protruding mental eminence is scored as a male (Buikstra and Ubelaker 1994). Image 10 indicates the amount of robustness necessary for each feature to be scored as a male or female. A score of a 3 is an indeterminate sex. A score of a 2 or a 4 is a probable sex of female or male, respectively. These scores are viewed together, and the sex with the most scores is the overall sex estimate for the individual (Buikstra and Ubelaker 1994).

For the overall scores in this study, the females were scored as a 5 and the males as a 1. This scoring was used as the statistical program used to analyze the data needed a numerical score in order to perform the proper statistical tests. A 3 was used for any individual who was scored as indeterminate or could not be scored due to the absence of skeletal features that are necessary to provide an accurate sex estimation.

3.2.1.2 Age Estimation

As subadult remains have unfused skeletal elements, correct measurements for the crural and nasal indices are impossible to obtain. Due to this, subadults were excluded from the analysis. The epiphyses of the postcranial remains in subadults have not yet fused to the diaphysis, an example of which is shown in Image 11 (Buikstra and Ubelaker 1994). Each of the ossification centers has a specific age category in which the epiphyseal fusions occur. The clavicle and scrum are the last to fuse with the age range extending to 32 for the sacrum of males (Buikstra and Ubelaker 1994). As the sacrum is unnecessary for either index measurements, individuals with these elements unfused will be included in the study. The epiphysis that fuses the latest in terms of the

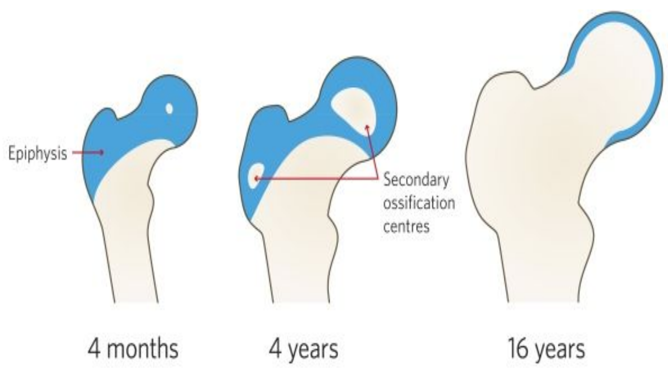


Image 11: The fusion points on a femur
https://www.rch.org.au/fracture-education/anatomy/Anatomic_differences_child_vs_adult/

measurements needed for the index calculations is the head and lesser trochanter for males, which can continue fusing until the age of 22 (Buikstra and Ubelaker 1994). This is illustrated in Image 11. As the length of the femur is necessary to calculate the crural index, any individuals who do not have this ossification center fused will not be used in the study as it will provide an incorrect measurement of the femur length. Thus the age range of individuals in this study will start at the age of approximately 22 years old for males. The epiphyseal fusion in female femurs is usually completed by age 20, and therefore the age of females in this study will begin at age 20 (Buikstra and Ubelaker 1994).

3.2.2 Index measurements

3.2.2.1 Crural index

The crural index is a measurement of the relationship between the tibial length and the femoral length expressed in a single number (Davenport 1933). The index is calculated by dividing the length of the tibia by the length of the femur and then multiplying this number by 100. Higher crural indices mean a longer tibia in relation to the femur. Crural indices are markers for the type of locomotion that is needed by the species, but has also been shown to be affected by climate. Higher crural indices have a correlation to tropical and warm weather climates, while lower crural indices are related to cold weather. The femoral and tibial lengths were measured using an osteometric board in the technique that is espoused by Moore-Jansen et al. 1994. The osteometric board that was used measures from 0 mm to 600 mm and was built for the Leiden laboratories at Paleo-Tech Concepts in Crystal Lake,

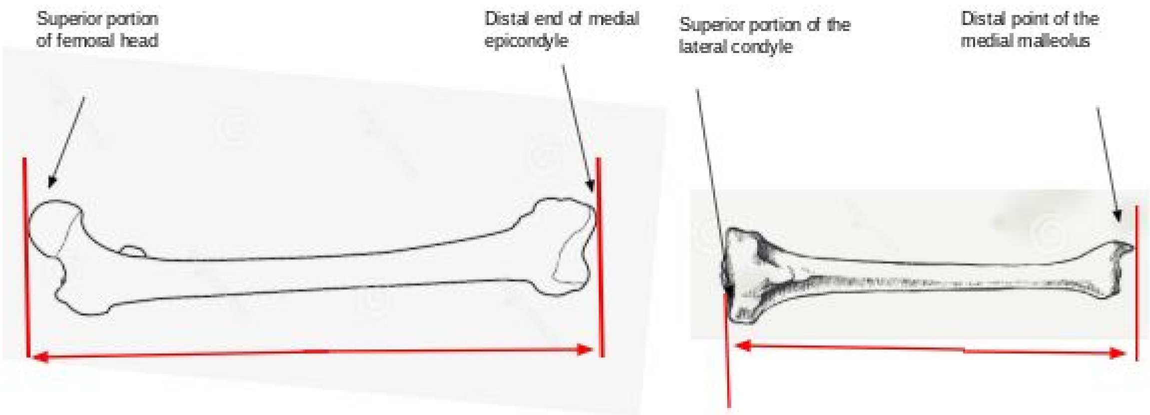


Image 12: An illustration of the measurements taken on the femur and tibia using osteometric board. after Moore-Jansen, P. H, 1994

Illinois. The same osteometric board was used for each measurement to eliminant calibration issues. To measure the femur, the most superior portion of the head of the femur was placed against the backboard of the osteometric board and the sliding board was pushed flush to the distal most part of the medial epicondyle. This is shown in Image 12. The red arrow indicates the measurement taken. When measuring the tibia, the superior portion of the lateral condyle, the highest point on the outside rounded protuberance, was placed against the backboard and the sliding board was pushed flush against the most distal point of the medial malleolus, the lowest point of the tibia. This measurement can be seen in Image 12. The blue arrow shows the measurement taken on the osteometric board. The measurements of the femur and tibia were taken from the right side of the individual unless the right element was missing, where the measurement was taken from the left element. Measurements taken from left elements or from reconstructed elements were noted but due to the small sample size from two of the collections, it was necessary to still use these measurements in the analysis.

3.2.2.2 Nasal index

The nasal index is a measurement of the relationship between the nasal height and the nasal width. It is calculated by measuring the height of the nasal opening and dividing that by the measurement of the width. This number is then multiplied by 100. The measurement of the height of the nasal opening is taken from the nasion, the highest point of the nasal aperture where the two nasal bones meet, to the akanthion, or the point on the nasal aperture's lower border that is directly below the nasion (Thomson 1923). The width is calculated by determining the largest width of the nasal aperture (Koirala 2014). Image 13 showcases both of these measurements. The nasal height is illustrated in red and the nasal width is illustrated in green. Both of these measurements are taken using a standard sliding caliper which results in a measurement in millimeters. The calipers used in this study were digital calipers from HBM Machines that measure from 0 mm to 150mm. The same pair of calipers was used for each measurement to prevent differences in calculation due to calibration differences. The measurements are then categorized via

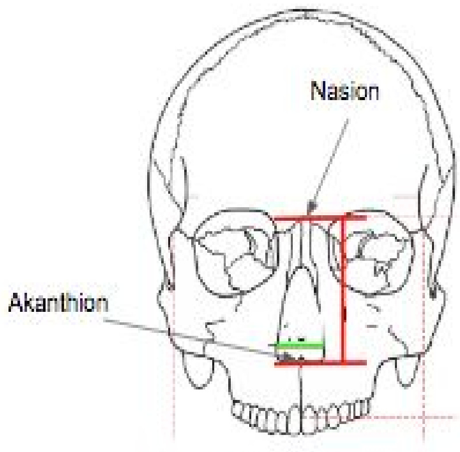


Image 13: This illustration shows measurements taken by the sliding calipers in green and red
after Moore-Jansen, P. H. 1994

three options. Leptorrhine noses have a nasal index of 69.9mm or less, meaning they are a more narrow nose. Mesorrhine follows this with a range of measurements from 70.0-84.9mm. The final possible category is platyrrhine which is a wider nose and falls under the measurements of 85mm or higher (Koirala 2014).

3.2.3 Statistical analysis

The statistical analysis for this study will be done using the software Statistical Package for the Social Sciences, abbreviated as SPSS and the software R. SPSS was first launched in 1968 and then sold to the computer company IBM in 2009. This program will be used to calculate correlations, normality, and to compare the different sets of data. R is a statistics system for calculations, graphing, and data manipulation. This program will be used to create the graphs to illustrate the results of the calculations done using SPSS. The calculations for each crural and nasal index will be made using Excel and then uploaded to both R and SPSS. Each statistical test that requires a graph will be run in both SPSS and R to ensure they are run correctly. The calculations that do not need graphing, such as the Shapiro-Wilk test of normality will be calculated twice on SPSS only.

Paired t-tests can only be used if data sets follow a normal curve, thus each data set will be tested for normality using a histogram. If the histogram does not follow a distinct bell curve, then a Shapiro-Wilk test or a Kolmogorov Smirnov test will be used to determine normality. A Shapiro Wilk test will be used in most data sets, as most of the tests run will rely on sample sizes of less than 50. However, the combined sample size of every group and sex is greater than 50, so a Kolmogorov Smirnov test will be used in determining the normality of this data set. The Shapiro-Wilk test relies on a null hypothesis of the data following a normal curve. If the p-value of this test is greater than 0.05, then the null hypothesis is significant and the data set can be treated as a normal curve. If the p-value is less than 0.05, then the null hypothesis is rejected and the data set cannot be considered a normal curve.

If the data is normally distributed, an analysis of variance test (ANOVA) will be used to determine the relationship between the environmental factors and the index measurements. The subsequent ad-hoc test that is used to determine the relationship between each component will be the Bonferroni ad-hoc test as it can be used in parametric data sets. If the data set does not follow a normal distribution, an ANOVA will still be used, but the ad-hoc test will differ. The Tukey HSD ad-hoc test will be used as it can be used on nonparametric data sets.

The next chapter will show the results of the SPSS analysis on the information gathered from each population. The nasal index and crural index will be analyzed separately as they are unrelated. Each of these indices will also be tested for a correlation to sex. If these measurements are correlated to sex it will be necessary to split each population into males and females and disregard the indeterminate sex estimates to not have the differences in sex skew the data regarding climatic correlations. The following chapter will take the information regarding humidity and temperature from each location and establish if the indices calculated from the skeletal measurements are related to these climatic factors.

4 Results

To begin the statistical analysis of the data sets, each collection was determined to follow a normal distribution using frequencies and a histogram. To further prove normality, tests of normality were run on each sample. A Shapiro-Wilks test was run on the data sets with less than 50 data points. For this test, the null hypothesis, or the hypothesis that states the data points are normally distributed, is rejected if the p-value is less than .05. If the data set has more than 50 points of data, then a Kolmogorov-Smirnov test of normality will be used to determine normality. The null hypothesis for this test is the same as the Shapiro-Wilks test; the data points are normally distributed. If the p-value is less than .05, then this hypothesis is rejected and the data points do not follow a normal curve of data. Determining normality or the lack of normality indicates the proper correlation test that can be run on each data set. Following this, paired sample correlations were run on sex and the nasal index and also on sex and the crural index to determine if there was a correlation. If there were correlations between sex and the indices studied, then correlation tests run to determine the effects of climate would have to have each data set split into males and females for accurate conclusions. Correlations for the components of the nasal index and crural index, the nasal breadth and height and the femur and tibia length respectively, were also determined. Using a paired sample correlations test, both the nasal index and crural index were not significantly correlated to sex, so the data sets did not have to be split into males and females. The nasal breadth and height were also not correlated to sex. The femur and tibia lengths were found to be correlated to sex, but this did not affect the correlation to the crural index as the crural index represents a ratio.

4.1 Middenbeemster

Middenbeemster had the highest amount of data due to the collection size and preservation state, which can be seen in table 1. Of the population of males, only five nasal indexes were missing; all due to the inability to measure both nasal breadth and height. Of the male crural indices, five individuals had incomplete data; two missing both femur and tibia lengths, two missing the tibia lengths, and one missing the femur length. The females were missing no nasal indices measurements. Two crural indices could not be calculated for the females; one due to a missing femur measurement and one due to a missing tibia measurement. Thus there were 23 female crural indices and 20 male crural indices that were used in the statistical analysis.

Table 1: The data set for the Middenbeemster sample

Individual Number	Sex	Nasal Height	Nasal Breadth	Nasal Index	Femur Length	Tibia Length	Crural Index
S151 V666	F	33.94	20.3	59.81	456	390	85.53
S160 V613	F	29.8	22.98	77.11	407	337	82.80
S174 V408	F	34.97	24.72	70.69	427	356	83.37
S155 V1509	F	30.16	22.14	73.41	421	360	85.51
S155 V196	F	31.62	21.02	66.48	441	370	83.90
S183 V311	F	26.32	20.57	78.15	439	360	82.00
S338 V721	F	30.74	20.32	66.10	400	332	83.00
S374 V861	F	34.18	25.2	73.73	423	360	85.11
S243 V381	F	34.59	23.35	67.51	416		0.00
S309 V616	F	29.34	21.72	74.03	432	370	85.65
S101 V131	F	28.6	20.63	72.13	370	315	85.14
S383 V880	F	31.66	23.64	74.67	430	352	81.86
S382 V818	F	29.12	23.51	80.73		379	
S380 V821	F	30.52	21.2	69.46	444	370	83.33
S370 V806	F	26.43	21.05	79.64	457	362	79.21
S372 V808	F	28.32	19.63	69.31	395	323	81.77
S242 V338	F	32.98	19.68	59.67	438	363	82.88
S251 V624	F	34.12	25.76	75.50	444	380	85.59
S369 V886	F	27.74	20.6	74.26	410	338	82.44
S226 V282	F	35.83	23.6	65.87	469	418	89.13
S236 V335	F	32.26	23.18	71.85	454	377	83.04
S289 V477	F	31.97	22.7	71.00	455	393	86.37
S257 V1006	F	33.37	19.86	59.51	465	375	80.65
S254 V357	F	32.24	23.01	71.37	405	344	84.94
S088 V094	F				428	345	80.61

S313 V926	M	32.63	21.89	67.09	451	378	83.81
S337 V714	M	33.78	22.2	65.72	493	416	84.38
S347 V741	M	33.27	24.64	74.06	483	432	89.44
S247 V379	M	33.11	25.55	77.17			
S310 V550	M	32.34	22.74	70.32	486	388	79.84
S261 V422	M	30.28	22.95	75.79	427	383	89.70
S363 V766	M	33.18	23.11	69.65	464	387	83.41
S402 V907	M	32.72	22.83	69.77	435	364	83.68
S404 V 113	M	32.51	24.41	75.08	461	377	81.78
S489 V1044/1056	M	32.01	21.88	68.35	454		
S108 V192	M	40.48	25.55	63.12		394	
S144 V222	M	37.96	24.42	64.33	462	380	82.25
S297 V498	M	34.4	23.69	68.87	464	395	85.13
S155 V196	M	31.46	22.23	70.66	441		
S158 V427	M	31.95	21.69	67.89	421	355	84.32
S162 V316	M	-	-		441	356	80.73
S180 V432	M	-	-		479	397	82.88
S186 V411	M	32.1	21.57	67.20	501	396	79.04
S194 V440	M				469	420	89.55
S093 V126	M	32.46	23.88	73.57	445	357	80.22
S070 V067	M	30.55	20.99	68.71	453	391	86.31
S237 V348	M				458	381	83.19
S249 V394	M	31.97	19.68	61.56	460	378	82.17
S250 V402	M	-	-		449	357	79.51
S253 V466	M	37.15	26.29	70.77			

The determination of a normal curve based on frequencies was done with both male and female nasal indices. The minimum recorded nasal index is 59.51mm and the maximum is

80.73mm. The data set follows a normal distribution, except for the three measurements of less than 60mm, which is more frequent than a bell curve would suggest as the following measurements are at a lower frequency. However, most of the data points follows the bell curve. Using a Shapiro-Wilk test for normality, the significance, or p-value, is .696 so this data set can be treated as a normal distribution.

The crural indices were also determined to follow a normal curve. The minimum crural index size is 79.04mm, with the maximum being 89.70mm. The average crural index size is 83.6mm. The histogram created out of this data follows a bell curve closely, but the upper bounds of the index size occurs too frequently to be considered a bell curve. Thus a Shapiro-Wilk test of normality was run to determine if the data set could be treated as a normal curve. The p-value of this test resulted in .076, so the null hypothesis was confirmed, and the data set is a normal curve.

The components of each index measurement, as well as the index itself, was run through a paired T-test to determine if there is a correlation between sex and the calculated measurement. The femur length has a less than .01 significance value with a -.544 correlation. As the males are coded as a 1 and the females are coded as a 5, the negative correlation with the high significance value indicates that the femur length is correlated with sex. The maximum tibial length had a negative correlation with a significance value of .001. The correlation was -.475. While the components of the crural index were correlated to the sex of the individual, the crural index itself was not. The crural index had a correlation of .014 with a significance of .927, so the results of the correlation were not significant.

The nasal index and its component were also tested for sex correlation. The nasal height had a p-value of .014, so there is a correlation between nasal height and sex. The correlation value is -.368, so there is a weak correlation of a higher measurement with male individuals of this population. The nasal breadth was shown through a significance value of .401 to not be correlated to sex in this population. The nasal index had a p-value of .367, and was therefore also not correlated to sex.

4.2 Nubia

Due to the size of the collection and the mummification status, many of the necessary measurements were missing. The same sample size forced the combination of males and probable males in each statistical analysis to have a large enough sample for SPSS to calculate the necessary data. The same was done for female and probable female individuals. Of the 23 individuals present (table 2), only 5 had the necessary measurements to create a nasal index. Three of these indices were from male or probable male individuals and two were from female or probable female individuals. The missing indices were all due to both the nasal height and breadth being unavailable for measurements. The crural indices had a higher rate of available metrics with ten valid measurements of crural indices. Of the crural indices, two values were from female or probable female individuals, one from an indeterminate individual, and seven from male or probable male individuals. The male crural indices that were unable to be calculated were due to five missing tibia measurements and one missing femur measurement. The indetermininet crural indices that were unable to be calculated were due to five missing tibia measurements and four femur measurements. The female measurements had two missing tibia measurements and three missing femurs. Of these missing measurements listed, two female crural indices had both femur and tibia missing, four indeterminate had both missing, and one male had both missing.

Table 2: The data set for the Nubian sample

Individual Number	Sex	Nasal Height	Nasal Breadth	Nasal Index	Femur Length	Tibia Length	Crural Index
U1 PF B2	M	-	-		430	370	86.05
U2 PC B1	M	22.18	25.1	113.17	480		
U2 PA B2	M				482	425	88.17
U8 PA L5 B1					453		
U8 PA L3 B1	PM	22.07	25.07	113.59	434		
U1 PE B1	F	24.11	25.48	105.68			
U8 PB B1	F					385	
U1 PF B1	PM				500	415	83.00
U1 PA L2 B1					439	379	86.33
U2 PF B1	PM				413		
U4 PD B1	F						
U7 PE B1	PM	27.79	28.14	101.26	479		
U4 PE B1	M				463	408	88.12
U2 PA B1	M						

U7 PA B1							
U2 PB B1	M				533	440	82.55
U1 PB B1 L6	PF	25.11	26.1	103.94	438	382	87.21
U2 PC B1							
U6 PA B1							
U4 PA B1	M				475	408	85.89
U4 PC B1	F				422	376	89.10
U4 PB B1							
9A1	M				477	407	85.32

As with the Middenbeemster population, tests of normality were run on the Nubian data to ensure the population could use a statistical analysis that assumes a normal curve. The nasal indices of this population had a minimum of 101.26mm and a maximum of 113.59mm. The histogram created from the frequencies shows the data does not follow a normal curve precisely, due to the larger frequency of data falling above 113mm. A Shapiro-Wilk test was run to determine if the data could still be considered a normal curve. The resulting significance for nasal indices was .289, so the null hypothesis was not rejected and thus the data set falls under a normal distribution.

Paired T-tests were run on the components of the crural index and the index itself with the Nubian population. There was a weak significance for the correlation of the femur length with sex in this population. The significance level was .140 with a correlation of -.432. The maximum tibial length however is approaching significance with a calculated significance level of .052. The crural index was calculated to not be correlated with sex as the significance level is .173. These correlations could be affected by the small sample size of this population.

The nasal index and its components were also tested for sex correlation. The correlation of the nasal breadth to sex could not be calculated due to the small sample size, however based on literature and the results of the Middenbeemster correlations for nasal breadth, it can be assumed there was no correlation. The nasal height had a p-value of .824, and was therefore not correlated to sex. The nasal index also had a p-value well over significance at .453, and so was not correlated to sex.

4.3 Suriname

As with the Nubian population, Suriname had a small population with many elements missing (table 3). This necessitated the combination of males and probable males into the same category and the combination of females and probable females as well. Of the 25 individuals in this population, only two individuals contained the necessary skeletal elements to calculate the nasal index; one female and one male. Eight individuals had calculable crural indices. Three of these individuals were in the female category and three were in the male category. The remaining two individuals were unable to be determined as male or female due to the poor preservation of their skeletal remains. Due to poor preservation, the nasal indices only had a sample size of two; one male and one female.

Table 3: The data set for the Suriname sample

Individual Number	Sex	Nasal Height	Nasal Breadth	Nasal Index	Femur Length	Tibia Length	Crural Index
TH17	?	25.49			-	--	
TH20	?				444	--	
TH22	?						
TH21	?						
TH5	PF				423	361	85.34
TH10	M				427	353	82.67
TH19-2	F				438		
TH2	F				376	302	80.32
TH3	M				429	361	84.15
TH8	?					340	
TH10	PF						
TH21	PM						
TH4	PM	32.31				341	
TH4-1	?						
TH14	PF					334	

TH20	?				443		
TH17	?	25.39					
TH22	?					349	
21	M				426	360	84.51
1	M	30.11	26.94	89.47			
15	?					331	
1.1	?					322	
TH 11	F	29.24	26.49	90.60	453	368	81.24
TH16	?				414	350	84.54
TH13	?				421	350	83.14

A histogram based on frequency created a potential normal curve for nasal indices. A Shapiro-Wilk test confirmed this with a p-value of .515. The nasal index and the components of the nasal index for the Suriname population were tested for sex correlation using a paired T-test. The resulting significance value of .432 for the nasal height means there is not a correlation between this element and sex. Nasal breadth could not be tested due to the small sample size of two measurements. The nasal index also had a sample size of two, so the correlation test could not be run.

The crural index histogram appeared to be a normal curve. The Shapiro-Wilk resulted in a p-value of .514 indicating a normal curve. The crural index and the components of the crural index were subsequently tested for sex correlation using a paired T-test. The femur length resulted in a significance value of .747, so it was not correlated with sex. The tibia length had a significance value of .341 and thus is not correlated with sex either. The crural index resulted in a significance value of .339, and was therefore not correlated to sex.

4.4 Correlations between components

The components of each index were ran through a paired t-test. Each of the components were also run through a paired t-test first with temperature and then humidity. Each component must first be run through a paired t-test with sex to determine correlation. The nasal height has a p-value of .2, so the correlation between nasal height and sex is not significant. The significance between nasal breadth is not significantly correlated with sex either as the p-value is .065. The femur has a p-value of less than .01 indicating a statistical significance. The correlation for this group is -.510, indicating the higher measurement of the femur, the more likely it is to be male. The tibia has a significance approaching .01, so there is a significance between tibia and sex. The correlation between these two variables is -.438, indicating the higher the measurement of the tibia, the more likely it will be to be male.

The femur and tibia were separated by sex as there is a correlation between length and sex. The male's femur and tibia lengths were not correlated to temperature as the p-values are over .05. The male femur length has a p-value of .172 so it is not correlated to temperature. The male tibia length however has a p-value of .007, indicating a correlation between temperature and the male tibia length. The unknown sex individuals were too small of a sample size to measure correlation. The female correlations between femur and tibia measurements and environmental factors all had p-values over .05, indicating no correlation.

The nasal breadth and height were not separated by sex as there was not a correlation between these components and sex. The nasal breadth had a p-value of less than .01 for both humidity and temperature. Humidity has a correlation of .616. The temperature has a -.472, which indicates a correlation with the nasal breadth decreasing as the temperature decreases. The nasal height had a p-value of less than .01 for both humidity and temperature. The temperature was correlated with a -.552 result, indicating a decrease in nasal height with a decrease in temperature. There was a correlation between humidity and nasal height with a .633.

4.5 Comparing all populations

The data set of the combined populations was tested for normality. Using a histogram of the frequencies, the measurements of the nasal indices appear to not fall into a normal curve. A Kolmogorov-Smirnov test of normality was run to determine the normality of the population as a whole. The nasal index has a significance value less than .01, so this data set does not follow the normal curve. The crural indices appears to be more normally distributed than the nasal indices. The Kolmogorov-Smirnov test confirms this with a significance value of .2, indicating a normal distribution.

To interpret the interaction between the environmental factors and the index measurements, a one-way ANOVA was used. The ANOVA was chosen to interpret the data as it can be used to read both parametric and nonparametric data. The nasal indices, as they are nonparametric will use the post-hoc test Tukey HSD as it is the appropriate test for data that does not follow normal distribution. The crural indices will use the Bonferroni post hoc test to determine the results of the ANOVA tests.

The ANOVA test was first run to determine the relationship between temperature and both indices. The test of homogeneity of variances indicates that the one way ANOVA could be conducted. The result of the significance of crural and temperature ANOVA is .014 which indicates a difference in the means of the crural indices between temperatures. The significance of the nasal indices was .014 which indicates the means of the nasal indices also differs between temperature. The Tukey HSD post-hoc tests on the nasal indices resulted in significant values of less than .05. The Bonferroni post-hoc test on the crural indices resulted in significance values of less than .05 in most cases. There was one group which had a significance value of 1; Suriname vs Middenbeemster. This indicates that the means were similar. The Nubian vs Suriname group is approaching significance with a value of 0.51.

The next ANOVA to be run was the connection between humidity and the different indices. The test of homogeneity of variances indicates the one way ANOVA could be conducted. The nasal indices had a significance value of less than .01 indicating a difference in the means of the nasal indices between humidity. The crural indices has a significance of .014 which indicates the means of the crural indices also differs between humidity. The Tukey HSD post-hoc tests on the nasal indices resulted in significant values of less than .05. The Bonferroni post-hoc test on the crural indices resulted in significance values of less than .05 in most cases. There was one group which had a significance value of 1; Suriname vs Nubian. This indicates that the means were similar. The Middenbeemster vs Suriname group is approaching significance with a value of 0.51.

After the statistical analysis of the data sets, R was used to create graphs mapping the spread of the data sets. The black circles represent Suriname, the red are Nubia, and the green stand for the Middenbeemster population. These graphs place the index measurements on the Y-axis and the population on the X-axis which gives a visual for how the different measurements are dispersed (table 4, table 5, table 6).

Table 4: The comparison of the Suriname, Nubian, and Middenbeemster populations' nasal index.

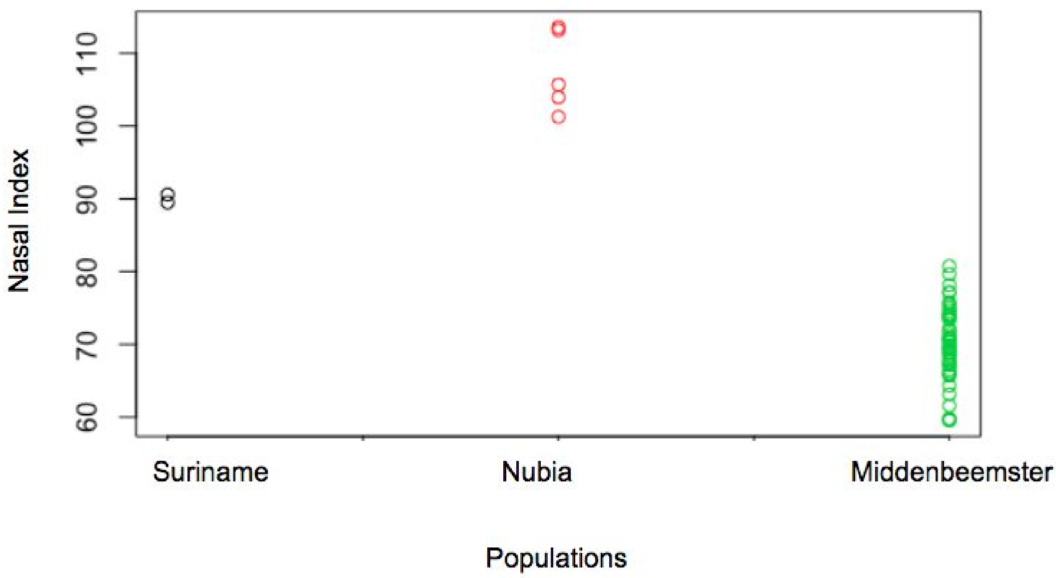
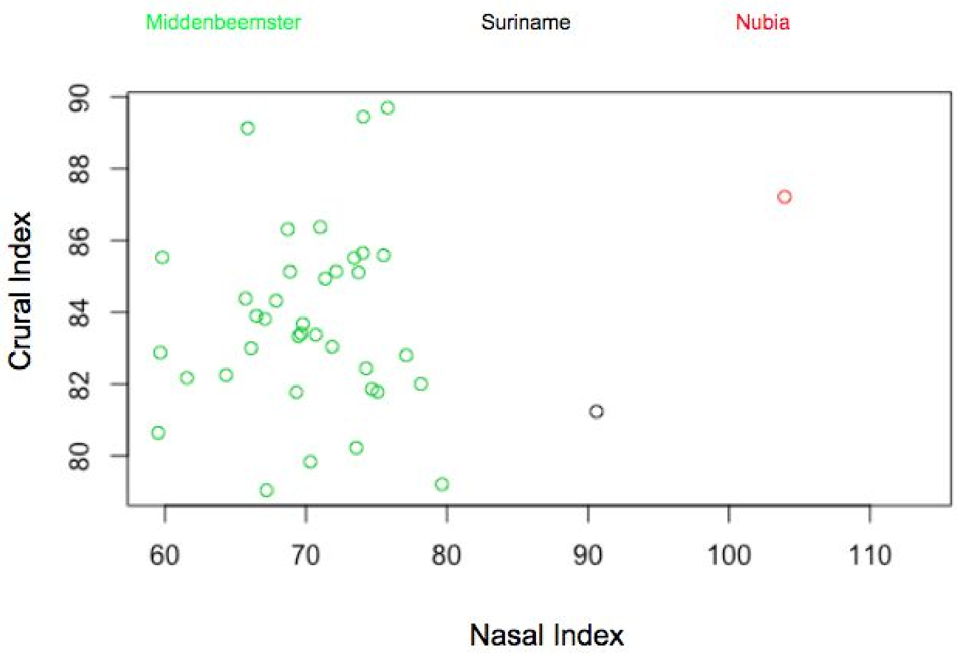


Table 5: The comparison of the Suriname, Nubian, and Middenbeemster populations' crural index

Table 6: The comparison of the Suriname (black), Nubian (red), and Middenbeemster populations' crural and nasal indices for the individuals with both indices.



The graphs created through R show the visual representation of the differences the statistical calculations produced between the populations. The spread of the index measurements can be seen for each population, which shows how the differences in humidity and temperature affects the size of the crural and nasal index. The differences in the nasal indices from each population is shown to have clear differences in each population, while the crural indices overlap. These differences are studied in greater detail through the ANOVA's that were run on each population, which pinpoints the exact correlation between the climate and the index measurements. The following chapter will use the statistics calculated to infer how much these differences in indices are influenced by the humidity and temperature of the location the population is from. The next chapter will also discuss the limitations and confounding factors involved in this study, as well as compare the results of this study to published studies.

5 Discussion

The nasal and crural indices have differing measurements based on the populations. The correlations between the measurements of each index and sex was determined in order to gain a better understanding of the mechanisms at work behind the differences in the measurements of the indices. Following these correlations, it was determined that the environmental factors had a higher correlation to the changes in nasal and crural indices which helps to expand the understanding of how and why different populations have different nose and body shape.

5.1 The crural index

The crural index is made up of the ratio of the femur to the tibia, and the length of the femur and tibia is influenced by stature. As stature is correlated to sex, the femur and tibia should be correlated with sex as well. The populations in this study had correlations of both tibial length and femoral length to sex. A correlation, as was predicted due to the correlation between sex and stature, necessitated the determination of a correlation between crural indices and sex. If a correlation exists between sex and the crural index, it is possible that differences found between crural indices were due to sexual dimorphism and not environmental adaptation. The crural index was not correlated with sex. Thus the ratio between the femur and the tibia stays constant despite stature or sex differences. The differences in crural index measurements between the three separate populations must then be due to adaptations to the environment.

5.1.1 Crural Index vs Temperature

The range of the tropical zone collection's crural indices are similar, but the minimum and maximum measurements between the Nubian collection and the Suriname collection differ. The similar range indicates the ratio between the femur and tibia stays relatively constant. The consistency in the crural indices shows that the body shape of these populations does not drastically vary. However, these two populations have consistent temperatures that are extremely similar to each other; Nubia at 30°C and Suriname at 27.5°C. The similarity in temperature between these two populations should indicate a similar body shape with similar maximum and minimum measurements if there is a correlation between temperature and body shape. However, the maximum and minimum measurements from these two populations differ. Suriname has a smaller crural index with the maximum being 84.54 mm, while Nubia has a larger crural index with a maximum of 89.1 mm. The range is similar in both populations indicating a consistent body shape, but this body shape is not consistent across all populations of the same temperature.

The crural indices of the Middenbeemster collection have a much broader range than the Suriname and Nubian collections. The range spans the ranges of the Suriname and Nubian ranges and beyond. The Middenbeemster site is located in a temperate climate zone, with temperatures fluctuating throughout the seasons. With such variance in temperature, it would be understandable that an ideal body size and ratio would have a wider range of possible measurements as the temperature has a wider range of possibilities. A specific and narrow range of crural index measurements would indicate a narrow range of an ideal body size for the climate. With a fluctuating climate, such as in temperate zones, a narrow range for an ideal body size would possibly hinder the adaptation to the environment as it would not allow for shifts in body types as temperature changes over time. While the range and minimum and maximum measurements of these populations indicate a possible correlation of the crural indices with temperature, analyzing the differences in the group's means will more accurately determine if such a correlation exists.

The ANOVA test run on the crural indices and temperature resulted in significant differences between the means in the populations, but post-hoc tests were run to find the true differences between each population comparison. The ANOVA resulted in a significance value of .014, which indicates there was a significant difference in the means of the populations in regards to temperature. A significant difference in the means indicates a correlation between crural indices and temperature. This would signify the minimum and maximum measurements and the narrow range of the tropical zone populations is due to the correlation between temperature and the crural index. The wide range of the Middenbeemster populations would be due to the fluctuation in temperature which creates a wider ideal crural index adaptation for this location. While the result of the ANOVA test supports a correlation between the crural index and temperature, the post-hoc tests do not support these conclusions.

The Bonferroni post-hoc test resulted in a significance value of 1 for the Suriname and Middenbeemster populations. This result indicates the means of these two populations were similar and showed no difference despite the ANOVA result. The Nubian and Suriname comparison formed a value of .51, which is not significant. The differences found in the means of these populations could be due to chance and the means could be different, but it is far from the desired .05 therefore it can be concluded that the crural indices of the Nubian and Suriname populations are similar. The Middenbeemster and Nubian populations had a significant difference in their means.

While the ANOVA test resulted in a significant difference in the means of all the populations, the post-hoc tests that were run to negate false-positive results indicated only one comparison had a difference in means. The small sample size of the Suriname population will have contributed to the Bonferroni test results, but there is no way to modify either the test or the sample size, so the results must be considered accurate. These results show that crural indices are not correlated to temperature in most populations. The differences between the means of Middenbeemster and Nubian populations indicates that there is a difference in the crural indices between these two populations. While there is a difference in the temperature between these two populations, the assumption that the crural indices are different due to temperature can be negated by the results of the Bonferroni post-hoc test on the Middenbeemster and Suriname population comparison. These two populations have a difference in temperature, but no difference in the value of the means. If there was a correlation between temperature and crural indices, it would be expected that the Suriname and Nubian populations would not have a significant difference in means as they have a similar average temperature. The Middenbeemster collection, however, should have a significant difference in means between both the Suriname and Nubian populations as the Middenbeemster average temperature differs from both the Suriname and Nubian populations. This result did not occur as the Middenbeemster and Suriname collections had no significant differences in their means. There was a significant difference between the Middenbeemster and the Nubian collections as expected, but without significant differences between the Middenbeemster and Suriname collections there is no support for a correlation between temperature and crural index size with these populations.

5.1.2 Crural Index vs Humidity

As temperature was found to be not correlated to the crural index measurements due to the post-hoc test results, the range of the crural indices and the minimum and maximum measurements of crural indices could have resulted from a correlation to humidity levels. The Middenbeemster population and the Suriname population has the closest humidity levels, so an expected result would be similar crural indices between these populations if the crural indices are correlated to humidity. A difference between the crural indices of both Middenbeemster and Suriname when compared to the Nubian populations crural indices would support a conclusion of a correlation between crural index measurements and humidity as the Nubian population has the lowest humidity and is the most arid of the studied regions. The Middenbeemster and Suriname regions both fall into a humid category and so will show a greater difference to the Nubian populations if there is a humidity correlation to the crural index.

However, the minimum measurement for the crural indices of the Nubian collection overlaps with the maximum measurement of the Suriname population. Five measurements of the Suriname population overlap with three of the lower measurements of the Nubian population. The measurements of the Middenbeemster collection span the entirety of the Suriname and Nubian crural index measurements and has a lower measured minimum boundary and a higher measured maximum boundary than both of these collections. If there was a correlation between humidity and crural index measurements, it would be expected that the Middenbeemster crural indices would match the Suriname crural indices and there would be no overlap in crural indices from the Nubian collection. The humidity of both the Middenbeemster region and the Suriname region does not fluctuate throughout the year, which would have possibly explained an overlap in crural measurements as there would be a wider range of an ideal crural index for the region if there was humidity fluctuations. The Nubian region also does not have a fluctuating humidity, so if humidity affected the crural index measurements, it would be expected to have a relatively narrow and static range of crural indices that differs from the humid regions of Suriname and Middenbeemster.

The ANOVA results for the correlation between the crural index and humidity indicates a correlation between these two elements as it resulted in a significance value of .014. This significance value shows that crural index has a direct relation to humidity. A correlation to humidity would indicate climate has an effect on the body shape of individuals, which would support Bergmann and Allen's Law in terms of human populations (Bergmann 1857 in Meiri 2003, Allen 1877). This correlation would disprove the minimum and maximum observations which support no correlation between humidity and the measurement of crural indices. However, a Bonferroni post-hoc test was run on the data to have a more accurate statistical analysis of the samples.

The Bonferroni post-hoc test resulted in less significance between the humidity and various populations. The Middenbeemster collection compared to the the Suriname collection resulted in a significance value of .51, indicating the means between the two collections were similar. This was to be expected as both Suriname and Middenbeemster have similar humidity levels with very little fluctuation throughout the year. There should be very little differences between the means of the crural indices of these groups if humidity and crural index measurements are correlated. However, the Suriname collection in comparison with the Nubian collection resulted in a significance value of 1. The Nubian collection originates from an arid environment, while the Suriname collection originates from a humid environment. The expected result of a comparison of Suriname and Nubian collections in regards to humidity would be a significance value of .05 or less indicating a difference in the variations of the means between the populations. If the crural index does have a correlation with humidity, the arid populations and the humid populations should have differences in the variations of means as the crural indices will be contrasting. However, the Bonferroni post-hoc test shows that despite the significance value from the ANOVA test, the Suriname and Nubian populations have similar means. The only group comparison that resulted in a significant p-value is the Middenbeemster and Nubian collection. This is the expected result for a comparison of an arid environment with a humid environment if crural indices were correlated to humidity. However, since the Suriname and Nubian comparisons are not significant in differences, there is not enough statistical evidence for a correlation between crural indices and humidity.

5.1.3 Crural Index vs Climate

The statistical analysis of the correlation between the crural index and temperature and humidity resulted in no significant correlation between these two environmental factors. As the length of the tibia and femur were correlated with sex, the individual components of the crural index could not be statistically analyzed for correlation with either of the climatic components as the sex correlation would skew the data. Due to this, only the crural index could be analyzed for a correlation between humidity and temperature. However, the statistical results indicate an absence of correlation between the environmental components used in this study and the crural index. An absence of correlation between the crural index and the environmental components would suggest that temperature and humidity are not selective pressures that act on the crural index.

If temperature or humidity had a selective pressure on the crural index, a correlation between the crural index and one of these environmental pieces would have occurred. A correlation between the crural index and temperature or humidity would indicate the crural index is linked to the environment and changes accordingly. If the temperature was a selective pressure on the crural index, then there would have been a marked difference between the Suriname and the Nubian population to the Middenbeemster population. However the means of the crural index from these populations are similar which indicates no statistical difference between the crural index of populations from differing temperature. The same logic can be applied to the humidity and these populations, but in the case of humidity a difference between the Middenbeemster and Suriname population and the Nubian populations would have been seen as the Middenbeemster and Suriname populations have similar humidity. This does not occur as the ANOVA and subsequent Bonferroni post-hoc test reveals the populations from differing humidity regions have similar means of crural indices. The similarity in means indicates no difference in the crural indices between these populations.

The similarity of the means between populations with drastically different humidities or temperatures suggests these environmental components do not affect the crural index. As temperature and humidity have not affected the crural indices of these populations according to the statistical analysis, this supports the conclusion that the climate a population lives in does not have an evolutionary effect on the crural index. There is no correlation between the size of the crural index and the environment, even though all three populations had enough time to adapt to the region they lived in. Thus this study indicates the crural index is not a physical adaptation that is affected by either temperature or humidity.

5.2 Nasal index

The nasal index is made up of the ratio of the nasal breadth to the nasal height. As no correlation was found with either the nasal breadth and nasal height, or with the nasal index and sex, sex is not a determining factor in the differences in the measurements taken. Therefore, environmental adaptation should be the defining factor to the changes observed in the nasal indices. The three different populations of varying humidities and temperatures should give a clear view of how these factors affect the nasal index.

5.2.1 Nasal Index vs Temperature

The ranges of the nasal indices are narrower than the crural indices for each collection. The largest range is from the collection from Middenbeemster with a range of 21.22mm with a minimum measurement of 59.51mm and a maximum boundary of 80.73mm. The Nubian collection has a lower boundary of 101.26mm and an upper boundary of 113.59mm creating a range of 12.33mm. The Suriname collection had only two points of usable data for nasal indices creating a lower boundary of 89.47mm and an upper boundary of 90.6mm. Thus the range for the Suriname collection results in 1.13mm, but due to the small sample size of this range and the boundaries will most likely differ from a larger sample and from the actual population. However the narrow ranges of the nasal indices from these populations and the differences between the upper and lower boundaries between the different collection indicates a difference in nasal indices that could be correlated to climate.

The temperature of the Middenbeemster region is more variable than either the Suriname and Nubian regions. Despite the variable temperature, on average Middenbeemster has a lower temperature than both Suriname and Nubia. If the temperature is correlated to nasal index size, Middenbeemster should differ from the Suriname and the Nubian nasal index measurements. Suriname and Nubia have similar temperatures, but the temperatures differ enough that there should be a difference between the variations in means. It is also important to note that the Suriname nasal index measurements is a small sample size and it is possible that in a larger sample size the upper bounds of this population's nasal indices would overlap with the lower bounds of the Nubian nasal indices. Due to the similarity in temperature, this would have been an expected outcome. However, as the current sample does not overlap, it would be expected to have significance differences if temperature is correlated to nasal index measurements.

The ANOVA results for the comparison of temperature and nasal index measurements generated a significance value of .014. The significance value of less than .05 indicates a correlation between temperature and nasal indices. This shows that climate works as an adaptive force on the nasal index of human populations and that different size nasal indices results in processing the air more effectively and is thus a positive trait. If this is a positive trait, nasal indices from certain regions should adapt over time to follow the ideal shape of the nasal index for the climate the population lives in. To ensure the ANOVA test was not skewed, a Tukey post-hoc test was used on the nasal index ANOVA data as the data was nonparametric.

The Tukey post-hoc test resulted in significant values of less than .05 for each comparison of the populations differences in means. This indicates that there is a significant difference in the variations of means between each population which suggests a correlation between nasal indices and temperature. A correlation between nasal index measurements and temperature supports the claim that the differences of a populations nose shape is due to adaptation to the climate. As an adaptive trait, the nasal index would change depending on the climate of the region and the length of time the population has lived in the region. The nasal index as an adaptive trait would have an ideal ratio between the nasal height and width to process the air moving through the nose. In warmer temperatures, less processing time is needed as it is already near the necessary temperature, resulting in a larger nasal index as the wider nasal width would better support a warmer temperature. The significance between the correlation indicates that nasal index is greatly affected by temperature. This supports Thomson's Rule of colder climates necessitating a narrow nose in order to thoroughly warm the outside air before it enters the pharynx.

5.2.2 Nasal Index vs Humidity

The narrow range of the nasal indices in each population and the fact that none of the nasal index measurements from differing populations overlap suggest that nasal indices might be susceptible to adaptation based on climate. The climate component of humidity should be compared to the nasal indices, as the nose is also instrumental in maintaining the proper moisture levels needed for the lungs to process the inhaled air.

The nasal indices had a significance value of .01 when an ANOVA was run on the relationship between the humidity and the nasal index measurements. This would indicate that there is a significant correlation between the nasal index and humidity. If these are correlated, then there is support for the proposal of the nasal index being an adaptive trait. As the humidity is different in regards to the populations, if nasal indices are a trait that is susceptible to environmental pressures, it would be expected that the variations of the differences in means would have a p-value of less than .05. As the resulting p-value is less than .05, it shows that nasal indices diverge in different humidities. This divergence is most likely caused by adaptation to the differing humidity levels, as the nose is necessary for retention of moisture. The function of the nose in the retention of water should make it more sensitive to humidity changes (Thomson 1923) and in turn this environmental pressure should cause an ideal nasal index to form in each differing humidity level (Darwin 1859, Thomson 1923).

In order to determine the accuracy of the ANOVA, the Tukey post-hoc test was run on the nonparametric nasal index data. The Tukey post-hoc test resulted in p-values that were less than .05 for each population comparison in regards to humidity. This indicates there is a significant correlation between nasal index measurements and humidity. This correlation between the changing nasal index measurements and the percentage of humidity supports the conclusion that nasal index size changes based on the environment as it is an adaptive trait that has changed over time. As the percentage of humidity changes, it would be expected that the nasal index changes as moisture increases in the air the nose would need to retain less water via the nasal passage. With the correlation between the nasal index and humidity statistically proven to be significant, this expectation is supported. The nasal index should have an ideal measurement to retain the necessary water levels needed by the lungs, but also compensate for the water saturation of the outside air.

5.2.3 Nasal Components Vs Humidity

As the nasal index is correlated with humidity, and consists of the measurement of the nasal height and nasal breadth, it stands to reason that these components should also be correlated to temperature. The nasal breadth, the measurement taken at the widest point of the nasal aperture, had a significance value of less than .01 when compared to humidity using a paired t-test. The nasal breadth was correlated to humidity with a correlation of .616. This correlation indicates the higher the percentage of humidity, the wider the nasal breadth. As higher humidity levels have greater water saturation in the air, water retention is not as important.

Nasal height, the measurement taken from the nasion to the lowest point on the nasal aperture, was tested for correlation to humidity using a paired t-test as well. The p-value resulted in less than .01 indicating a correlation between nasal height and humidity. The correlation resulted in a .633 which indicates a correlation between this environmental factor and the nasal height. Thus as the humidity increases, the nasal height does as well. This would increase the surface area of the inner nasal aperture, which would assist in the release of excess moisture.

The nasal breadth then has its correlation to temperature calculated via a paired t-test. The resulting significance value of less than .01 indicates a correlation between these two factors. The correlation resulted in a -.472. As the correlation is negative, this indicates the nasal breadth shrinks as the temperature decreases. This would restrict the outside air from entering the nose as freely, and force more of the air to move past the walls of the nasal aperture, which helps warm the inhaled air. This would be a more necessary adaptation in colder temperatures as the nose would have to increase the temperature of the air by a larger percentage than in regions where the outside temperature is already comparable to the internal body temperature.

The nasal height was also compared to temperature using a paired t-test and the significance value resulted in less than .01, signifying significance. The correlation resulted in a -.552, which indicates that the nasal height decreases as the temperature decreases. As the main function of the nose is to warm the air to internal temperature, in locations where the air is already warm the nose needs to warm the air less. Thus a larger nasal height in extremely hot temperatures will keep the air from becoming overheated, while a larger nasal height in extremely cold regions will assist in warming the air.

5.2.4 Nasal Index vs Climate

The nasal index is correlated in a statistically significant way to both temperature and humidity in the samples in this study. This correlation indicates that the nasal index is directly affected by both temperature and humidity. Thus the hypothesis that temperature and humidity are selective pressures on the size of the nasal index is supported in this study. The nasal index, however is created using two separate measurements, the nasal height and breadth, and are also correlated to the environment. These components could help indicate which environmental factor, temperature or humidity, has a greater role in forming the nasal index size. As the nasal index size is correlated to these components, the means of the nasal indices change between each population. The means are unique enough to be statistically significant, so each of these three populations has a nasal index that is more suitable for the humidity and temperature of their region. If the means were similar across all populations, then the nasal indices would not have been affected by temperature or humidity as each of these three populations have unique temperature and humidities. However, as the means were different across the populations, the nasal indices were affected by the climatic conditions of the different regions.

The difference in means and the correlation between the nasal index size and the environmental factors tested in this study, supports Thomson's overall idea that the nasal index is evolutionarily affected by climate, and differing nose shape and size is due to the function of the nose and how it is affected by climate (Thomson 1923). As the nose is in direct contact with the outside air and functions as both a temperature control and moisture retention device (Zaidi 2017), the changing nasal index size would assist to adapt the nose to the climate in order to function better. A wider nose in warmer temperatures will help the nose not overheat the air, while a narrow nose in colder temperatures, such as in the Dutch population, will increase the warming power of the nose. A wider nose will also suit a more humid environment better, as there is less of a need for water retention, while a narrow nose will suit a dry environment as it will retain the moisture in the air more effectively. The populations within this study show the expected correlations between the nasal index size and the humidity and temperature that follows Thomson's rule.

The nasal height and nasal breadth are both correlated to temperature and humidity in the same way; that is when the temperature or humidity increases, so does the size of the nasal height and breadth. Due to this, the size of the nasal height and breadth must be related to each other, as they are correlated to the same environmental factors in the same way. This would indicate that a certain range of the ratio of the nasal height to nasal breadth is necessary for the architectural integrity of the aperture structure. As the nasal height increases, so does the nasal breadth. The correlation between nasal height and humidity is slightly stronger than with nasal breadth. This suggests that the nasal height increases at a slightly faster rate than the nasal breadth when it comes to adapting to the environment. The nasal height is also very slightly more correlated to temperature. The difference in correlation is so slight, that the size of the nasal height and nasal breadth most likely changes along the same rate due to the humidity. The similarities in both the correlation results suggest that the structure of the nasal aperture needs a certain ratio of height to breadth for support. The nasal height cannot increase more than the nasal breadth can support it and vice versa. Thus both temperature and humidity are suggested to play equal roles in the size of the nasal index.

5.3 Clothing: a confounding factor

The invention of clothing that can withstand harsh climates allowed for humans to spread further away from the equator and into regions with less hospitable climates. The rapid expansion of humans throughout the globe occurred too fast for the slow development of natural selection to keep pace. Over the millennia that passed following human expansion, evolution would have had the time necessary to slightly alter the physical appearance and shape of certain attributes to better suit the environment. However, by this point clothing would have changed the way evolution functioned, as the clothing would have helped protect against inclement weather.

Clothing that protects the lower face from the elements, also acts as an extra layer of tissue that air must migrate through before entering the nose. This layer helps warm the air before it even reaches the nose, which helps the nose with the burden of warming the outside air to 90% of the needed temperature (Zaidi 2017). This clothing layer also creates a moist pocket of air around the nose and mouth caused by the simple act of breathing (Salloum 2007). The moisture captured by clothing aids in moisture retention, which is a fundamental function of the nose (Zaide 2017, Salloum 2007). Due to this added layer of warm, moist air, the nasal height and breadth may not be forced to evolve to better suit the surroundings as the human invention has been used to accelerate the functionality of the nose.

The acceleration of functionality of the nose through use of clothing would disrupt the natural progression and pattern of evolution. Evolution relies on slight mutations that create more functional physical attributes to better suit the environment, but the use of clothing bypasses this by allowing the nose to remain functional regardless of the shape. Covering the nose with an outer layer creates an artificial warming device that works as an extra nasal aperture (Yi 2004). This would allow humans to live in cold and dry environments, such as the Arctic tundra, without having an extreme adaptation to the weather. Clothing functions as the adaptation to this weather, which would allow for slight adaptations, but would most likely negate the need for substantial physical changes to the architecture of the nose.

The crural index should also be affected by clothing as Bergmann's and Allen's rules relies on the effects of climate on endothermic thermoregulation (Bergmann 1857 in Meiri 2003, Allen 1877). Humans, unlike other ectotherms, do not have to rely on the slow physiological changes of evolution to adapt to extreme environment. Humans force the environment to adapt around them. With inventions such as clothing and wearing fur as a thermal layer, humans were able to move freely between climates without a regard for physiology. This added thermal layer would affect how the body regulates its temperature, as instead of needing to keep the body at core temperature in climates that are below freezing using only the circulatory system, the body has an extra layer of insulation that helps prevent loss of body heat (Yi 2004). The prevention of body heat loss means the climate will not affect the evolutionary trajectory of the distal limbs in as extreme of a way as it would if body heat was lost naturally. Bergmann and Allen's rules expect shorter distal limbs and a more spherical body shape in colder climates as these adaptations help preserve body heat due to the ratio of body mass exposed to the elements and body mass not exposed (Bergmann 1857 in Meiri 2003, Allen 1877). However, the preservation of body heat through the use of clothing as an insulating device will disturb the application of Bergmann and Allen's rules.

As the body will have to exert less energy into keeping the core temperature at the correct level, there will be less environmental pressure to adapt to the colder climate. A deficit in environmental pressure caused by the protective nature of clothing will cause less drastic adaptations in the distal limbs. Bergmann and Allen's rules will still be applicable, as clothing helps protect against the harsh cold, but the body will still experience the cold, just to a lesser degree. Thus the rules regarding the optimal body shape and size for endothermic thermoregulation will still apply, but the adaptations to conserve body heat will not be as drastic as the adaptations of endotherms that do not have insulating clothing layers. In warmer and more humid areas, clothing is also used to counteract the effects of these environmental pressures. Clothing in reflective colors, such as white, help to lessen the amount of light and heat absorbed by the body. Loose robes help capture air flow which also cools the body (Salloum 2007). As a result, the changes in the crural index between warmer and colder regions might be more minute than expected.

The statistical analysis of the crural index that resulted in no correlation between temperature or humidity and crural index size might have occurred due to the application of clothing as a means to counteract these environmental pressures. Humans are able to live in extreme temperatures as humans make the environment adapt to them instead of vice versa. The comparison between temperate zones and tropical zones could have been too close spatially to have had a statistical difference due to the confounding factor of clothing. The use of clothing to survive in colder regions could have caused the populations in mild temperate regions, such as Middenbeemster, to not undergo statistically significant adaptations to the environment. As temperate zone regions have the most variable of climates when compared to tropical or arctic zones, the use of clothing could have resulted in a lack of a strong enough environmental pressure to cause an adaptation to the temperature or humidity (Reisa 2006). The temperature in particular fluctuates drastically throughout the year in Middenbeemster, with summer weather reaching up to 20°C and winter weather plummeting to 2°C (Schier 2010). This fluctuation could cause little change in the crural index as during the harsher winter months the use of insulating clothing could have compensated for any physical adaptations that would have helped maintain core temperature. Thus there could be changes in the crural index that are correlated to temperature or humidity, but in order to be statistically significant, a more drastic temperature and humidity difference would have to be compared, such as the use of an arctic zone population compared to a tropical zone population.

5.4 Limitations

Due to the availability of the collections and the preservation status of the collections, the scope of this study was rather narrow. The small sample size of the Suriname and Nubian populations decreased the statistical power of the results on these populations. The small quantity of individuals available is problematic when attempting to draw inferences from the population as a whole, as the sample represents the population. The small sample size is less representative of the entire population’s variations and any outliers in the sample will have a greater statistical weight than in an appropriately sized sample. The margin of error in this study for these two collections will also be larger due to the size of the samples.

The collections only covered tropical and temperate zones as there were no available Arctic zone collections. An ideal study would use Arctic zone collections as well as tropical zones, to compare against temperate zone populations. Temperate zones have widely variable climates, with temperatures fluctuating throughout the year (Reisa 2006). As the temperature shifts so drastically, measurements that are highly correlated with temperature will have a broader range as there will not be one single ideal body type for the shifting temperatures. The broad temperature range allows for a greater amount of temperature correlated traits to emerge, as the environment constantly changes, so most traits are better suited for the different variations of temperature. The tropical zone populations are expected to have stricter measurements of ideal body proportions for the climate, as there is less variation in the temperature (Reisa 2006), so over time the traits that better suit this narrow temperature range will be exhibited by most of the population. The same narrow temperature range is present in the arctic zone, meaning the same boundaries of a narrow range of temperature correlated measurements should be present. Comparing the tropical zone populations with temperate zones and arctic zones would give a better understanding of how the human body adapts to the environment. The arctic and tropical zones both have static climates which would allow the presence of adaptations to occur at a faster pace as the more suitable traits will survive in these environments. The variable climate in the temperate zones allows for traits that are less well suited for certain climates to survive, as the climate is constantly changing so these traits may be better suited during certain times of the year. The variability of the temperate climate body types makes generating data about adaptations to different climates difficult as the temperate climate populations will not have as obvious of adaptations as populations who are exposed to more severe and static environments.

While a comparison of tropical zone populations and arctic zone populations would have generated more obvious conclusions as to the differences in adaptations to extreme temperatures, the comparison to a temperate zone population should still show slight differences in temperature adaptation. However, only one temperate zone population was available for this study, so humidity comparisons will have to be done across climate zones. The temperate zone population, the Middenbeemster collection, was from an area of high humidity. The tropical zone populations, the Suriname and Nubian collections, are from high and low humidity areas, respectively. Therefore a comparison of adaptations due to humidity can be compared with the tropical zones of similar temperatures, but when comparing humidity adaptations for the temperate zone, the only available comparison was a be a tropical zone population. This is problematic in that it will create problems separating temperature adaptations from humidity adaptations due to the extreme differences in temperature between the two sites. To counteract this issue, correlation tests were run on each individual aspect of each index and on the indexes themselves in an attempt to determine which adaptations were due to humidity before comparing different climate zones. The components of the nasal index were both correlated with temperature and humidity, while the crural index components were correlated to neither. The correlation between nasal height and breadth with both humidity and temperature is problematic in this study as it becomes difficult in determining which aspect of climate causes more of an adaptive response. The comparison between both tropical zone populations will have a more accurate response as to how humidity affects adaptations, but this information will have no comparative data in this study as there is only one temperate zone population and therefore no arid temperate environment to compare the Middenbeemster collection to. This same issue arises with temperature, as there are two instances of high temperature and one of low temperature, hindering the discovery of whether humidity or temperature is the most dominant adaptive pressure.

The collections that were utilized in this study were from populations that had very little to no gene flow with populations outside of their climate zones (van Duijvenbode 2017, Schrader 2017, van Spelde and Hoogland 2018). Any traits that arose in these populations were due to adaptive pressures from the environment, not from gene flow from other populations with a different set of adaptive traits. Current populations will have increased gene flow from around the world as globalization increases. As small differences in the skull, most of which are caused by adaptation to the environment, are the defining feature of determining ancestory in modern forensic cases, this strategy may not be practical in the future. While there are differences in certain areas of the body due to the environment, notably the nasal index and crural index as is studied in this thesis, these differences are not based on the population an individual is related to, but instead the environment the population is from. This means there should be overlap in features in areas of the world that have similar humidity and temperature measurements. This will cause complications in the determination of the ancestry of an individual when relying on nasal and crural indices. These complications increase as globalization spreads causing gene flow in between different populations. The increase in gene flow will create nasal indices that will not be reliable in estimating ancestry as the nasal index of individuals will no longer rely on generations of slow adaptations, but instead will be a mixture of the parental traits. While there are differences in certain indices of different populations, it is based on the environmental pressures. These differences can be used in modern and ancient populations to estimate ancestry with varying levels of success, but in the future as gene flow across different populations becomes greater, this method will no longer be a reliable way to estimate the ancestry of individuals in forensic cases.

5.5 Study comparison

As the nasal index correlations with temperature and humidity was modeled off of Thomson's original publication in 1923 on the correlation between climate and the nasal index, it is important to compare the results of Thomson's work and this study. Thomson had a greater variety of populations to work with, with varying degrees of temperature and humidity changes. However, Thomson assumed that "hotter places (are) slightly drier (Thomson 1923)," which as can be seen in most tropical zone regions, is not correct. Hotter temperatures are not connected with the amount of water saturation in the air, and thus temperature and humidity must be treated as two separate factors that are each affecting the nasal index. Thomson does note that there are exceptions, and thus treats humidity as a separate factor, which was also done during this study. Thomson's final findings were that temperature is more strongly correlated with the nasal index size, while humidity plays a smaller role (Thomson 1923). If both humidity and temperature are affecting the nasal index in the same way, such as the adaptation for a wider nose would be applicable for both warm temperatures and high humidities, then the nasal index will increase a large amount. However, if the humidity and temperature are at odds with each other, such as a warm, dry area where a wide nose will be more applicable for the temperature, but a narrow nose will better help the moisture retention, then the nasal index will increase, but not as much as when the components are in harmony (Thomson 1923). The study conducted above resulted in a very similar correlation between the nasal index size and both temperature and humidity. Neither temperature or humidity had a stronger effect on the size and shape of the nasal aperture. In fact the hot and dry population that was studied, the Nubian population, had a larger nasal index than the hot and wet Suriname population, which is not in agreement with Thomson's result of the largest nasal indices originating in areas that have both high temperatures and humidities (Thomson 1923). The Nubian population, as it is hot and dry, would fall in an intermediate category which Thomson proposed would create nasal indices of intermediate size. Later studies, such as an anthropometric study produced by E. Crognier in 1981, support the hot and dry climates as the climates with the largest nasal index (Crognier 1981).

Crognier used anthropometric data from European, North African, and Middle Eastern populations to study climatic variables and their correlation to physiological traits (Crognier 1981). The results of Crognier's study is nasal index size is smaller in cold and wet areas or in areas where the temperature fluctuates (Crognier 1981). These results are similar to my study, as the Dutch population is the lowest nasal index, but it can also be considered a cold and wet area or an area where the temperature fluctuates throughout the year. The widest nasal index size in my study was found in the Nubian population, which is considered a hot and dry area. My study agrees with the results found in Crognier's study on the nasal index in relation to climate, and both of these studies are not in agreement with Thomson's original conclusions on how the nasal index is affected by temperature and climate.

In regards to the results of my study on the crural index and its relation to climate, my results tend to disagree with most literature on the subject. Studies conducted by E. Trinkaus, D. H. Temple, and more result in support for Bergmann and Allen's rules in human populations

(Trinkaus 1981, Temple 2011, Cowgill 2012) . The distal limbs in these studies are shorter to conserve heat and energy, which has an effect on the crural index (Trinkaus 1981, Temple 2011, Cowgill 2012). The shorter the length of the tibia, the smaller the crural index will be. The results of my study is constrained by the access to populations and larger sample sizes, which could have resulted in a lack of correlation between the crural index and temperature and humidity. It would be important to study larger sample sizes of these populations to determine if they do follow Bergmann and Allen's rules, which the present published studies suggest (Trinkaus 1981, Temple 2011, Cowgill 2012), or if these populations are exceptions to the rules.

6 Conclusion

Adapting to the environment is the building block behind the inner workings of evolution. Certain climatic parts, notable humidity and temperature, have been observed to be selective pressures on human nasal and crural indices. Correlations between climatic components and anthropometric measurements were considered as a possibility only at the start of the twentieth century. This was a drastic change from the racist assumptions of earlier anthropometric studies, which attempted to correlate physical features to criminality and intelligence levels in an attempt to create a scientific basis behind segregation and other race related laws. The correlations behind race, criminality, and physical features were unfounded and twisted the statistical results in order to support the outcome that was wanted.

6.1 Nasal index

In terms of the nasal index, Thomson and Buxton's research into the correlations between the nasal index and the environment was a groundbreaking study that introduced the concept of adaptation to the environment to the human nasal form (Thomson 1923). The original hypothesis was not only that climatic factors are selective pressures that cause the nasal indices to adapt, but that this adaptation has a pattern; the cold, arid regions will have a long, narrow nose while the hot, wet climates will have the widest noses (Thomson 1923). This generalization, known as Thomson's Nose Rule, has been studied throughout the twentieth century, with varying results.

While Thomson and Buxton's research resulted in the rule that the nasal index is smaller in a colder and drier the environment and the larger in a warmer and wetter the environment is (Thomson 1923), further studies including the research done in this thesis shows that this trend is not completely accurate. Crognier's study agrees with the results of this thesis, in that the nasal index tends to be the largest in populations with hot and dry environments (Crognier 1981). The population in this thesis with this environmental criteria, the Nubian population, did in fact have the largest nasal indices. While this does not seem to be beneficial for the water retention factor of the nasal functions as it would allow for a greater amount of water to escape, it is possible that the larger nasal index is needed for structural support of the nasal aperture. Regardless of which climates tend towards which nasal index types, this study and the research before it supports the hypothesis that climatic factors are the largest selective pressure behind the shape of the nose.

The populations in this study indicate that hot and dry areas have the greatest size of nasal indices, as the Nubian population had larger nasal indices that the other populations. Following the Nubian population in terms of nasal index size is Suriname, which had the second largest nasal indices in the populations studied. This would suggest that a hot and humid area does not require larger indices due to the differences in humidity. The high humidity in Suriname could indicate that a larger nasal index would introduce too much moisture into the nasal cavity and pharynx, so a smaller index in this climate is more suitable. The Dutch population had the smallest nasal index, as well as the coldest temperature. The temperature in the Beemster region, however, is not extreme and falls into a temperate climate. The temperature also varies throughout the year, which could affect the size of the most suitable nasal index. As the climate does not tend to freeze for long periods of time but also does not increase past ambient temperatures for extended periods, the smaller nasal index could be an adaption to this temperature fluctuation. The humidity in this area most closely resembles Suriname, which also had a smaller nasal index on average. However, there are no indications of either humidity or temperature having a larger role in the size of the nasal index.

Statistically speaking, the correlations between temperature and humidity on the changes to the nasal index were extremely similar. The similarities in correlations suggest that neither factor is a dominant environmental pressure. This study shows support for both humidity and temperature playing a role in the differences of nasal index size. This research also suggests both of these factors play an equal role in the size of the nasal aperture. The environmental factors of humidty and temperature seem to be the strongest contenders behind the evolution of the nasal index. According to the correlations found in these populations, sexual dimorphism, another possible contender, does not play a role in the nasal index, as sex showed no correlation to nasal index size. Thus humidity and temperature appear to be the strongest factors in regards to the nasal index size.

6.2 Crural index

The crural index should fall under the thermoregulatory rules developed by Allen and Bergmann. These rules indicate that the best body shape to conserve energy and heat is a sphere as the ratio of surface area to volume is the greatest in terms of geometric structures (Bergmann 1847 in Meiri 2003, Allen 1877). The surface area is where heat escapes from the body, so a smaller surface area to volume ratio will stop the transfer of heat from the body (Bergmann 1847, Allen 1877). If this rule applies to the human body structure, in colder temperatures a spherical body shape should evolve. In order to create a spherical body structure, the distal limbs should be shortened. Therefore in colder temperatures, if this biological rule applies to the distal limbs, such as the tibia, then they should be shorter than in warmer climates which would affect the overall crural index. While many studies have shown support for the application of Bergmann's and Allen's rules, this thesis did not reach the same conclusion. The populations in this study do not have a statistically significant difference between the crural indices of the differing locations. This could be due to the small sample size, or it could be due to other factors such as terrain and nutritional access having a larger role in crural index size. This study does however, support the lack of a correlation between the crural index and the sex of the individual. Most studies indicate a correlation between the femur and tibia length and the estimated sex, but the crural index remains uncorrelated as the ratio between the two measurements stays similar regardless of the sex.

6.3 Further research

While there have been many studies showing evidence in support of a correlation between climate and physical differences, this might not be the only factor that influences physiology. Further studies should take into consideration how the terrain and elevation affects the crural and nasal indices respectively. The crural index is the lever that propels the body forward, and therefore could be affected by changes in the terrain. Flatter terrain with a good foundation would be easier to traverse than mountainous or sandy areas. This might affect the crural index measurements more than climatic factors. Changes in elevation alters the air pressure, which affects how one breathes. This might be reflected in the nasal index. Nutritional access should also be considered in future studies. The crural index in particular is made of skeletal elements that are sensitive to nutritional access and are susceptible to changes in growth behavior due to lack of nutrition.

In future studies, it would be beneficial to have a larger and broader sample size. A larger sample size from each temperature zone representing both high and low humidities would give a better overview of the correlation between climate and crural and nasal indices. It would be ideal to have similar socioeconomic statuses in the samples to account for the factor of nutritional access. `

Further research into morphological features that indicate ancestry should also be conducted. The size and shape of the nasal aperture are the most widely used and reliable measurements in forensics when it comes to estimation of ancestry (Hefner 2009). This becomes problematic when faced with the conclusion that the nose shape and size is more strongly correlated to climate than to degrees of related ancestry. This would confound forensic studies and the use of morphometric features as reliable proof of ancestry.

6.4 Final Conclusions

This research adds to the body of literature that is working to move past the racial bias that birthed anthropometrics, and to instead focus on the function adaptation to the environment plays in human existence. The results of this study support the previous research regarding the nasal index and the adaptations to the temperature and humidity. In regards to the crural index, this study does not support the adaptation to humidity or temperature, but this could be due to a small sample size. The reaction of the physical structure of the human body to air pressure, terrain, and differences in nutrition should be considered as possible factors in the results of this study as well as in future research.

Abstract

Natural selection is the impetus behind phenotypic variations among biological specimens as environmental pressures act upon these variations allowing the most suitable traits to flourish. This process affects humans creating physical differences between different populations. One of the most studied environmental factors in regards to the affect on human physiology is climate. This study uses three separate populations from different environments to research the correlation between humidity and temperature on two skeletal indices as well as the affect of sex on these indices. The populations have different humidities and temperature so an ANOVA analysis will determine if the crural or nasal index means are significantly different. The results of the ANOVA differed between crural and nasal indices; the crural index was not correlated with the climatic factors and the nasal index was found to be correlated in these populations. Sexual dimorphism did not effect either the nasal or crural indices.

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Image References

Cover Image:
https://web.stanford.edu/class/history13/earlysciencelab/body/skeletonpages/241.gif

Image 1:
https://www.mayoclinic.org/diseases-conditions/nasopharyngeal-carcinoma/symptoms-causes/syc-20375529

Image 2: http://glasber.info/human-skeleton-206-bones-labeled/

Image 3: https://www2.palomar.edu/anthro/adapt/adapt_2.htm

Image 4: http://hashtag-bg.com/world-map-no-label/

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Image 6: Schrader, S. and S. T. Smith, 2017. *Socializing Violence: Interpersonal Violence Recidivism at Abu Fatima (Sudan)*, Chapter 2, 27-42

Image 7: Vikatou. I., M. Hoogland, and A. Waters-Rist. 26 October 2017. Osteochondritis Dissecans of skeletal elements of the foot in a 19th century rural farming community from The Netherlands. *International Journal of Paleopathology.* 19, 53-63.
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Image 9: Buikstra, J. E., and D. Ubelaker, 1994. *Standards for data collection from human skeletal remains.* Research series no. 44. Fayetteville, Arkansas: Arkansas archeological survey research series no 44.

Image 10: Buikstra, J. E., and D. Ubelaker, 1994. *Standards for data collection from human skeletal remains.* Research series no. 44. Fayetteville, Arkansas: Arkansas archeological survey research series no 44.

Image 11: https://www.rch.org.au/fracture-education/anatomy/Anatomic_differences_child_vs_adult/

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