LIBRARY
Te Tumu Herenga
THE UNIVERSITY OF AUCKLAND

RESEARCHSPACE@AUCKLAND

http://researchspace.auckland.ac.nz

ResearchSpace@Auckland

Copyright Statement

The digital copy of this thesis is protected by the Copyright Act 1994 (New Zealand).

This thesis may be consulted by you, provided you comply with the provisions of the Act and the following conditions of use:

- Any use you make of these documents or images must be for research or private study purposes only, and you may not make them available to any other person.
- Authors control the copyright of their thesis. You will recognise the author's right to be identified as the author of this thesis, and due acknowledgement will be made to the author where appropriate.
- You will obtain the author's permission before publishing any material from their thesis.

To request permissions please use the Feedback form on our webpage.
http://researchspace.auckland.ac.nz/feedback

General copyright and disclaimer

In addition to the above conditions, authors give their consent for the digital copy of their work to be used subject to the conditions specified on the Library Thesis Consent Form and Deposit Licence.

Note : Masters Theses

The digital copy of a masters thesis is as submitted for examination and contains no corrections. The print copy, usually available in the University Library, may contain corrections made by hand, which have been requested by the supervisor.

Cold Case:
Cold induced vasodilation response, and the origins of Polynesian body morphology as an adaptation to a cold environment.

by

Peter Charles Robert Wilberfoss

A thesis submitted in partial fulfilment of the requirements for the degree of Doctor of Philosophy, University of Auckland, 2012

Acknowledgements

I would like to express my thanks to some of the people who have helped me over the last few years. My supervisors, first Professor Rufus Wells, and then more recently Professor Kendall Clements have not had an easy time having a student of anthropology such as myself passing through their marine biology lab. At times it must have seemed like a central railway station in the developing world with my many and varied participants wending their way past the centrifuges and the glass jars of marine anatomy towards my tank of cold water. My thanks to both of them for taking on the challenge, and to Professor Philip Harris, the post graduate advisor for the School of Biological Sciences, for putting us together.

I must also include my thanks to my fellow students in the marine biology lab, many of whom were the first to sample the pleasures of 5ºC water, and who were kind enough to encourage others when they knew full well the discomfort involved. They also often acted as guides for the many participants who had to find their way through the maze to and from our basement lab. To all my 286 participants I must express my gratitude for taking the time to participate, and for enduring the pain that without exception, they all chose to endure. At one point the pain of hand immersion in the cold water was unfavourably compared by one participant to childbirth. I must admit the first time I tried the test myself I thought my research had ended before it began. I literally could not see how I could get so many people to participate in something so painful.

I would like to acknowledge the help I have received in more technical areas, particularly with the statistical analysis. Dr Marion Blumenstein from the Student Learning Centre, Jessica Thomas from the Statistical Consulting Centre, and Dr Daniel Hurley, a Bioinformatics Research Fellow from the Department of Molecular Medicine and Pathology at the Faculty of Medical and Health Sciences all took the time to assist, review and advise on the analysis of my results. Professor Geoff Irwin from the Anthropology Department also kindly reviewed the section on Pacific colonization.

On a more personal note I would like to thank my children, Laura, Robbie and Adam, who had to endure having a father as a student at University. Their support, patience and understanding is something to treasure. This also includes my parents Janet and Robert, who have had many more years' experience of my idiosyncrasies. Finally I would like to acknowledge the love and support of two special friends, Victoria Barnao, and Jo Wallis, who at different times and in different ways made this project all the more fun.

Table of Contents

List of Figures

List of Tables

Abbreviations

Glossary of abbreviations	
ANOVA	Analysis of Variance
AUT	Auckland University of Technology
BP	Before present
C	Celsius
CIVD	Cold induced vasodilation
cm	Centimeter
Diam	Diameter
EG1	Ethnic Grouping 1
EG2	Ethnic Grouping 2
Est.	Estimated
Euro	European
kg	Kilograms
MANOVA	Multivariate Analysis of Variance
Min	Minimum
Max	Maximum
mm	Millimeter
mtDNA	Mitochondrial DNA
PCA	Principal Component Analysis
PNG	Papua New Guinea
Sig	significance
SD	Standard deviation
SHR	Sitting height ratio
Std.	Standard
T_{av}	Average temperature over 30 minutes of cooling
T_{mean}	Average temperature from Tmin to end of test
T_{max}	Maximum temperature achieved during first CIVD response
T_{min}	Minimum temperature during 30 minutes of cooling
T_{30}	Temperature after 30 minutes of cooling
$T_{pretest}$	Temperature prior to cooling
T_{freq}	The frequency of CIVD cycles during the test period
T_{index}	Index based on T_{av}, amplitude and onset time
UOA	University of Auckland
UK	United Kingdom

Abstract

The origins of Polynesian body morphology have been a source of speculation since early European explorers marvelled at their large physique. Climate is considered the major evolutionary factor behind body morphology. Bergmann's and Allen's Rules suggest that Polynesians exhibit a cold adapted body form, despite inhabiting a tropical environment. However, Polynesians have only inhabited the Pacific region for several thousand years; their origins lie in Asia.

Past research has suggested this cold adapted body form evolved as a response to voyaging in the cold Pacific maritime environment. The emergence of Lapita culture in Near Oceania around 4,000 years ago, and its subsequent expansion by the ancestors of modern Polynesians across the Pacific in less than 3,000 years, does not provide the necessary time frame to evolve cold adapted body morphology. If Polynesians have cold adapted characteristics, their origins must lie in the high latitudes.

This research examined the variation in human body morphology and resistance to cold, and its relationship to biogeographical ancestry. A total of 286 participants from Polynesian, Melanesian, European, Asian, Indian, and African ethnic groups were measured for body size and shape, and tested for their cold induced vasodilation response. Three questions were examined. To what extent does body morphology, specifically body size and body shape, represent adaptations to ancestral climate? To what extent does cold induced vasodilation response represent an adaptation to an ancestral climate? In the light of these results what are the likely ancestral origins of Polynesian body morphology?

The results clearly indicate the cold adapted body morphology, and strong resistance to cold as displayed by cold induced vasodilation response, found in Polynesian populations when compared with other populations from both cold and tropical environments. This adds weight to the hypothesis that Polynesian ancestral origins lie in the cold climate of Northeast Asia many thousands of years ago. A robust physique may have been a significant advantage for early Oceanic explorers in their canoes, contributing to the success of their colonization of the Pacific. These origins may also be a factor in the high rates of obesity and diabetes found in modern Polynesian populations.

Chapter 1. Introduction

1.1. Overview

The starting point for this present study is the anomaly of the Polynesian body morphology. Whilst researching the high incidence of diabetes among Polynesian communities, the author came across the work by Philip Houghton on the relationship between Polynesian body morphology and adaptations to climate (Houghton, 1980; Houghton, 1990, 1991a; Houghton, 1995; Houghton, 1996). Houghton clearly demonstrated Polynesian body morphology was much more similar to populations inhabiting cold environments rather than those populations with tropical ancestral origins, despite the tropical environment Polynesians inhabit in the Pacific Ocean.

Climate has been seen as a major evolutionary factor in the differences in body morphology between human populations, in particular body shape and limb proportions. Bergmann's and Allen's rules were developed in the nineteenth century, and considerable research over the last 100 years has confirmed their validity. Cold adapted populations tend to be larger, with a wider and longer trunk, and relatively shorter limbs. This reduces the body mass/surface area ratio, allowing less heat to be dispersed through surface skin, and the retention of core body heat. Conversely populations in a warmer environment tend to be longer and leaner to facilitate heat loss.

Houghton's hypothesis was that Polynesians had developed this cold adapted body morphology as a result of their voyaging on a cold and inhospitable Pacific Ocean in small canoes. There is no doubt that voyaging on the Pacific Ocean in a canoe would have exposed these early explorers to a cold and wet maritime environment, and that a robust physique would have been a considerable attribute to enhance the chances of survival. Houghton proposed this adaptation would have developed either during the thousands of years of human occupation of Near Oceania, or during the expansion of the Lapita populations into Remote Oceania. This hypothesis is readily quoted in reference works on Polynesian body morphology (Molnar, 2002, p. 201).

More recent research has demonstrated that the ancestral origins of Polynesians lie in Asia, with limited interaction with indigenous populations in Near Oceania. Their emergence in Near Oceania around 4,000 years ago, and subsequent expansion across the Pacific in less than 3,000 years did not provide the necessary time frame to evolve cold adapted body morphology. In addition the method of voyaging during the period of exploration and colonization of the Pacific would have militated against any significant evolution of body morphology among the wider Polynesian population. However, a robust physique would still have been a significant advantage for early Oceanic explorers in their canoes, and may well have contributed to the success of the colonization of the Pacific.

If Polynesians did not develop their seemingly cold adapted body morphology during their expansion across the Pacific Ocean, and if the development of such a body morphology takes many thousands of years in an extremely cold climate, then at some point before their arrival in Near Oceania, the ancestral origins of the Polynesian people may have been in the high latitudes in a seasonally cold environment. Modern research in genetics, linguistics and archaeology has demonstrated an Asian origin for Polynesian populations, with the consensus pointing towards an origin in the vicinity of Taiwan around 5,000 years ago. To date little research has looked at the origins of Polynesian populations prior to this period.

Taiwan has only been occupied by human populations for not much more than 5,000 years; before this period of time the Pacific North East Asia was the centre of the emergence of agriculture and complex social organization. This region has been occupied by human populations for more than 30,000 years, much of that time during the last ice age. This would have been an extremely cold environment. This is possibly the environment from which the ancestors of modern Polynesian populations derive their ancestry, and their cold adapted body morphology.

The present study looks at the research on the evolution of varying human body morphologies, as a response to diverse climates, and examines the dispersal of modern human populations into Asia in the Late Pleistocene. Polynesian origins are explored, including a review of the available genetic, linguistic and archaeological evidence. Human adaptations to cold environments are considered, including cold induced vasodilation response.

The primary reaction of the human body during exposure to cold is the protection of core body temperature to preserve the functioning of vital organs, utilising heat conservation by way of vasoconstriction, which constricts the flow of blood to the body's extremities, in particular the limbs, fingers and toes, as well as other mechanisms such as shivering. Cold induced vasodilation (CIVD) response is a secondary response of the human body preventing, or slowing the loss of temperature in the extremities. A brief flow of warm blood to the extremities, in particular fingers, helps to maintain manual dexterity, assisting survival in extreme cold. Research has identified differences in CIVD response between populations with varying biogeographical ancestry, suggesting that the response is genetic in origin.

If this is the case then CIVD response may be helpful in identifying those populations with ancestry in a seasonally very cold climate. In conjunction with other research associated with population origins, including archaeology, genetics and linguistics, this may help the search for the likely ancestral origins of such a population, in this case Polynesians.

1.2. Aims of this Research

The main part of this thesis is the study of CIVD response, and in particular variation between human populations from different ancestral environments. The purpose was to verify the genetic basis of CIVD response, and its use in examining the hypothesis that Polynesians are a cold adapted population, with their origins in Northeast Asia many thousands of years ago. In addition there is a brief review of research on the relationship between cold adapted populations and high rates of obesity and diabetes. Polynesians have some of the highest rates of obesity and diabetes in the world. Some research indicates a possible relationship between cold adapted populations and these chronic health problems.

Participants were obtained from a total of six population groups; European, African, Indian, Asian, Melanesian and Polynesian sample groups were tested for their CIVD response. In addition a number of anthropometric measurements were obtained from each participant, and the data analysed.

A CIVD response testing programme was undertaken over a wide sample of the general Auckland population, in particular individuals with ancestry from Polynesian, European, Indian, Asian, African and Melanesian regions. Participant's ethnicity was qualified by determining their recent genealogy back three generations. Basic anthropometric measurements were also taken from subjects including biiliac breadth, biacromial width, height, weight, triceps skinfold and skin pigmentation.

Past studies of CIVD response have had small sample sizes, with a limited number of populations of varying ancestry. The present study has 286 participants in total and adopted a research methodology in line with studies completed overseas so that results were comparable.

CIVD response was measured by testing whether participants show evidence of resistance to hand cooling when exposed to 5° C water for 30 minutes. Resistance was assessed in terms of changes in finger surface temperature over time. A CIVD response is defined as an increase of at least 1°C or more during exposure to cold (Little et al. 1971, Hurlich and Steegmann 1972; So 1975). On exposure to cold, blood vessels in the fingertips initially constrict to prevent heat loss. A number of different studies have shown that populations, whose ancestors occupied at least seasonally cold climates, often respond to moderate cold stress through variable amounts of rewarming of the fingertips after five to 10 minutes of exposure to cold. This rewarming response results from small blood vessels in the fingers expanding periodically, increasing the peripheral blood flow.

Auckland is an ideal location for this research as the city contains many individuals with varying ethnicity including Polynesian and European ancestry, and its temperate climate should ensure that none of these individuals have any acclimatization to a cold environment. Therefore any measurable resistance to cold observed is more likely to be the result of an inherited genetic trait.

There are a number of important factors which make this research significant. These include:

- the large number of participants tested
- the wide range of different ethnic groups represented by the participants
- the large number of body morphology and CIVD response variables measured
- the detailed comparisons between body shape, body size and CIVD response variables for all participants, and among the different ethnic groups
- the analysis of these variables in conjunction with the likely ancestral environments of the different populations
- the identification of those variables which are the best indicators of a seasonally cold ancestral climate for modern human populations
- the analysis of these variables for Polynesians in conjunction with previous research on Polynesians origins, including archaeological, genetic and linguistic studies.

No study to date has yet tried to use CIVD response to identify the likely ancestral origins of a particular population. This present study represents the first attempt to utilise CIVD response testing for this purpose.

Whilst using the testing of cold resistance to track the geographical origins of Polynesians back possibly 20,000 years may seem innovative, the question must be asked what else is available to look this far back in the past for Polynesians? Many articles have been published on the genetic origins of Polynesians and the results are contradictory, in particular with regard to the level of genetic admixture with indigenous Melanesian populations, and none of the research has identified the likely origins of Polynesians back more than a few thousand years (Oppenheimer 2004, Hill et al. 2007). This present study may help understand the unique body morphology of Polynesians, the possible origins of that body morphology, and the particular issues that this morphology may contribute to their current health problems.

1.3. Hypotheses

Following on from the broad range of the topics to be covered as outlined above, a series of hypotheses have been developed for testing as part of this dissertation. These hypotheses are as follows:

Hypothesis 1

There will be no difference in body size between populations of different ancestral environments.

Hypothesis 2

There will be no difference in body shape between populations of different ancestral environments.

Hypothesis 3

There will be no difference in CIVD response between populations of different ancestral environments.

It is expected in the light of previous studies that significant differences in body size, body shape and CIVD response will be identified among the different ethnic groupings of participants that represent populations from different ancestral environments. The likely climate from these ancestral environments will be identified as to whether they were seasonally cold or tropical. Further analysis of differences among the ethnic groups for the different variables should reveal which groups differ significantly from the others, for each variable.

From this analysis the variables most likely indicating the physical characteristics of a population from a seasonally cold climate should be identifiable. The physical characteristics of Polynesians populations can be compared to see whether they are similar to those of the cold adapted populations to determine whether the characteristics of Polynesian represent an adaptation to a seasonally cold climate. If that is the case then populations ancestral to Polynesians may have originated from a seasonally cold climate.

If the indication is that Polynesians are more similar in their physical characteristics for body size, body shape and CIVD response to populations from a seasonally cold climate than those populations from a tropical climate, then the hypothesis that Polynesians are a cold adapted population will be more likely.

If this is the case then it is my hypothesis that the genetic, linguistic and archaeological evidence indicates an ancestral geographic location for Proto-Polynesians in the region of Northeast Asia. This differs from Houghton's hypothesis, which regards Polynesians as a cold adapted population, but places the origin of these cold adaptations in the Pacific maritime region. This issue will be addressed in a later section.

1.4. Thesis Structure

Chapter one provides a brief introduction to the present study.

Chapter two examines the evidence for the argument that climate is the major regulatory factor for human variation in body morphology, and that this is a result of the evolutionary process of natural selection over many thousands of years for any particular human population. This is largely based around Bergmann's and Allen's rules. This is crucial for this present study as one of the basic assumptions behind the research premise is that body morphology represents adaptations to ancestral environment. Identifying those body morphological variables which best represent the physical characteristics of a cold adapted population is an important part of determining whether Polynesians do represent a cold adapted population.

Chapter three looks at the arguments to date on the likely origins of modern Polynesian populations. This is divided into sections which review the archaeological, genetic and linguistics research. If Polynesians are a cold adapted population then by using the existing research on the likely origins for their ancestors, this narrows down the possible regions with a suitably cold climate that these ancestral populations may have inhabited many thousands of years ago prior to their migration into the Pacific.

Chapter four reviews the evidence supporting the concept that CIVD response is an inherited characteristic representing an adaptation to a cold environment. If this is the case then this provides the basis for the use of CIVD response as a means by which a population from a seasonally cold ancestral climate can be identified. Again this is a basic assumption behind the research premise.

Chapter five outlines the methodology used in the measurement and analysis of the many morphological and CIVD response variables, and the selection and categorisation of the participants.

Chapter six covers the detailed analysis of these variables. This is divided into three major sections, one each for body size, body shape and CIVD response. The results for the participant group as a whole, as well as for each different ethnic group are analysed as well as the relationship between the different variables.

Chapter seven provides the discussion on the results in conjunction with the identification of likely ancestral environment for each ethnic group. This chapter is structured around the three basic research questions addressed by this present research.

1. To what extent does body morphology, specifically body size and body shape represent adaptations to ancestral climate? Although past research indicates a strong relationship, modern lifestyles have affected the physical expression of this relationship in different ways for body shape and body size.

2. To what extent does CIVD response represent an adaptation to an ancestral climate? To what extent does this present study support past research in this area?

3. What are the origins of Polynesian body morphology? Does this body morphology represent an adaptation to a seasonally cold climate, and if so where and when did this likely develop? This question brings together the results of the first two questions specifically for the Polynesian population, and reviews the result in the light of existing research on Polynesian origins.

Following on from the results of this present study, a new hypothesis is proposed for the origins of Polynesian body morphology.

Chapter 2. Human Body Morphology

All humans exhibit physical differences between each other. These variations can be large or small, but within each part of the world there are recognizable physical traits particular to human populations that have lived in those geographical areas for thousands of years. Despite the relatively small genetic differences between these different human populations (Crawford, 2007, p. 24; Lahr & Foley, 1998), these physical traits are distinctive, and for many years formed the basis of racial classification of different human populations (Madrigal & Barbujani, 2007, pp. 20-32). Racial classifications are no longer appropriate in a scientific context. There are no clear biological boundaries between geographically different human populations, indeed individual variation is generally more diverse within human populations than between such populations (Jobling, Hurles, & Tyler-Smith, 2004, p. 277).

Rather than rely on outdated racial concepts, this study is concerned with quantifiable biological variation between human populations whose ancestry lies in different geographical parts of the world. These groups will be described as human populations, or ethnic groups with varying biogeographic ancestry. Although ethnic groups can have additional meaning in terms of various social and political applications (Molnar, 2002, p. 33), the term provides a convenient, and easily understood classification of the human populations to be the subject of this study. A full description of the ethnic groups that participated in this research can be found in section 5.1.

Body morphology, body shape, phenotype or physique, these all represent a combination of the physical expression of the genotype and the developmental factors associated with the environment inhabited. How these factors interact to produce the varying body morphology found in different populations throughout the world forms the basis of this chapter.

2.1. Human Variation

The biological basis for human variation is based on our understanding of the principles of, firstly inheritance and secondly natural selection. These principles form the basis of the modern synthesis, a comprehensive theory of evolution that combines Darwinian theory and the science of genetics (Campbell & Reece, 2005, p. 455). Darwinian theory is based on four tenets (Huss-Ashmore, 2000, p. 4):

1) A population will tend to produce more offspring than can survive.

2) Individuals within a population vary.

3) Some of this variation is inherited.

4) Those individuals best suited to their environment will be more likely to reproduce successfully, passing their genetic material on to the next generation.

Therefore over time, through natural selection, heritable traits that enhance survival will increase in proportion in the population, making that population better adapted to their environment. Modern genetics provided a scientific explanation of how this variation is inherited, and population genetics gave rise to the study of how populations change genetically over time.

This genetic variation differs between individuals, each one having a unique genotype, with the possible exception of monozygotic twins. This can be reflected in phenotypic variation between individuals which are seen as physical traits. Not all phenotypic variation is inherited, it is the product of the interaction between genotype and many environmental and cultural influences experienced throughout the lifetime of the individual from conception to death (Campbell & Reece, 2005, p. 462; Terwilliger & Lee, 2007, p. 40). Only those phenotypical traits which are genetic in origin can be passed on to their offspring.

The role of the environment in understanding human adaptation is important. A characteristic of humans is their ability to adapt to new environments enabling humans to occupy much of our planet, covering diverse and at times extreme habitats (Huss-Ashmore, 2000, p. 13). Some environmental stressors that can affect phenotype are heat, cold, altitude, disease and malnutrition; research in human adaptability has focussed on how these stressors impair our ability to function in different environments and the biological response to counter this impairment. Human populations sometimes have differing responses to the same environmental stressors, and even where populations have the same adaptations, their effectiveness may vary (Frisancho, 1993, p. 8).

Adaptive responses may be classified as genetic, physiological, developmental, or behavioural (Moran, 2008, p. 6). It is important to distinguish between adaptations that are inherited and those that are developmental. Functional adaptations are beneficial adjustments made by humans to their environment that can be temporary or permanent, resulting from short-term or lifetime processes. They may create physiological, structural, behavioural, or cultural changes that improve human ability to function in their environment (Frisancho, 1993, p. 4). These are developmental adaptations that occur by way of acclimatization and habituation due to the plasticity of the human body, and its ability to change or mould itself to environmental circumstances (Campbell & Reece, 2005, p. 712; Moran, 2008, p. 6). Changes in phenotype during lifetime may not necessarily improve an individual’s functioning or survival, and a developmental response to the environment is only adaptive if it does improve functional performance (Schell, 1995).

These developmental responses are different from inherited adaptations that form the basis for natural selection, and are unable to be passed on to offspring. Genetically inherited phenotypic traits can be beneficial or otherwise and again are only adaptive if they provide a survival or reproductive advantage. It can be argued that it is difficult to show that these beneficial phenotypic traits have arisen by adaptation rather than by chance (Huss-Ashmore, 2000, p. 14). It may be expected that genetic change is the least likely response to a change in environmental conditions, for two reasons: 1) genetic change has a long time frame, so is of less value in response to a rapidly changing environment; and 2) genetic change has a high population cost in that it requires the death, or reduced reproduction rates of less well adapted individuals. Therefore it is more likely that genetic adaptations will arise where a developmental response is unable to deal with the changed environmental stressors, such as where they occur over a long period of time, or where there is no effective developmental response (Huss-Ashmore, 2000, p. 16).

Biogeography is concerned with the distribution of plants and animals around the different regions of the world. Patterns can be identified in different human populations, or ethnic groups, and there are clear phenotypic differences between geographically diverse human populations. To decide whether people are members of the same population group, there are a several non-biological factors that can be taken into consideration (Jobling et al., 2004, p. 276).

- Geographical proximity
- A common language
- Shared ethnicity, culture, religion

Grouping different human populations biogeographically enables researchers to compare the variation in phenotypic traits exhibited between these groups, and consider the impact of different environments and the types of biological responses that each population has developed in response to the particular stressors found in that environment.

2.2. Factors Regulating Body Morphology

Climate is regarded as the major regulatory factor for body shape (Damon, 1977, p. 221; Ruff, 1993). The relationship between human body size and shape and climate has been established through research dating back to the 19th century when ecogeographical patterns noted by Carl Bergmann, a German physiologist, were defined as a rule. Bergmann made three major observations (F. C. James, 1970):

1. Warm blooded animals help sustain a constant temperature by maintaining a balance between the internal production of heat and the loss of heat through its surface.
2. The ratio of body surface area to body mass is one of the limiting factors that govern body size.
3. When other factors are constant, the larger species in a genus will occur in a cooler climate.

Bergmann's rule was subsequently revised by Rensch (1938) who reduced the definition to within species variation rather than the interspecific variation between closely related species identified by Bergmann (Blackburn, Gaston, & Loder, 1999; Mayr, 1956). Within a morphologically variable species of geographically dispersed warm-blooded animals, those with cold habitats in higher latitudes will tend to have a larger body mass than do their conspecifics at lower, warmer latitudes.

Related to Bergmann's rule is Allen's rule, put forward in 1877 by Joel Allen, an American zoologist (J. A. Allen, 1877). Allen observed that endotherms from cooler climates often exhibit shorter extremities than their conspecifics at lower latitudes. This works in a similar way to Bergmann's rule in that longer limbs have a greater surface area relative to mass than shorter ones. The difference is that Bergmann's rule relates only to changes in the ratio of surface area to mass, whilst maintaining geometric similarity, whereas Allen's rule introduces the concept of a change in shape relative to climate (Holliday, 1997a).

Natural selection acts on populations to minimize the surface area/mass ratio to conserve heat in colder regions, because heat loss in any animal is directly proportional to their surface area (Ruff, 1991). A larger mass and shorter extremities help maintain thermoequilibrium in the body's core temperature in a cold environment. Conversely in the tropical regions of the lower latitudes, efficiency in heat dispersal is the important adaptive factor and a leaner body shape provides more surface area in relation to body mass to radiate excessive heat. Around

70% of metabolic heat is lost through radiation, therefore the surface area/mass ratio is a major factor in the retention or dissipation of heat (Molnar, 2002, p. 199).

Ruff (1991) calls this the cylindrical thermoregulatory model. The closest geometric model for the human body shape is that of a cylinder. Within a cylindrical shape, in order to maintain a constant surface area/mass ratio over differing heights, breadth must remain constant (see Figure 1 below). Conversely, if you want to vary the surface area/mass ratio, you must change absolute breadth. This model predicts that within a particular environment changes in height should have little or no effect on variation in breadth. With environments of different temperatures, absolute breadth should vary to change the surface area/mass ratio, with a wider breadth in colder regions and narrower in warmer regions. This has been clearly demonstrated to be true for heat dissipation, and is assumed to be true for cold loss.

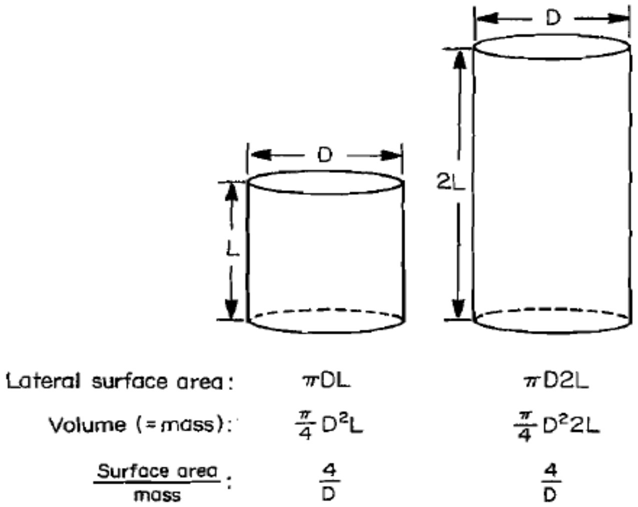


Figure 1. The cylindrical thermoregulatory model for the human body. (Ruff, 1991).

Mammals must sustain their body temperature within a narrow range, and this temperature is largely maintained by metabolic heat production, which is itself proportionate to body weight. A larger body will produce more heat both at rest and during exertion (Molnar, 2002, p. 199). Small adjustments to the metabolic rate will maintain a normal body temperature however, if the ambient temperature falls too low, or goes too high, changes in the metabolic rate cannot compensate for this. Selection acts on the extremes of environmental stressors when a population are engaged in activities that represent the greatest danger of injury. Therefore genetic adaptations conforming to Bergmann’s and Allen’s rules are more likely to occur in habitats with extreme environmental conditions. Examples of the application of

Bergmann's and Allen's rules can be found in many mammalian and avian species, as well as groups of related species that vary in their body proportions across a geographical range (Ashton & Tracy, 2000; Blackburn et al., 1999; F. C. James, 1970). Studies have shown over 72% of birds and 65% of mammals conform to Bergmann's rule (Meiri & Dayan, 2003).

Despite the considerable body of supporting evidence, the validity of these rules has been questioned. Such factors as availability of food resources, insulative fur, feathers and physiological adaptations can be seen as more important than surface area/mass ratios (Geist, 1987; Huston & Wolverton, 2011; Irving, 1957; McNab, 1971, 2010; Scholander, 1955, 1956). Cultural adaptations also alleviate the conditions of environmental stressors (Frisancho, 1993, p. 6). For example an Inuit igloo represents a micro-climate much less severe than the external environment (Ruff, 1991; Wilber, 1957).

This fails to take into account two important factors; these cultural adaptations would take some time to develop, and during this period physical adaptation to the extremes of cold would play a more significant role. The micro-climate found in the igloo still depends on generating body heat, which is assisted by a cold adapted body, and relies on a plentiful supply of calories, which must be obtained from the cold external environment (M. T. Newman, 1956). The caloric intake in a cold environment is considerably higher than that required in a tropical environment, and the supply of these quantities of calories has been the principal survival factor in traditional Inuit life, thus requiring a considerable period of time spent hunting for food in the cold (Webster, 1952; Weyer, 1969, pp. 6; 56-57; 116-117).

There is evidence for genetic control over human body shape, particularly brachial and crural indices, as these elements appear early in fetal development (Warren, 1998). Differences in brachial and crural indices have been related to ancestral climate (Holliday, 1999; Holliday & Ruff, 2001; Ruff, 1994), although not all studies concur with this analysis (Porter, 1999). Parental height is another predictor for stature, especially mid-parent height, which suggests a role for genetic influences in stature (Bogin et al., 2001, p. 205). Twin studies have also indicated a strong genetic heritability for stature (Silventoinen et al., 2003). One study on the heritability of stature, weight, head and chest circumference in Central Asians indicated a strong genetic component substantially influencing differences between individuals (Livshits, Roset, Yakovenko, Trofimov, & Kobyliansky, 2002).

It has been suggested that only smaller mammals conform to Bergmann's rule, although in general larger bodied species tend to live in higher latitudes than their smaller relatives (Blackburn et al., 1999; McNab, 1971; Steudel, Porter, & Sher, 1994). However, such criticism does not negate the validity of the rules, as this validity is not based on theoretical interpretation but on observed empirical evidence, which is considerable (Ashton & Tracy, 2000; Holliday, 1997a; Meiri, 2011). Experimental assessment of Allen's rule confirms the ability of short limbs to reduce the metabolic cost of retaining body temperature, while longer limbs provide greater heat dissipation (Tilkens, Wall-Scheffler, Weaver, & Steudel-Numbers, 2007).

Recent genomic studies are beginning to investigate the underlying genetic patterns behind human adaptation to climatic variation (Hancock et al., 2011; Hancock et al., 2008). Strong association with climate is found in allele frequencies associated with pigmentation, cancer, infection and autoimmune diseases. However, it is argued that there are few fixed or nearly fixed differences between human populations, and of those that occur, most are found in East Asia (Coop et al., 2009). This may suggest that the selection process is secondary to the stronger influence of population migration, drift and history.

Whilst the underlying mechanism(s) behind Bergmann's and Allen's rules may be debated, the ecogeographical pattern is clearly established (Blackburn et al., 1999; Meiri, 2011; Meiri & Dayan, 2003). If these patterns are genetic in origin, it may be expected that we can see evidence of these evolutionary trends developing over time.

2.3. Evolutionary Trends in Hominid Body Shape

Many early hominids (*Australopithecines, H. habilis*) had body proportions considerably different from modern humans (Ruff, 2002). Upper limbs were disproportionately large compared to lower limbs, and body mass large relative to stature, possibly reflecting retained arboreal characteristics and the allometric impact of a smaller body size (McHenry & Berger, 1998; Ruff, 1991). Within 1.5 million years, with the advent of *H. erectus*, body proportions were well within the range of variation found in modern human populations (Ruff & Walker, 1993, p. 235). From this point in time hominids were fully terrestrial, therefore any changes in body shape are more likely to reflect adaptations to other variables such as climate (Ruff, 2002). Although a lack of post-cranial skeletal remains are an issue, there is sufficient evidence to draw some conclusions (Ruff, 1993).

Sexual dimorphism is a factor in hominid populations, but has been of decreasing significance since early *Homo* (Ruff, 2002). Sexual dimorphism in body mass between males and females in living human populations is around 15% (Armelagos & Van Gerven, 1980;

Brace & Ryan, 1980; McHenry & Coffing, 2000), and does not appear to be affected by latitude, either for Upper Palaeolithic populations, or modern human populations (Ruff, 2002). Thus, although average body mass is under the influence of climatic differences, sexual dimorphism in body mass is likely more a consequence of other environmental and behavioural factors.

Fossil evidence suggests that both early *H. erectus* (Ruff & Walker, 1993, pp. 241-243) and early modern African (Stringer, 1989, pp. 86-87) morphology show a tropical adaptation. The discovery of a near fully complete juvenile male skeleton in West Turkana, Kenya (KNM-WT 15000) dated to about 1.5 million years ago gives a clear indication of body shape in early H. erectus (Ruff, 1993). KNM-WT 15000 exhibits limb and body proportions that fall within the range of modern tropical populations, as illustrated in Table 1 below.

Table 1. Biiliac breadths and stature estimates for KNM-WT 15000 and two modern human comparative samples. Adapted from Ruff (1991).

Sample	Biiliac Breadth (cm)	Stature (cm)	Biiliac/stature
KMN-WT 15000	23	160	0.144
(Est. adult)	(26.6)	(185)	(0.144)
Modern African	23.1-26.3	137-175	0.148-0.174
Modern European	27.4-29.8	156-176	0.160-0.188

Early African *H. erectus* shows a significant increase in body size compared with other earlier hominids but with little or no increase in body breadth (Henry, 1992; McHenry, 1994; Ruff & Walker, 1993, pp. 239-243). This effectively maintains the surface area to mass ratio resulting in a more linear body shape similar to that found in modern tropical populations. *H. erectus* spread out of Africa no later than 1.6 million years ago, which would have been the first time hominids were exposed to a colder environment. While there is no evidence for hominids in an extremely cold climate, Northern China at 40°N providing the highest latitude for evidence of *H. erectus* to date, this would have exposed these hominids to a seasonally cold environment by at least 780,000 years ago (Ciochon & Bettis III, 2009; Shen, Gao, Gao, & Granger, 2009; Zhu et al., 2004).

Following increases in average body size, firstly about 2 million years ago, with the appearance of *H. erectus*, and secondly about 500,000 years ago, about the time *Homo* remains appear in higher latitudes, there is a decline in average body size around 50,000 years ago, including among higher latitude populations (Holliday, 1997a; Ruff, 2002). There are a number of reasons put forward for this decline in average body size, including technological improvements that reduce the selective advantage of a larger body mass (which are nutritionally more expensive), reduced nutritional values, reduced gene flow, or a changing environment (Ruff, 2002).

The earliest evidence of hominids in a very cold environment is archaic *Homo (heidelbergensis, rhodesiensis, antecessor, neanderthalensis),* who began to occupy Northern Europe as high as 55°N from around 700kya (Hublin, 2009). In this region we also find the first evidence of cold-adapted body proportions similar to those found in modern populations (Trinkaus, 1989, pp. 61-63). In particular Neandertals, of whom there is a large collection of fossil skeletal material available, exhibit a number of cold-adapted features including an increase in body mass, a wide body breadth, and short limbs dating back as early as 500,000 BP (Churchill, 1998; Holliday, 1997a; Ruff, 2002; Trinkaus, 1981, pp. 187-224; Weaver, 2009). Comparison of Neandertal body shape variables with a number of modern populations saw them most similar to Koniag 'Eskimo' (Holliday, 1997b). Early *Homo* displays variation in body shape consistent with latitudinal variations in climate, with cold adapted populations exhibiting shorter limb length, and broader biiliac breadth, with a clear difference between tropical and high latitude populations for both modern and early *Homo* (Ruff, 2002).

H. sapiens body proportions in Late Pleistocene Europe are consistent with a population dispersal from Africa followed by a subsequent adaptation to a colder climatic conditions (Holliday, 1997a). In particular, early European *H. sapiens* exhibit body proportions that are more linear, similar to tropical populations, including longer limb length, despite their glacial environment (Holliday, 1997a, 1999; Ruff, 2002). Over time body proportions of European populations change, becoming less linear, and moving towards the current cold-adapted modern body form by 20,000 years ago (Holliday, 1997a, 1999; Ruff, 2002). It is possible there are a number of factors influencing the pattern of changes in European body shape; however, the best explanation may reflect significant gene flow between Europe and Africa, and possible population replacement as populations continue to move northward from Africa and Asia into Europe, which would tend towards the maintenance of a more tropical linear European body form (Holliday, 1997a; Ruff, 2002; Trinkaus, 1981, pp. 215-218).

An extensive (2,749 skeletons) study of body morphologies in relation to latitudinal clines in the Americas on pre-contact skeletal material shows conformity with Bergmann's and

Allen's rules, including body mass, brachial and crural indices, body width, and sitting height ratio (Auerbach, 2007). This is particularly significant when the extreme morphologies found in the north are compared with those found in the equatorial latitudes. Variation in the mid-latitudes is less established, suggesting it is only exposure to extremes of climate that can effect significant morphological change. This is over a time period of around 10-15,000 years following the movement of human populations into the Americas and the subsequent occupation of most parts of that region (Auerbach, 2007; R. Hall, Roy, & Boling, 2004).

The evidence demonstrates that early *Homo* showed obvious body morphological adaptation to latitudinal variations in climate, from the hypermorphic cold adaptations of the Neandertals, to the tropical African linear build of *H. erectus*, with much variation in between. As *H. sapiens* moved out of Africa, into Europe, and subsequently into the Americas, body morphological changes in lines with Bergmann's and Allen's rules can be seen developing over thousands of years. In Europe the tropical build of the populations moving north from Africa gave way to the European cold adapted body form, while in the Americas the converse was true; the cold adapted migrants from Northeast Asia developed tropical adaptations as they moved into the tropics of Central America. These adaptations, although thousands of years old, and despite cultural buffering against climatic extremes, are still reflected in modern human populations.

2.4. Modern Human Morphological Variation

Variation in many physical characteristics can be observed in modern human populations. These differences occur between individuals within populations and can also be quantified as statistical differences between populations (Stinson, 2000, p. 426). To the extent that mean body shapes and sizes of regionally grouped populations, in particular trunk size and shape, and limb length, are directly related to ancestral climatic environments, this implies a genetic rather than developmental origin.

A review of 149 separate indigenous population studies from 10 regions of the world, ranging from Inuit to African found an inverse relationship between weight and mean annual temperature (Roberts, 1953). Even after controlling for stature, given there was a correlation between stature and weight as expected, a strong correlation still existed between weight and temperature, the mean weight of a group being strongly influenced by the temperature of its environment, with stature merely providing additional variation. For a given stature, a lower weight in a higher temperature environment gave a higher surface area to mass ratio, advantageous for body cooling, suggesting the applicability of Bergmann's rule.

The effect of nutrition was considered, and while not discounted, it was not considered to adequately explain the results (Roberts, 1953). The lowest weights did not appear in the areas of greatest population pressure, nor did the highest appear in the areas of better living conditions. For example the highest weights, after allowing for temperature and stature were Polynesian and Central Asian rather than America or Europe. Poor nutrition should have the greatest influence during early developmental period, affecting stature, but elimination of the stature factor did not significantly reduce the correlation between weight and temperature. All of these studies were undertaken in the first half of the 20th Century, and many prior to World War II. This was before the secular trend of increasing body weight in developed, and some developing nations, a trend attributed to the modern Western diet with higher levels of fat and sugar.

Roberts updated his work on the relationship between climate and human morphology in 1978, (Roberts, 1978). Basal metabolic rate, body weight, and body shape were all found to be positively correlated to mean annual temperature, and again, even after allowing for stature, body weight showed a significant correlation with temperature (Roberts, 1978, pp. 12-19). As above, much of this research was conducted before the significant rise in body weights that has arisen as a consequence of the change in diets towards modern western high calorie food. Nutrition would still have been a factor with regard to European diets compared to third world diets, but as in the previous study (Roberts, 1953), the lowest weights were not always in the areas of highest population pressure, nor are the highest weights all found in the areas with the highest living standards (Roberts, 1978, pp. 18-19).

When sitting height ratios were evaluated, again a strong relationship between body morphology and mean annual temperature was found, with lower relative sitting heights corresponding with higher temperatures, suggesting a more linear body shape in tropical populations with longer limbs and shorter trunks (Roberts, 1978, pp. 19-24). One exception was for Europeans, showing little distribution pattern, although at medium to high values (Roberts, 1978, p. 20).

Body weight and body shape correlations with temperature were considered to be examples of Bergmann’s and Allen’s rules reflecting surface area/weight ratios providing efficiency of body heat loss in tropical climates for lighter, more linear body shapes, and body heat retention for heavier more compact body shapes (Roberts, 1978, pp. 29-35). Roberts (1978, p. 21) study also shows a high sitting height ratio for Polynesians. Roberts (1978, p. 21) concluded that body proportions are more closely related to temperature than body size. This conclusion is supported by a study of Native Americans based on data collected in the 1890's along the Pacific Coast, where sitting height ratios were found to correlate to Bergmann's and Allen's rules (R. L. Hall & Hall, 1995).

Another study found Asians had significantly shorter legs , and Africans longer legs, than other groups (Bogin & Rios, 2003), suggesting Asians had higher sitting height ratios. Europeans were intermediate in length, along with Pacific Islanders.

More recently Roberts work was re-evaluated by Katzmarzyk and Leonard (1998), reviewing 418 studies covering populations in eight regions that have been published since 1953. The study found similar relationships between body size and mean annual temperature, consistent with those found by Roberts (1953). They concur that humans appear to conform to Bergmann's and Allen's rules with comparable climatic variation in body proportions as found by Roberts. However, the strength of the relationships had declined, with weaker correlations and more modest regression slopes, particularly among tropical populations, which they attribute to modern trends in increasing body mass. This may reflect the impact of acculturation and changed lifestyles, including improved nutrition and healthcare in the developing world tropical populations.

Studies in many countries show secular trends towards increases in height and weight during the last 150 years, see Table 2 below, with only a few isolated groups in New Guinea, Brazil and Mexico showing a lack of secular increase (Eveleth & Tanner, 1990, pp. 205-206). Studies of secular trends in Japan (Takahashi, 1986), Russia (Dubrova, Kurbatova, Kholod, & Prokhorovskaya, 1995; Vlastovsky, 1966), Canada (Shephard, 1991, p. 171) as well as Japanese migrants to Hawaii (Froehlich, 1970), and various Israeli migrations (Benoist, 1975), highlight increase in stature but generally no gain in biiliac breadth (Ruff, 1993). The offspring of migrants tend to retain the body proportions of their ancestral homeland (Benoist, 1975; Holliday, 1997a; Kaplan, 1954).

In many developed countries, this secular trend of continued increase in body size has slowed considerably in the latter part of the 20th Century (Eveleth & Tanner, 1990, p. 206; Stinson, 2000, p. 436), particularly in Northern Europe (Cole, 2003), which may suggest some form of genetic potential that determines an upper limit of adult stature and other anthropometric dimensions (Bogin, 1999, p. 333; Stinson, 2000, p. 437). It is likely that the recent positive secular trends observed are developmental in nature and related to nutritional and health improvements, given the timescale involved (Ruff, 2002; Stinson, 2000, p. 437).

Table 2. Estimated average heights (cm) of men who reached maturity between 1750 and 2000 in Europe (Fogel & Grotte, 2011).

Period beginning	Denmark	France	UK	Hungary	Norway	Sweden
1750	-	-	165.5	167.4	165.6	168.1
1775	165.7	163.0	168.6	166.6	165.5	166.7
1800	166.2	163.7	167.9	163.1	166.6	166.7
1825	166.7	164.3	171.2	163.5	167.4	167.3
1850	165.3	164.7	167.2	162.3	168.7	168.0
1875	167.8	165.4	168.0	163.8	169.6	169.5
1900	169.3	166.3	168.2	165.4	171.0	171.9
1925	171.5	168.0	170.0	168.4	173.8	173.9
1950	175.5	171.2	175.0	170.7	177.6	177.2
1975	183.2	174.7	176.6	-	179.5	179.2

Nutritional and disease differences have been put forward as an explanation for the biogeographic differences observed in body morphology (Bateson et al., 2004; Dettwyler, 1992; M. T. Newman, 1960; Stini, 1969). Body shape is less affected by nutritional stress or disease then body size (Eveleth & Tanner, 1990, p. 195; Holliday, 1997a; Ruff, 1993), although not all research supports this conclusion (Bogin et al., 2001, p. 216; Eveleth & Tanner, 1990, pp. 195-196). If nutritional and health concerns were the primary factors influencing body shape one would expect to see consistently smaller physiques in third world countries, but that is not the case (Ruff, 1993, 2002). Given a good environment for growth, the most significant differences between ethnic groups are those of body shape rather than size (Norgan, 1998, pp. 378-379).

Modern tropical populations such as Africans have consistently longer leg length relative to trunk length compared with higher latitude populations such as European and Asiatics, as well as longer arms, despite being more likely to be exposed to poor nutrition and healthcare (Eveleth & Tanner, 1990, p. 186; Ruff, 1993). The general relationship to Bergmann's and Allen's rules in Africa does vary given the extreme microclimates found in sub-Saharan Africa. Stature tends to be taller in dryer, hotter, areas, but relative weight tends to be higher in more moist and humid climates; increasing the body's surface to weight ratio by body mass reduction provides an adaptation to the evaporation of sweat in hot and humid air, leading to such examples as pygmy populations (Hiernaux & Froment, 1976; Hiernaux, Rudan, & Brambati, 1975).

Australian Aborigine populations, possibly the population that has had the second longest time frame inhabiting a tropical environment after Africans, show body morphology consistent with Bergmann's and Allen's rules (Gilligan & Bulbeck, 2007). Australian

Aborigines are characterized by the classic warm adaptive features of a linear build and extended distal limbs. Even morphological variation across the Australian continent reflects biological adaptation to climatic conditions.

Studies on Arctic circumpolar populations show broader trunks and greater weight for stature in these populations in comparison with nutritionally similar Lapp populations, indicating genetic control over these differences (Auger et al., 1980, p. 254). A comparison between Bering Strait Eskimo and US males showed the Eskimo were shorter, with higher sitting height ratios and upper arm musculature, and much shorter leg length. There were no significant differences in body weight or triceps skinfold thickness (Johnston, Ensroth, Laughlin, & Harper, 1982).

A study on anthropometric variation in Europe and the Mediterranean areas showed morphological correlation with climate, again consistent with Bergmann's and Allen's rules (Crognier, 1981). The most important correlates for post cranial conformity with ecogeographical rules were the climatic extremes of cold and moisture. A study of brachial and crural indices showed much lower indices for Lapp and Eskimo populations compared with African and central American populations (Trinkaus, 1981, p. 211).

Native American populations in the Americas, display the same ecogeographic variation in body morphology, with cold adapted body morphology found in populations in the northerly high latitudes when compared with those in the more tropical regions (Bogin & Rios, 2003; R. L. Jantz, Jantz, & Marr, 2007). One study found the most Northerly of the Native American populations to have the most cold adapted body morphology, with populations in Central America the least, and those of South America of an intermediate shape, corresponding to climatic gradients (Johnston & Schell, 1979, pp. 275-291).

Secular changes in body shape in a short time frame are possible, for example lower limb length is seen as disproportionately contributing to increases in stature (Bogin & Rios, 2003; L. M. Jantz & Jantz, 1999). This is confirmed in studies on Japanese populations, who have shown a significant increase in stature since 1950. Almost all of this increase has been in leg length, with no change to trunk length (Eveleth & Tanner, 1990, p. 112).

Human physical characteristics in modern populations, particularly body mass, or weight can vary significantly, even excluding gender differences and Pygmy populations (Ruff, 1994). Stature, or height, shows a smaller variation. However, the regional trends for weight or stature are not as significant as the relationship between biiliac breadth and latitude (Ruff, 1993, 2002). A comparison of the level of correlation between body weight, stature and latitude in Figure 2 below, highlights the contrast with the correlation between biiliac breadth and latitude as illustrated in Figure 3 below. Clearly the strongest relationship with latitude is biiliac breadth.

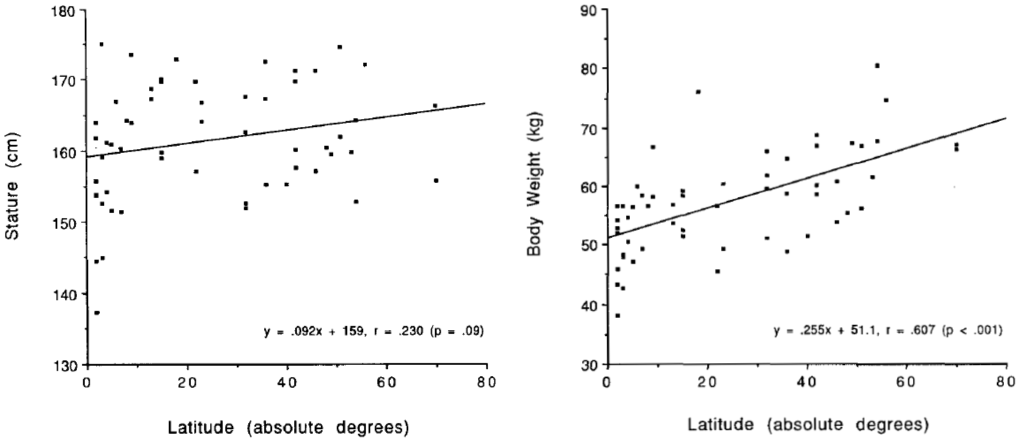


Figure 2. Changes in stature and body weight with latitude in modern populations (Ruff, 1994).

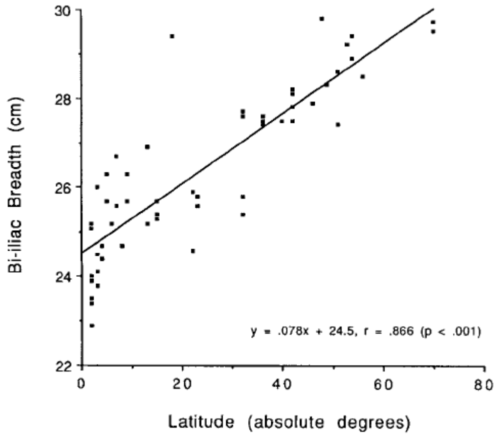


Figure 3. Change in biiliac breadth with latitude in living human populations (Ruff, 1994).

Changes in body mass and stature, whilst clearly variable, do not affect the body mass to surface area ratio, as long as biiliac breadth remains constant. As biiliac breadth is a morphological physical trait strongly correlated to latitude (Holliday, 1997a; Ruff, 1993, 1994, 2002), this may indicate the ratio of body mass to surface area is an important adaptive factor in temperature regulation. There is no gender bias in biiliac breadth for a given stature (Hiernaux, 1985, pp. 191-209).

Within each climatic population group, absolute biiliac breadth shows little variation, thus as populations become taller they become relatively more linear (Ruff, 1991). However, there are significant differences between each climatic grouping, with populations in colder climates having progressively wider biiliac breadths than those in warmer climates, irrespective of stature. Overall, this supports the predictions of the cylindrical thermoregulatory model as outlined by Ruff (1991). An example of how this is represented in the human body shape is illustrated in Figure 4 below where humans of tropical ancestry show a more linear body shape and longer peripheral limbs.

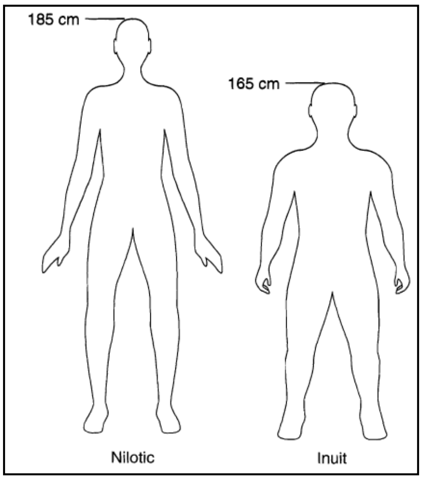


Figure 4. Body outlines in living human populations drawn to their natural scale (Molnar, 2002).

Although not directly related to body morphology, recent research on cranial morphology does provide an interesting insight into adaptation to climate in human populations. This study examined 7,432 males from 135 geographically diverse populations using 33 craniometric linear measurements (Hubbe, Hanihara, & Harvati, 2009). These measurements were correlated with annual temperature and rainfall for each region. The regions providing the majority of intergroup differentiation were the most northern regions, Northern Europe, Northeast Asia, and Extreme North America, all showing a correlation with climatic variables. Interestingly the measurements from Northern Europe were a distinct set from the other two northern regions. The results indicate a strong climatic signature on the morphological variation of human populations subjected to extreme cold conditions, but that the Northern European population had different adaptive pathways in adjusting to their environment (Hubbe et al., 2009).

Modern human morphological change, if related to climate, must reflect adaptations that have developed since the recent movement of human populations out of tropical Africa over the last 60-80,000 years to new and varying climates. To understand these morphological adaptations it is necessary to review these population movements.

2.5. Modern Human Dispersals

Africans have inhabited a tropical environment for as long as modern human populations have existed, and are the only human population that have not experienced any change in environment other than those that have occurred on the African continent. Although there have been many fluctuations in the African environment over the last 150,000 years, at no time has it been less than tropical. It is the differences between Africans and all other human populations that can indicate cold environmental adaptations in *H. sapiens*.

No discussion on the origins of anatomically modern humans can ignore the on-going debate over the two main hypotheses concerning the first emergence of *H. sapiens*. The ‘Out of Africa’ hypothesis places the ancestry of modern humans in sub-Saharan Africa sometime before 100 kya followed by a dispersal out of Africa after 60kya, either through the Levant, or through a southern route via the Horn of Africa into West Asia, displacing local populations of archaic *Homo* (Macaulay et al., 2005; Trinkaus, 2005). Alternatively, the ‘regional continuity’ or ‘multiregional evolution’ hypothesis argues modern humans did not have a single point of origin but evolved independently from local populations in Africa, Asia and possibly Eastern Europe (Aiello, 1993). In this model the emphasis is on gene flow between contemporaneous populations to ensure genetic continuity over time.

There are also a number of related theories that combine various aspects of these two hypotheses. It is not the intention to debate these two hypotheses here except to say that a recent dispersal of modern humans out of Africa is now widely accepted (Macaulay et al., 2005; Oppenheimer, 2009; Richards, Bandelt, Kivisild, & Oppenheimer, 2006, pp. 223-265; Stringer, 2002), and this thesis will proceed on the assumption the Out of Africa hypothesis is the most accurate interpretation to date of the available data.

Dating for the emergence of anatomically modern humans in Africa is based on both archaeological and genetic studies. Estimates from the study of several mtDNA polymorphisms show the first emergence of modern humans dating back to around 190 kya (Cavalli-Sforza & Feldman, 2003). This is supported by analysis of the earliest mtDNA lineages, L1 types, dating back to more than 130 kya, that are restricted to Africa and immediately adjacent Arabian and Mediterranean areas (Forster, 2004). The small number of mtDNA lineages, probably between one and eight distinct types, suggests the breeding female population size for the origins of *H. sapiens* was modest and located in south or east Africa. There was likely an early initial dispersal across Africa before 130 kya and a second major dispersal throughout Africa around 80-60 kya prior to the modern human migration out of Africa after 60 kya by a small population which gave rise to the two founder mtDNA haplogroups outside Africa, M and N (Forster, 2004).

This expansion out of Africa involved a population moving into Asia and from there to the other continents along two routes (Cavalli-Sforza & Feldman, 2003). The southern expansion route around the Indian Ocean reached Oceania between 50 and 40 kya. The second route was through the Middle East to Central Asia from where migration occurred in all directions reaching Eastern Europe and Northeast Asia by at least 40 kya.

The Levantine caves have been the subject of a number of studies regarding two sets of fossils, Neanderthal-like specimens from Tabun and more modern ones from Skhul and Qafzeh. Recent analysis indicates Neanderthal populations may have been present in the region from about 120 kya, but were definitely present after 80 kya , with anatomically modern fossils present between 130-80 kya and then re-emerging around 50 kya coinciding with the disappearance of Neanderthal fossils around 45 kya (Shea, 2003). The technology associated with the first occupation by modern humans and Neanderthals are similar, both reflecting Middle Palaeolithic assemblages. The re-emergence of modern humans after 50 kya is associated with more sophisticated Upper Palaeolithic technology. The early exodus out of Africa, evidenced by the remains at Skhul and Qafzeh around 130 kya in the Levant, has not left any descendants in the modern mtDNA pool (Forster, 2004).

Interpretation of this data suggests that there were two waves of dispersal of modern humans from Africa/Asia into the Levant, with the first wave unable to compete and replace Neanderthals, and who were eventually displaced between 80 and 50 kya during cooler climatic conditions (Shea, 2003). The second wave after 60 kya by modern humans, with Upper Palaeolithic/LSA assemblages, appears to have rapidly replaced Neanderthal populations and allowed further dispersal into Western Eurasia. If the Levant did not allow the early dispersal of modern humans into West Asia, the southern route is most likely the initial source of movement of modern humans out of Africa given the early dates for the occupation of Sahul by modern humans by 50-40 kya (Bowler et al., 2003).

Ice age conditions in the past 100,000 years have helped determine timing and routes for prehistoric humans settling the world (Forster, 2004). The successful exodus after 60 kya coincides with low sea levels at that time along the southern dispersal route around the borders of the Indian Ocean. This is supported by the archaeological evidence for the occupation of the coast of Eritrea and human exploitation of marine resources around 125 kya (Macaulay et al., 2005; Stringer, 2000). The second population could have moved north into more difficult climatic conditions in Eurasia and thence into Europe during an inter-glacial between 30-40 kya replacing Neanderthal populations, and finally into Northern Asia and America.

Studies of Y chromosome variation estimate the most recent common ancestor to have their origins in Africa somewhere around 40-140 kya (Underhill et al., 2000) or 150 kya (Hammer et al., 1998), with their dispersal out of Africa between 35-89 kya (Underhill et al., 2000). These studies correspond reasonably well with the mtDNA research outlined above. The hominid fossil record between about 800 and 150 kya remains unclear, with a number of different taxons being used to describe a range of hominids intermediate between *Homo erectus* and *Homo sapiens,* including *H. heidelbergensis, H. rhodesiensis, H. helmei* and archaic *H. sapiens*. A number of physical traits are attributed to these archaic specimens to distinguish them from *H. sapiens* including long low crania, large brow ridges, large prognathic faces with big teeth and lack of a chin, although they generally exhibit large brain sizes (McBrearty & Brooks, 2000).

What this shows is there appears to be a gradual evolution from *Homo erectus* to *Homo sapiens* with no clearly defined single evolutionary event, but with anatomically modern humans established in Africa by at least 130 kya, and possibly as early as 200 kya (Bräuer, Yokoyama, Falguères, & Mbua., 1997; Deacon, 1992; Grun et al., 1996; McDougall, Brown, & Fleagle, 2005). Debate remains over whether there was one exit or two for the dispersal of modern humans out of Africa, and whether the route(s) was(were) through the Levant or via the Horn of Africa probably across the Red Sea to Yemen (Oppenheimer, 2009). A possible scenario for the dispersal of modern humans is shown in Figure 5 below.

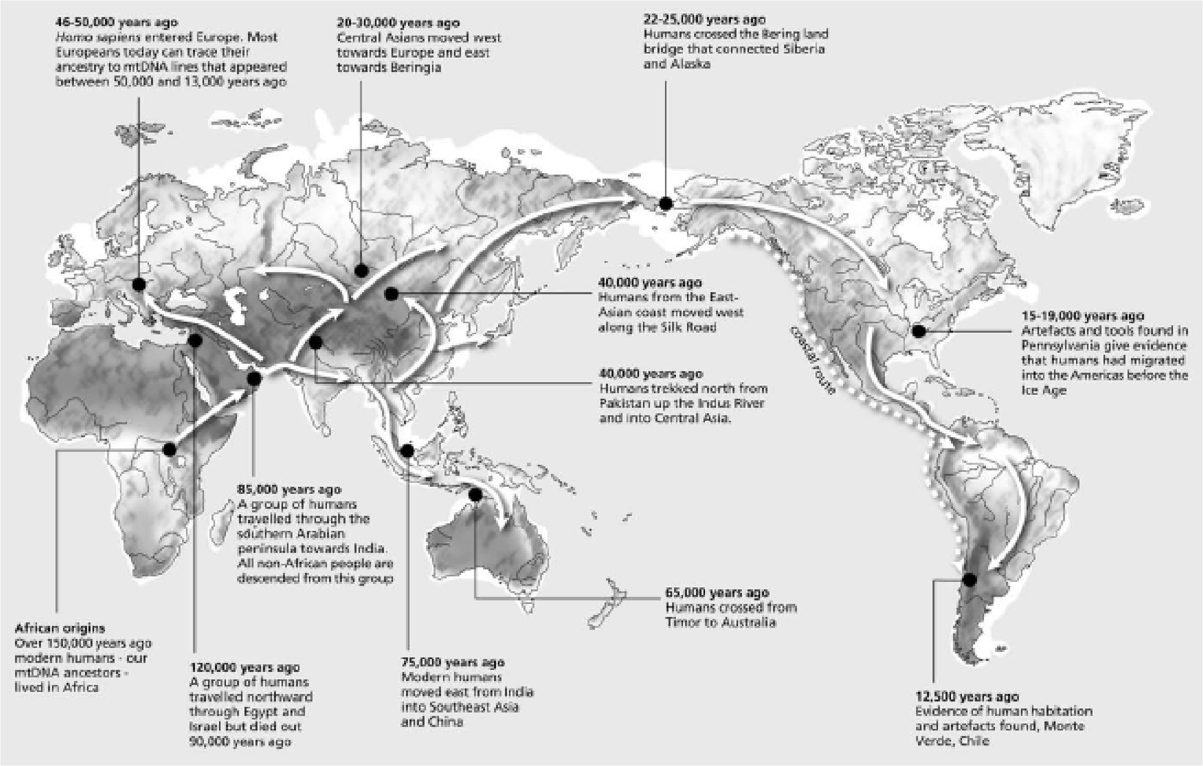


Figure 5. Outline map of possible modern human dispersals (Oppenheimer, 2009).

2.6. Time Scale for Modern Human Morphological Variations

It is important to understand the likely timescale within which these differences in body shape and size between populations in different latitudes may have evolved. It is likely that different morphological adaptations may vary in the timescale within which they develop. There may also be differences between the variability which is based on genetically influenced polymorphism as opposed to the variability which depends on genetically influenced plasticity (Hulse, 1960).

Body weight is responsive to environment. Individuals with European or Asian descent tend to weigh less if they have been raised in a tropical climate, and are often smaller in build and stature (Hulse, 1960). A study of 15,000 US servicemen showed a relationship between mean temperature of their birth areas and body weight, with those from the cooler north environment weighing more on average (R.W. Newman & Munro, 1955), however, body weight can be responsive to many factors; a study on Italian-Swiss living in California found they weighed on average over 7 kilograms more than their close relatives in Switzerland, and were significantly taller, a circumstance that cannot be related to climate (Hulse, 1964). There are many similar such studies showing the effect of dramatic growth in a single generation where a change of conditions conducive to growth has occurred (Boas, 1940), although these rates of growth tend to slow in subsequent generations (Froehlich, 1970; Stinson, 2000, p. 436). It is the extent of that plasticity, the limitations of the range within which such variation may occur, which differs between populations (Hulse, 1960).

As body proportions are less susceptible than body mass to fluctuations in environment, they may be expected to have been evolving over a longer time frame, since the first dispersal of modern humans from Africa into less tropical climates. One such example is American Indians, who represent a population that has inhabited America, via the Arctic, for around 15-20,000 years, and the equatorial areas of that region, probably around 15,000 years (Goebel, Waters, & O'Rourke, 2008; R. Hall et al., 2004; Oppenheimer, 2009).

Bergmann's and Allen's rules appear to apply to human adaptation in America (Auerbach, 2007; M. T. Newman, 1953). Native American populations in the north retain cold adapted body morphology. Populations in the central and south regions have a more tropical body form, although they share few common tropical adaptations with equatorial African populations, and they do retain some Arctic adaptations (Auerbach, 2007; Bogin & Rios, 2003; Brace, 1998; Coon, Garn, & Birdsell, 1950, pp. 41-48,137-138). On this basis it is likely that 15,000 years might be required to produce morphological adaptations to climate (Brace, 1998; Holliday, 1997a; Hulse, 1960; M. T. Newman, 1953).

Analysis of Early Upper Palaeolithic (30,000-20,000 BP) European skeletal material indicates body proportions more similar to sub-Saharan African populations, including limb proportions and higher brachial and crural indices usually associated with tropical adapted populations, despite occupying Europe during a glacial period (Holliday, 1997a, 1999; Lahr & Foley, 1998; Ruff, 1994; Trinkaus, 1981, pp. 187-224). This is in contrast to European populations before (*archaic Homo* and Neandertals) or after this period (Trinkaus, 1981, pp. 187-224).

Body proportions of Late Upper Palaeolithic European populations are more in line with the cold adapted modern European populations after 20,000 BP, with these body proportions showing a gradual change to this form between 30,000 BP to 20,000 BP (Holliday, 1997a, 1999). There is even a suggestion that these changes appear first in the much colder northern European Mesolithic populations, compared with populations in warmer Southern Europe (Holliday, 1999). This change in body proportions has been interpreted as a result of the migration of tropically adapted populations out of Africa and into Europe before 30,000 BP and a gradual adaptation to the glacial environment, providing evidence of at least a 10,000 year period for such adaptation (Holliday, 1997a, 1999; Stringer, 1984; Weaver & Steudel-Numbers, 2005).

Human populations show empirical evidence of three levels of body morphological adaptation to cold climates that has developed in populations living in seasonally extremely cold climates over thousands of years; a relatively longer and wider trunk, wider shoulders and hips, and relatively shorter distal limbs (R. Hall et al., 2004). There is some evidence that rates of evolutionary change are slower among mammals in colder climates at higher latitudes than warmer ones, which would support a longer time frame for the evolution of cold adaptations in populations moving from a tropical climate (Gillman, Keeling, Ross, & Wright, 2009).

There is, however, one modern human population that is a complete anomaly to those ecogeographic rules, living in a tropical region, but displaying cold adapted body morphology. The body morphology for this population, found in Polynesia, is covered in the next section.

2.7. Polynesian Body Morphology

Polynesian populations inhabit an area of the Pacific Ocean generally defined as that bordered by Tonga and Samoa in the west, Easter Island to the east, Hawaii to the north, and New Zealand to the south, as illustrated in the map shown in Figure 6 below. With the exception of New Zealand, and a few smaller islands such as Easter Island, most of the area inhabited by Polynesian lies firmly within the tropics, presenting a generally hot and humid environment.

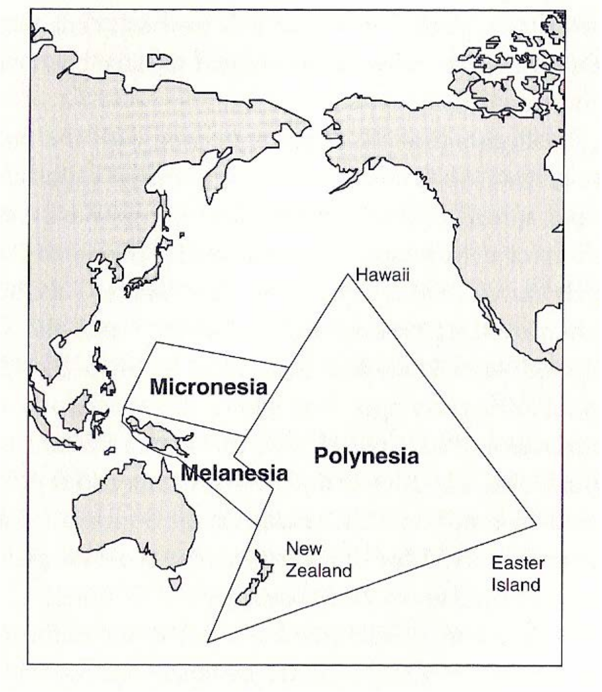


Figure 6. Map showing Polynesian, Melanesian and Micronesian boundaries.

Given the tropical nature of their environment, it may be expected that Polynesians have a body morphology characteristic of a warm adapted population, that of a smaller body mass in relation to surface area, and longer limbs and a shorter, narrower trunk. In fact the opposite is true. Polynesians are characterised by a large boned, relatively tall, wide and robust body morphology (Howells, 1979, p. 272). This body shape is characteristic of a cold adapted population, an anomaly that has been the subject of research and conjecture.

From the earliest European voyages of exploration in the Pacific, dating back to the 16th century, the written records from these explorers show the inhabitants of these islands were, by European standards, considered unusually tall and well built.

The Spanish were the first European explorers to visit the Pacific. Despite crossing the Pacific, Magellan did not view any people until reaching Guam, where he provides these comments from his circumnavigation of the world during 1519-1522.

These people are as tall as we, and well built. (Pigafetta & Skelton, 1994, pp. 60-61)

Magellan was followed by Quiros who, first as chief pilot, and then as commander, made three voyages into the Pacific between 1595 and 1607. He provides a little more description of the Polynesians he encountered.

(Marquesas) ...*well-formed, robust, good legs and feet...a strong and healthy race, and indeed robust.* (Queirós et al., 1904, p. 17)

(Tuamotus) ...*a very strong man, muscular and of good stature.* (Kelly & Martin, 1966, p. 164)

(Cook Islands) *The men were well-built and robust, of good height...* (Kelly & Martin, 1966, p. 172)

In 1642 Abel Tasman, a Dutch explorer, led a voyage into the Pacific, and had these comments on the physique of the Polynesians.

(Tonga) ...*somewhat more than ordinary height* ... (Sharp, 1968, p. 153)

... *the women are comparatively quite as sturdy of body and limbs as the men* ... (Sharp, 1968, p. 164)

Jacob Roggeveen was another Dutch explorer visiting the Pacific in 1721. He commented on the physique of the inhabitants of the region.

(Easter Island) *These people are well-proportioned in limbs, having very sturdy and strong muscles, are generally large in stature* ... (Roggeveen & Sharp, 1970, p. 97)

(Tuamotus) *The men were all strong and well-made fellows, in all respects similar to those of the Paaslant* (Easter Island) ... (Roggeveen & Sharp, 1970, p. 138)

(Samoa) *The Indians of this first island are like the Paaschlanders in sturdiness and robustness of the body ... fat and sleek ...* (Roggeveen & Sharp, 1970, pp. 151-152)

In 1768 French explorer Louis de Bougainville visited Tahiti with this description of the inhabitants.

... *produces men of great size; it is very common to see them measure six (Paris) feet* (1.95m) *and upwards in height. I never saw men better made, and whole limbs were more proportionate* ... (Bougainville, 1967, p. 249)

Captain James Cook was a prominent English explorer who made three visits to the Pacific. He made these descriptions during his first voyage in 1769.

(Tahiti) ... *the men in general are tall, strong limb'd and well shaped, one of the tallest we saw measured Six feet 3 inches and a half* (1.87m), *the superior women are in every respect as large as Europeans* ... (Cook & Beaglehole, 1988a, p. 123)

(New Zealand Maori) *The Natives of this Country are a strong raw boned well made Active people rather above than under the common size especially the men* ... (Cook & Beaglehole, 1988a, pp. 139-140)

(Tonga) *The Men seem in general strong and raw boned, pretty tall and well proportioned ... The women are also rather tall, well formed ... but are rather fat ...* (Cook & Beaglehole, 1988b, pp. 808-809)

In 1772 a French expedition commanded by Marion du Fresne visited New Zealand. The journal of Ensign Jean Roux records the following description.

These Islanders are generally tall, well built ....strong and vigorous looking, We measured some of them, who seemed to be the tallest among them, and they were over six feet (1.83m) *and well proportioned. Their usual height, as far as I could see, is five foot five* (1.65m) *to five foot six* (1.68m) *inches. They are all well built....* (Ollivier & Spencer, 1985, pp. 139-140)

In 1849, Captain John Erskine wrote a brief description of many of the occupants of the islands he visited.

(Fijian Chief) *It was impossible not to admire the appearance of the chief: of large, almost gigantic, size, his limbs were beautifully formed and proportioned.* (Erskine, 1853, p. 186)

(Samoan men) *I never saw a people more prepossessing in appearance and manner; the men were in general of large stature and well formed...* (Erskine, 1853, p. 36)

The men were a remarkably fine-looking set of people, and among them were several above six feet high (1.83m), *with Herculean proportions*. (Erskine, 1853, p. 41)

(Tongan men) *The Tongans, in personal appearance, resemble so closely the Samoan.... On further acquaintance with this people, one is struck with the marked superiority in stature....* (Erskine, 1853, p. 155)

(Comparison between Fijians and Tongans) *The standard of height among the Feejeeans is about the same as that of their neighbours; but their more muscular and less rounded limbs* .... (Erskine, 1853, p. 240)

Manley Hopkins was an Englishman who was consul-general for the Hawaiian king, based in London, and he published a history of the Hawaiian Island in 1863. He provided the following description.

The Hawaiians are strong, well-made, and active; in height rather above the height of our own country [England] *... the remarkable height and bulk of the chiefs, both males and females ... a chief and chiefess ... so unwieldy ... they were unable to walk.* (Hopkins, 1866, pp. 349-350)

These are but a small selection of many examples showing how early European explorers were impressed with the size and physique of Polynesians. Although these historical descriptions lack scientific precision, they provide an indication as to the physique of Polynesians at the time of first contact with early European explorers, and represent the first written records describing Polynesian morphology. At this time Europeans themselves were somewhat shorter than present day populations, as per Table 2 above.

Arthur S. Thomson was the surgeon-major in the 58th Regiment of the British Army and was stationed in New Zealand for 11 years. He made a number of physical measurements on 147 Maori males over the age of puberty who visited the Auckland military hospital for vaccination in 1849 (Thomson, 1854). The average height of the men was 5 feet 6 ¾ inches (1.70m). This compares with an average European male height in 1850 of 1.62m to 1.68m, as per Table 2 above. Thomson (1854) makes the point that the nourishment of Europeans would be much above that of the Maori.

A comparison of weight and chest circumference between the Maori and British soldiers in New Zealand showed little difference, but the Maori were superior in weight to the Belgians (Thomson, 1854). Of interest are Thomson's comments in relation to body shape. Maori were perceived as having longer bodies and shorter legs than Englishmen of similar stature, with the shortening of the legs occurring in the thighs, and their longer bodies due to the size of their spinal bones and the cartilage between them (Thomson, 1859, pp. 69-70). This is indicative of a high relative sitting height ratio, even in comparison to a supposedly cold adapted population such as Englishmen.

A similar exercise looking at the physical dimensions of Maori was undertaken by Peter Buck, medical officer for the Maori Battalion in the First World War. During the return to New Zealand on the troop ship in 1919, Buck undertook a series of physical measurements of 814 Maori troops, 424 who classified themselves as full blooded Maori (Buck, 1922, 1923).

The average weight for full blooded males was 163.9 lb. (74.3kg) and the average height was 67.3 inches (1.71m), very similar to Thomson's height measurements. Relative sitting height (sitting height index) was recorded at 53.8, again indicating a long body length relative to leg length.

Between 1921 and 1942, a series of studies were published by the American Museum of Natural History and the Bishop Museum of Hawaii on the physical characteristics of a number of Polynesian populations (Howells & Moss, 1933; Shapiro, Beaglehole, & Beaglehole, 1942; Shapiro & Buck, 1936; Shapiro, Handy, & Handy, 1930; Sullivan, 1921, 1927; Sullivan, Gifford, & McKern, 1922; Sullivan & Handy, 1923), along with a study by the Peabody Museum (Dunn & Tozzer, 1928). Although these studies focussed mainly on cranial anthropometry, an analysis of stature was compiled from these studies showing an average stature of 1.71m for males and 1.63m for females.

These studies note that Polynesian populations show a remarkable homogeneity of stature, with a predominantly tall stature (Shapiro et al., 1930, p. 7). The Tongans in particular are described as one of the tallest populations of mankind (Sullivan et al., 1922, p. 247), and were considered at the time to be one of the least inter-mixed populations of Polynesians with other ethnic groups, based on the 1917 and 1920 census data (Sullivan et al., 1922, p. 234). The Cook Islanders are described as tall, robust and well formed (Shapiro & Buck, 1936, p. 8). At this time the average height for British military recruits between the ages of 24 and 29 was between 1.65m and 1.70m (Floud, Gregory, & Wachter, 1990, p. 138). The relative sitting heights at an average in excess of 52 are more indicative of a cooler climate body shape (Roberts, 1978, pp. 19-24).

A comparison of morphological measurements on two different populations, Polynesians, and Native Alaskans, (representing a known cold adapted population), using methodology based on Ruff (1994) on the relationship between climate and body shape and size, examined the cold adapted characteristics of Polynesian body morphology (Leach, 2006). On the basis that Polynesians are a cold adapted population, close similarity between Polynesians and Alaskans might be expected. Measurements were compiled from 341 skeletons from the American Museum of Natural History in New York, and the National Museum of Natural History (Smithsonian Institution) in Washington D.C., being 251 Alaskan pre-contact individuals, and 90 Polynesian individuals, predominantly from the Marquesas and Easter Island.

The study generally concluded that there was a correlation of body morphology between Polynesians and Native Alaskans, and that Polynesians did appear to exhibit a cold adapted body morphology (Leach, 2006, p. 92). Although there were differences in stature, surface area to body mass and stature to body mass ratios, along with biiliac breadth were closely correlated (Leach, 2006, p. 91). The study did not provide many comparisons with warm adapted populations, which would have put the differences into context, however, one example given was of the Tutsi of Sub-Saharan Africa who have a surface area to body mass ratio of 298.33, well above both the Alaskan (273) and Polynesian (277) sample groups (Leach, 2006, p. 40). Global stature/mass ratios range from 3.86 (Bushmen) to under 2.6 (Finland, Iceland, England) (Houghton, 1991b; 1996, p. 58). Both sample groups present at the lower end (Alaskan 2.73, Polynesian 2.77), suggesting cold adapted populations (Leach, 2006, p. 47). Houghton (1991b) put the values for Polynesians as low as 2.2.

Polynesians appear to have a much greater weight for their stature and age than populations from a similar tropical climate, second only to Central Asians (Roberts, 1953). This data was further analyzed by Katzmarzyk and Leonard (1998). In terms of surface area to body mass, Polynesians are again more closely related to cold adapted populations.

Limb segment proportions, particularly brachial and crural indices, are another feature of body morphology largely correlated with climatic factors (Holliday, 1999; Holliday & Ruff, 2001). An examination of the variation in limb segment lengths and proportions among a sample of Polynesian and South East Asian populations, mainly from archaeological remains, but also using some living samples found Polynesian populations to have low brachial and crural indices, although with a high variability, corresponding to cold adapted body morphology. This was referred to as the Polynesian enigma, a population with many features which appear to be cold adapted, despite inhabiting a tropical environment (Biggs, 2003, pp. 107-109). A recent comparison of Indian, Polynesian and European populations found Polynesians to have longer leg length than the other two populations, however, trunk height was not measured so sitting height ratios could not be compared (Rush, Freitas, & Plank, 2009).

Archaeological analysis of skeletal remains has shed little light on the early body form of the earliest inhabitants of Polynesia. These remains have generally been limited in number, fragmentary, and no consensus has been reached on whether these represent a similar body morphology to modern Polynesian populations (Addison & Matisoo-Smith, 2010; Kirch, 1997, p. 100), but are regarded as relatively tall, if not necessarily robust (Pietrusewsky, 1996). Houghton (1996, pp. 49-51) provides a summary of skeletal breadth and total body mass estimates from a number of prehistoric Pacific Island archaeological sites and concludes that these people were of substantial frame. Estimates of stature for prehistoric East Polynesian populations range from 1.70m to 1.74m (Chapman & Gill, 1998; Houghton, Leach, & Sutton, 1975). Excavation of an early Lapita site in Vanuatu comprising 36 individuals indicated large robust males and gracile females (Bedford, Spriggs, Buckley, Valentin, & Regenvanu, 2009, p. 227; Buckley, Tayles, Spriggs, & Bedford, 2008).

Large physical size remains a common feature of modern Polynesian populations, which show a particular propensity to develop obesity (Pawson, 1986, p. 255). Although this is not uncommon in populations adopting a westernized diet, it appears to affect Polynesian populations more than others

Finally, on a more colloquial note, it was reported that Polynesians now make up 25% of the Australian rugby league players, despite representing only 0.5% of the population, and in New Zealand make up more than half the rugby union players, despite comprising only 17% of the population (Williams, 2008). This is seen as mainly due to the larger physical size of Polynesians, particularly at younger age levels, in what are regarded as extremely physical sports.

In one study linking Polynesian morphology with Asiatic Mongoloid populations, analysis shows that Polynesians have an extended growth stage in adolescence, beginning earlier than comparable populations (Katayama, 1996). This extended growth stage in adolescence is seen as the main reason for the larger body size, but an adaptation to cold environments is seen as the main factor in Polynesian body shape.

2.8. Houghton’s Hypothesis

Various explanations have been advanced as to why Polynesian populations inhabiting a tropical environment should exhibit many morphological characteristics of a cold adapted population. These explanations include the concepts of culture, sexual selection, status, diet and lack of disease (van Dijk, 1991). Certainly large body size has a number of cultural factors, including fattening rituals and high aesthetic value (Pollock, 1995), however, even those advocating sexual selection as the major factor in the large Polynesian phenotype acknowledge that the population would already have to have a larger range of body size (van Dijk, 1991).

Whilst these factors may have had some influence in the maintenance of Polynesian morphology, they provide no viable explanation as to how the phenotype developed in the first place, provide no sufficient time frame for selection, and are not supported by any data. Considerable work in the area of the anomaly of Polynesian body morphology has been undertaken by Philip Houghton (Houghton, 1978; Houghton, 1980; Houghton, 1990, 1991a, 1991b, 1996; Houghton et al., 1975), and as a result of his research he has advanced a hypothesis that remains the only significant explanation to date.

The starting point for Houghton's hypothesis is that Polynesian body morphology does reflect an adaptation to a cold environment, as illustrated in section 2.7 above. This morphology developed as a consequence of selective pressures arising from oceanic voyaging in small canoes in a maritime environment that is both cold and wet. In fact Houghton (1990) goes so far as to describe the environment in these term:

...this oceanic world can effectively be considered one of the coldest of global environments... (Houghton, 1990).

Houghton (1990; 1996, pp. 63-101) provides evidence as to the likely effect on the body temperatures of the occupants in a small canoe on the Pacific Ocean, soaking wet, windy, and often engaged in the physical exertion of paddling. The loss of body heat would be considerable and a large robust body, as well as a body with lower surface area to mass ratio, would have a considerable advantage over a smaller body in maintaining core body temperature, along with limb function. Increased musculature would assist in maintaining metabolic rate, through the mechanism of shivering, delaying the onset of hypothermia.

An estimate of survival at sea under average climatic conditions, allowing for variations in mass and stature, clearly show that Polynesians would have had a significant survival advantage when compared with the smaller bodied Melanesian populations (Houghton, 1996, pp. 63-69). Computer simulation showing survival proportions for males and females whilst voyaging over a 10 day period demonstrated a larger body mass clearly had a better survival rate in cold and wet conditions (Houghton, 1996, pp. 81-87).

Two possible scenarios are advanced by Houghton as to how these selective pressures could have produced the Polynesian morphology. The western part of island Melanesia has been occupied by humans for more than 30,000 years, and voyaging for trade purposes has been a feature of this region, encompassing Asia, and Australia and Near Oceania for much of that time (J. A. Allen, 1982). This would provide both an adequate time frame for selection and an oceanic voyaging environment (Houghton, 1980, p. 73; Houghton, 1990).

This first scenario is now regarded as unlikely. Polynesians are generally considered as having Asian origins, arriving in Melanesia little more than 4,000 years ago (Friedlaender et al., 2008; Hurles, Matisoo-Smith, Gray, & Penny, 2003; Serjeantson & Hill, 1989). Although there was extensive voyaging in Island Melanesia for trading, the trips would have been relatively short, around 3-4 days in average, with good inter-visibility between islands, have involved largely males, and would have been too safe to have involved large loss of life (J. A. Allen, 1982, pp. 193-203; Irwin, 1989, 2010; Kirch, 2000, pp. 112-114).

The second scenario involves voyaging from Island Melanesia into Remote Oceania, the colonization of the area of the Pacific now inhabited by Polynesians, known as the Lapita expansion due to its close association with the Lapita Cultural Complex (Anderson, 2002; Anderson & O'Connor, 2008). This is a different type of voyaging, involving longer more hazardous journeys, initially into the unknown, and probably subject to the type of wet and cold conditions outlined by Houghton (1990). It is likely that a large and robust physique would have been an advantage in these early voyages of exploration. However, as to whether this voyaging would have provided the necessary selective pressures to produce the Polynesian morphology is questionable.

The first problem is one of time frame. The earliest evidence of Lapita culture is found in Island Melanesia around 3300-3500 BP, with expansion into Remote Oceania, initially West Polynesia, following by at least 3000 BP (Anderson & O'Connor, 2008; Hurles et al., 2003), a time frame of around 500 years. Colonization of East Polynesia was relatively recent and rapid (Wilmshurst, Hunt, Lipo, & Anderson, 2011) concluded over a further period of around 2000 years as illustrated in Figure 7 below.

Figure 7. Map showing Polynesian colonization of the Pacific (McLenaghen, 2012).

This relatively short time frame does not allow sufficient time for the evolution of the distinctive Polynesian physique, which would require many thousands of years to evolve (Brace, 1998; Holliday, 1997a; Hulse, 1960). Houghton himself refers to this problem when he concludes that such physical changes ...*could have emerged in a few hundred years, but I suspect most would want a few thousand...* (Houghton, 1996, p. 175). Houghton dismissed this criticism by asking if his hypothesis was wrong, where was the evidence for physically large Proto-Polynesians in Asia, particularly in the region of Taiwan (Houghton, 1996, p. 175). In this respect Houghton may have needed to cast his gaze wider in the Asian region, towards the north, and back much further in time for this evidence.

Not only was the period of colonization relatively rapid, but the method of voyaging had a number of strategies to minimise the hazards, included upwind exploration, to enhance the ability to return (Irwin, 1992, p. 56; 2008; 2010, pp. 131-141). Lapita canoes were large, fast and safe, utilising sails and navigation techniques (Irwin, 1989; 2010, pp. 131-141). The process would likely have involved a period of exploration, followed by a return to the discovered islands with domesticated plants, animals, along with the colonizing population (Irwin, Bickle, & Quirke, 1990).

Whilst physique might have played a part in the ability of the initial explorers to voyage and search for islands, it would likely have played little or no role in the subsequent multiple voyages of colonization, with long range contact being initially maintained after colonization (Irwin, 2008; Irwin et al., 1990), enabling continuing gene flow between islands, and mitigating any selection process that may have occurred during exploration. Once the islands had been colonized, normal domestic voyaging for fishing and trading would not have provided any pressure for morphological adaptation.

There are other problems with Houghton’s hypothesis. His analysis was based on the fact that early Polynesian explorers would have had a lack of clothing and shelter in their exposure to the wet and cold (Houghton, 1990). In fact there is no reason to suggest this was the case. The large canoes were often fitted with special structures on which to sleep, sit or cook, and sometimes had mat work canopies for protection against the weather, and even cabins, or deck huts with portable fire places (Oliver, 1974, p. 196; Pawley & Pawley, 1994, pp. 329-361). The explorers would not necessarily have been continually exposed to the elements.

Part of Houghton’s contention is that as the Polynesian explorers moved east across the Pacific, covering larger areas of ocean, and consequently longer and more hazardous voyaging, that body morphology became increasingly robust (Houghton, 1996, p. 32). On this basis those populations in the periphery of Polynesia, Hawaii, New Zealand and Easter Island should exhibit the most extreme physique, but this is not the case (Friedlaender, 1998). Tongans are generally regarded as among the most robust of the Polynesian populations (Gonda & Katayama, 2006; Howells, 1970; Sullivan et al., 1922, p. 247), however, Tonga was one of the earliest islands colonized (Hurles et al., 2003).

Human populations have inhabited Near Oceania, and have been involved in voyaging in that region, for nearly 40,000 years (Bedford & Spriggs, 2008; Bentley et al., 2007). The question arises why these inhabitants of Near Oceania never colonized further east into Remote Oceania in all this time, whereas those populations associated with the Lapita Cultural Complex, the progenitors of modern Polynesian populations, moved into Near Oceania around 4,000 years ago and, within a few hundred years, had colonized central East Polynesian, including Fiji, Tonga and Samoa (Hurles et al., 2003).

There are a number of factors that have been advanced as to why these Lapita populations were able to successfully colonize Remote Oceania. These include innovations in water transport, including canoe construction, house construction, pottery, tool making, and subsistence economy (Green, 2003). Their development of a portable economy that could be transported from island to island included fishing methods, plant and animal domestication and cloth production (Kirch, 2000, pp. 109-112) They also demonstrated advances in navigation and sailing techniques (Irwin, 1989). Lapita social structure may also have played a role in driving exploration and colonization (Kirch, 2000, p. 97).

Houghton's arguments in relation to the nature of the cold adaptation of the Polynesian morphology, and the usefulness of such a physique in oceanic voyaging are persuasive. This robust physique is in contrast to the much lighter build of the ethnic groups in Island Melanesia who are descendants of the populations who have inhabited the region of Near Oceania for over 30,000 years (Howells, 1970; Pietrusewsky, 2006).

These provide another factor behind the success of Lapita populations in colonizing Remote Oceania. The physical demands of oceanic voyaging are such that a robust physique will provide an added advantage in long voyages of exploration and colonization. If these early Lapita populations originated in Northeast Asia many thousands of years ago, they would have adaptations to a cold environment that would assist survival in long and hazardous open water voyaging. The physical and robust nature of the Polynesian physique may have been an important factor in the ability of the early Lapita populations to explore and colonise the Pacific.

2.9. Summary

Body morphology is influenced genetically, through inherited characteristics, and developmentally, through the environment. Body proportions are under stronger genetic influence than body size, and are influenced by climate, as defined by Bergman's and Allen's rules. Polynesian body morphology provides an anomaly to these rules, with cold adapted characteristics despite inhabiting a tropical environment.

Polynesians have inhabited their tropical Pacific environment for around 4,000 years. This is not a long enough time frame to develop their cold adapted body morphology; therefore they must have developed these characteristics before they moved out of Asia to Oceania. These robust physical attributes may have contributed to their ability to colonize Remote Oceania.

On this basis Houghton's hypothesis, which suggests they developed their physique while voyaging on the inhospitable ocean, is unconvincing. The only area in Asia cold enough to have contributed to the development of such a cold adapted physique is North Asia, and the time frame required would be at least 10-15,000 years.

Chapter 3. Polynesian Origins

3.1. Introduction

Remote Oceania was the last part of the world to be colonized by human groups, more than 3,000 years ago. Despite this recent prehistory, debate continues over the origins of these people and the source of their ultimate ancestry. Like most human populations throughout the world there is unlikely to be one single ancestral group from which these people are derived; more likely there are a number of different elements that have combined to make up the people who first occupied Remote Oceania, now known as the Polynesians. Information on their origins will provide an understanding of the ancestral environments that have helped shape Polynesian body morphology.

Current research identifies a number of ancestral links between Polynesian and Asian populations, making this a region of cultural and genetic importance for Polynesian populations, but in addition there are elements derived from indigenous Melanesian populations, representing a diverse genetic and cultural heritage. The three main areas of research looking at Polynesian origins are the fields of genetics, linguistics, and archaeology, and these have led to a number of models being developed to explain the colonization of the Pacific.

3.2. Pacific Colonization Models

The immediate origins of Polynesians populations lie with the Austronesian speaking populations inhabiting Near Oceania more than 3,500 years ago, and associated with the Lapita culture (Sheppard, 2009). The ancestral origins of these ’Lapita people’ is less clear-cut. Much of their cultural complex is derived from Island Southeast Asia, and a significant element of their genetic heritage is also associated with Southeast Asian populations, however, there was also admixture and interaction with indigenous Melanesian populations that had been living in Near Oceania for tens of thousands of years.

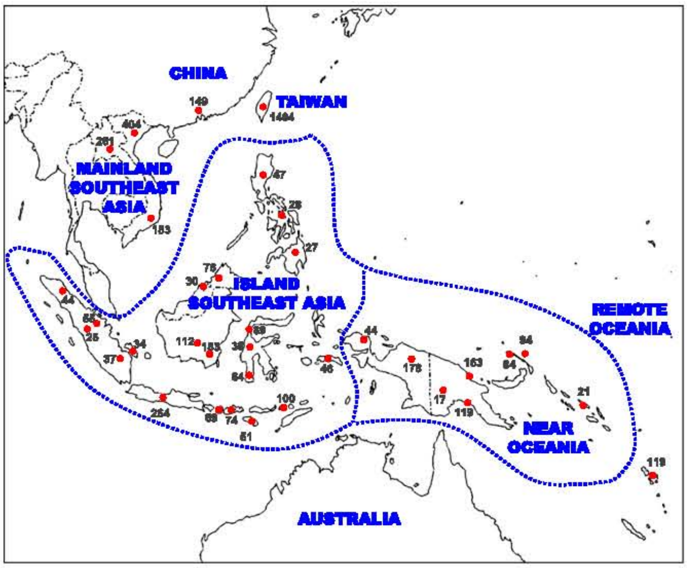


Figure 8. Map Showing China, Taiwan, Southeast Asia, Near Oceania, and Remote Oceania (Soares et al., 2011).

A number of different models have been proposed to explain the origins of these Austronesian speaking populations, and their distinctive culture that included agriculture, horticulture, fishing, pottery, weaving and long distance voyaging known as the Lapita Cultural Complex (Green, 2003). The two primary models originally put forward are the ‘Express Train Model’ (Diamond, 1988), and the “Entangled Bank Model’ (Terrell et al., 2001).

In the Express Train model the Lapita culture represents a number of highly mobile groups of ocean voyaging colonists, often labelled Austronesians (Hurles et al., 2003), who expanded rapidly out of Island Southeast Asia, possibly from the vicinity of Taiwan, through Near Oceania and on to Polynesia with limited interaction with local Melanesian populations in the second millennium BC (Bellwood, 1995, pp. 96-111; Diamond, 1988). They are generally associated with coastal settlements in Melanesia, possibly due to their maritime economy, but may also relate to a genetic resistance to malaria, which would have given them an advantage over indigenous populations in occupying coastal areas (Clark & Kelly, 1993; A. V. Hill et al., 1987; Tsukahara et al., 2006).

With the entangled bank model, there are no clear signals indicating the ancestry of Polynesian populations came from the west, with the Lapita culture representing an indigenous development in Near Oceania. There was sufficient time period in Near Oceania to allow for social and economic innovation, as well as the adoption of technologies from regions to the west, leading to the local development of the Lapita culture (Terrell et al., 2001; White, Allen, & Specht, 1988).

These two models lie at either end of a continuum that represents a diverse range of views; it is possible to put forward alternative intermediate models that encompass different aspects of the two primary models depending on how the data is interpreted. For example the ‘Slow Boat Model’ differs from the express train model in that it allows for much greater interaction between Austronesians coming in from the west, and indigenous inhabitants of Melanesia (Kayser et al., 2006; Kayser et al., 2000; Whyte, Marshall, & Chambers, 2005). Another variation on the slow boat model argues that the origins of the Austronesians lies in Island Southeast Asia, in the vicinity of eastern Indonesia (Oppenheimer & Richards, 2001; Richards, Oppenheimer, & Sykes, 1998)

There is a growing acknowledgement that the existing data does not support a simplistic model for either contention. Green’s ‘Triple I’ model, also known as the ‘VC (voyaging corridor) Triple I model’, integrates aspects of the Express Train and Entangled Bank models including *intrusion*, being the movement of people and their culture into the Bismarck Archipelago, where aspects from the existing populations were then *integrated* into a new cultural pattern, which then underwent *innovation* creating the Lapita culture before the movement into Remote Oceania (Green, 2003).

It is possible that there was more than one migratory event from Island Southeast Asia into Near Oceania, with debate centring on the ‘Out of Taiwan’ scenario as part of the *intrusion* aspect in the Triple I model. Under this scenario Austronesian speaking populations emerged from Taiwan around 5,000 years ago, moving through Island South East Asia before arriving in Near Oceania 4,000 years ago, and developing the Lapita Cultural Complex as a precursor to movement into Remote Oceania (Hurles et al., 2003; Kirch, 2010). Given the level of genetic homogeneity among Polynesians, it is likely that the ancestral origins of modern Polynesian populations derived from a relatively small founding population that represented only a subset of the genetic diversity among Near Oceanic populations associated with Lapita culture.

3.3. Genetics

When discussing biogeographic variation, Mayr (1942, p. 72) distinguishes between species in which biological variation is continuous between populations, and species in which groups of populations have distinctive biological characteristics, often separated by borders. With no clear biological boundaries between geographically diverse populations of humans, researchers look for distinctive genes by which individuals can be associated with groups in order to identify human global population structures or clusters.

Studies on the genetic origins of Polynesians have to deal with the problems associated with a small founding population, genetic drift and selection, on-going migration in prehistoric times, which might be different for males and females, and post-contact admixture and migration, particularly with Europeans (Hurles et al., 2003). Present-day gene frequencies may not represent ancestral gene frequencies. What is clear is that modern Polynesian populations display an overall genetic homogeneity (Friedlaender et al., 2008).

Recent research has focussed on understanding the genetic relationship between Polynesians and indigenous Melanesian populations, which goes to the heart of the ‘express train’ versus ‘entangled bank’ debate. The fewer the genetic links, the faster the train. In addition, where in Asian can we find the source of the Asian elements of the Polynesian genetic traits? The main debate seems to be between the ‘Out of Taiwan’ model, and the Island Southeast Asia origin.

Studies of mtDNA haplogroups have generally favoured an Asian origin for Polynesian maternal lineages (Cox, 2005; Kayser et al., 2006; Lum & Cann, 2000; Melton et al., 1995; Redd et al., 1995; Trejaut et al., 2005). There are few closely related lineages in this region found in populations of Remote Oceania, in contrast to the many diverse haplotypes present in Near Oceanic populations (Friedlaender, Gentz, Green, & Merriwether, 2002).

The most distinctive genetic feature of Polynesian populations is a haplotype found in the hypervariable region-I (HVR-I) of the control region of the mtDNA, haplotype B4a1a (Pierson et al., 2006). When the three single nucleotide polymorphisms (SNPs) found in the B4a1a haplotype are combined with a 9 base pair deletion in the intergenic region between the COII gene and the Lysine tRNA gene, found in very high frequencies in Polynesian populations, this combination is known as the Polynesian motif and is a useful marker in tracking the evolutionary history of Pacific populations (Hertzberg, Mickleson, Serjeantson, Prior, & Trent, 1989; Redd et al., 1995).

The motif is largely absent from indigenous Melanesian populations, with low levels found in some coastal populations, and almost entirely absent in inland populations, as shown in Figure 9 below (Hertzberg et al., 1989; Redd et al., 1995; Trejaut et al., 2005). Indications are that the mtDNA gene flow was directional from Austronesian populations to indigenous Melanesian populations (Ohashi et al., 2006). The 9-bp deletion occurs in lower frequencies in some Asian, including Mongolian and Tibetan populations, and many Native American populations (Kolman, Sambuughin, & Bermingham, 1996; Lorenz & Smith, 1994; Redd et al., 1995).

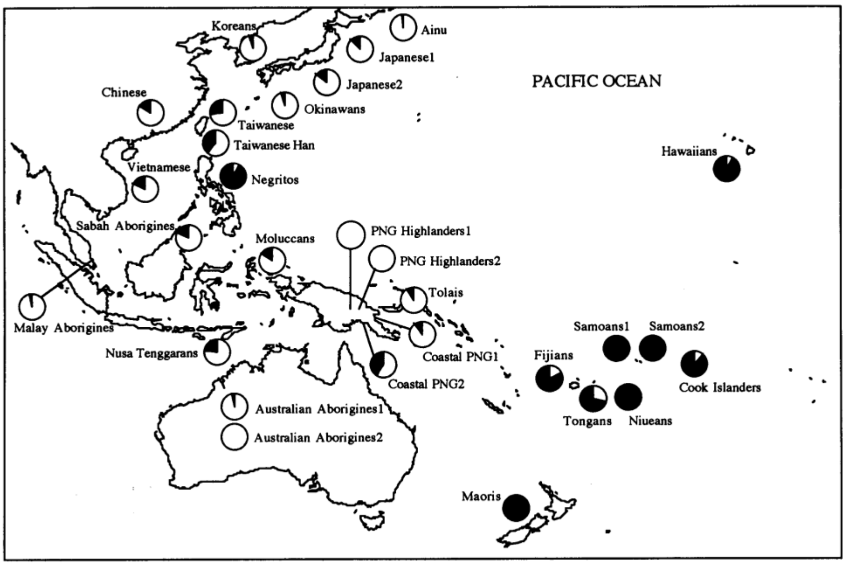


Figure 9. Distribution of the 9 base pair deletion in Asian and Pacific populations.

The frequency of the deletion for a given geographical area is shown by the black area in each pie chart (Redd et al., 1995).

The B4a haplotype is present in high frequencies among the indigenous Taiwanese populations that inhabit the mountainous east regions of Taiwan, and have maintained a geographic isolation from the mainland ethnic Chinese migrants for thousands of years (Chow, Caeiro, Chen, Garcia-Bertrand, & Herrera, 2005; Sewerin et al., 2002; Trejaut et al., 2005). The B4a haplotype is also found in a number of Island South East Asian populations in the Philippines and Indonesia, as well as Mongolia, and other parts of Central, Northern and Eastern Asia, and Madagascar (Pierson et al., 2006; Razafindrazaka et al., 2009; Schurr & Wallace, 2002; Tanaka et al., 2004; Trejaut et al., 2005). Both Polynesian and native North American populations trace their descent from East Asian mtDNA haplogroup B4 ancestors (Underhill & Kivisild, 2007).

Dating for this motif using the most recent common ancestor (TMRCA) is around 17,000 years (Pierson et al., 2006), or 13,200 ± 3,800 years (Trejaut et al., 2005). While there are some issues with the frequency and dating of the B4a1a haplotype in relation to the ‘Out of Taiwan’ scenario, these do not exclude the possibility that the origins of this haplotype lie in Taiwan (Friedlaender et al., 2007; Pierson et al., 2006), although not all agree with this scenario (C. Hill et al., 2007; Soares et al., 2011; Trejaut, Yen, Loo, & Lin, 2011). Recent studies have also linked Y chromosomal haplogroups with indigenous Taiwanese (Mirabal et al., 2012).

Analysis of other mtDNA haplogroups, as well as genetic markers associated with malarial resistance, confirms the complexity of genetic relationships between Near and Remote Oceanic populations, with some links between Polynesians and coastal populations in Near Oceania, but few links with inland population groups (Friedlaender et al., 2007; C. Hill et al., 2007; Serjeantson & Hill, 1989, pp. 287-288). Overall studies have put the Asian mtDNA component of Polynesian populations as high as 79%, with the balance of 21% representing Melanesian influences (Kayser, Lao, et al., 2008; Kimura et al., 2008).

Studies of other genetic traits have also shown links between indigenous Taiwanese, and Austronesian speaking populations in Island Southeast Asia and Oceania, as well as genetic affinities to Native Americans. These include studies of the Lewis secretor type gene (J. G. Chang et al., 2002), mtDNA 9 base pair deletion (Wallace & Torroni, 2009), HLA genes (Arnaiz-Villena et al., 2010; Chow et al., 2005; Sewerin et al., 2002), HLA haplotypes (Lin et al., 2000; Mack et al., 2000), 14 neutral biparental short tandem repeat (STR) loci (Lum, Jorde, & Schiefenhovel, 2002), human JC virus genotypes (Yanagihara et al., 2002), and autosomal STR loci (Regueiro et al., 2008).

Analysis of non-recombining Y chromosome markers (NRY) shows a different picture, suggesting a much higher indigenous Melanesian component in Polynesian genetic origins (Capelli et al., 2001; Delfin et al., 2012; Hurles et al., 2002; Kayser et al., 2006; Scheinfeldt et al., 2006; Underhill et al., 2001). This would indicate a much closer genetic relationship between the two populations than shown by the mtDNA studies, with the majority of Polynesians more likely tracing their paternal heritage to Pleistocene migrants into Melanesia than to more recent Austronesian speaking Neolithic agricultural immigrants. Again the results vary with some studies still suggesting a closer relationship between Polynesians and Asians than indigenous Melanesians, providing a similar picture to the mtDNA analysis above (Cox et al., 2007; Kayser, Choi, et al., 2008). A number of possible explanations have been put forward for this discrepancy between the mtDNA and the Y chromosome analysis.

If there was significant NRY admixture between Austronesian and indigenous Melanesian populations, it must have either occurred within a short period of time, as the time frame for the emergence of Lapita culture in Island Melanesia and the settlement of Remote Oceania is relatively short, approximately four generations, or there must have been continued post-settlement contact between Near and Remote Oceania (Gray, Drummond, & Greenhill, 2009). As this would have involved long distance voyaging, it is likely males would have predominated in this post-settlement contact.

There is both linguistic and ethnological evidence for matrilineal lineages combined with matrilocal residence patterns in Proto-Oceanic society, whereby males moved to their wife's villages (Hage & Marck, 2003; Jones, 2011; Lansing et al., 2011). Such patterns are favoured where there is a prolonged male absence for reasons such trade, warfare and resource exploitation. Long distance trade and exchange networks, as well as resource exploitation, were all aspects of Lapita culture.

A similar pattern has been observed in Micronesia where males are readily assimilated into matrilineal descent groups (Levi-Strauss, 1987, pp. 183-184). In this region the continuation of matrilineal descent has been associated with long distance voyaging (Hage & Marck, 2002). Integration of Austronesian peoples arriving from Island Southeast Asia with coastal indigenous Melanesian populations, combined with matrilocal residence patterns in Near Oceania, would have introduced indigenous Melanesian Y-chromosomes into the Lapita gene pool prior to the colonization of the Pacific (Cox, Karafet, Lansing, Sudoyo, & Hammer, 2010; Jordan, Gray, Greenhill, & Mace, 2009). Matrilocal residence patterns have been associated with high with-in group diversity for NRY and large between group diversity for mtDNA (Oota, Settheetham-Ishida, Tiwawech, Ishida, & Stoneking, 2001).

An alternative explanation concerns the sampling involved in mtDNA and NRY markers, which have 25% of the sample size of autosomal markers. These can be more susceptible to random genetic drift, and represent a small portion of genetic variation, often based on a single locus (Friedlaender et al., 2008). A study using a genome scan of autosomal markers (687 microsatellites and 203 insertions/deletions) from 952 individuals representing 41 Pacific and Asian populations has provided the most comprehensive genetic analysis of Melanesian and Polynesian affinities to date, as show in Figure 10 below (Friedlaender et al., 2008).

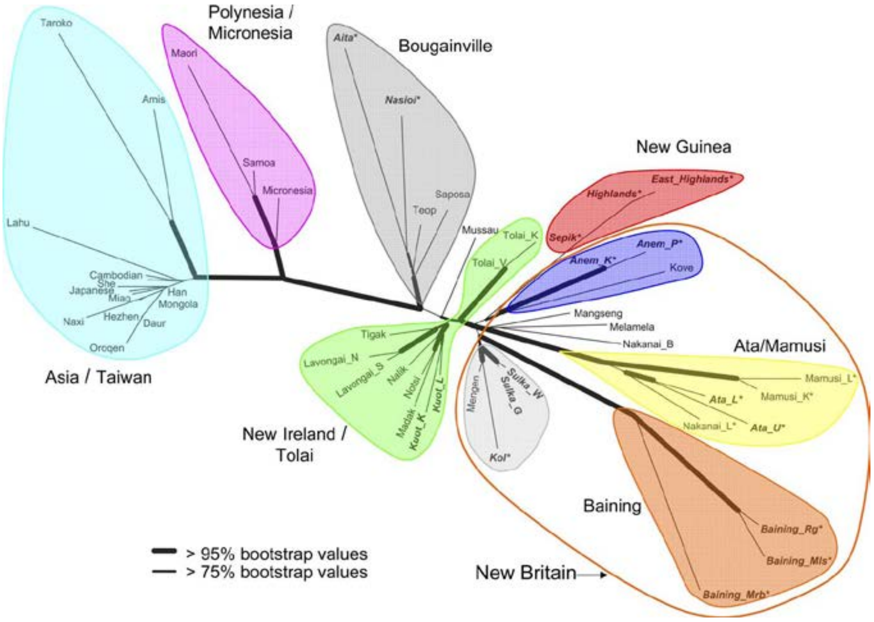


Figure 10. Neighbor-joining F_{ST}-based tree for autosomal markers (687 microsatellites) from the Pacific and East Asian populations.

The range of bootstrap values are indicated by branch thicknesses. New Britain populations are circled. Papuan-speaking groups are in bold italics; inland groups in Melanesia have asterisks (Friedlaender et al., 2008).

The study concluded that Polynesians have a strong genetic relationship with Asian/Taiwanese indigenous groups, but only a weak association with any Melanesian groups. There was a weak 'Austronesian' genetic signature among Austronesian speaking Melanesian populations, and none at all within Papuan speaking populations. East Asian populations retain the closest genetic links with Melanesian groups, but these are distant (Friedlaender et al., 2008). Another study on autosomal characteristics provided a similar link between Polynesians and indigenous Taiwan populations (Hunley et al., 2008), as does more recent analysis looking at mtDNA links between Philippine and indigenous Taiwanese populations (Tabbada et al., 2010). This supports the expansion of Austronesian people from the vicinity of Taiwan as being responsible for the ancestry of Polynesian populations, but with some interaction with indigenous Melanesian populations.

Little in the way of ancient DNA analysis has been completed in Oceania, largely due to the scarcity and poor preservation of skeletal material in the tropical environment. Analyses of ancient DNA from Lapita human remains (Hagelberg, 1997; Hagelberg & Clegg, 1993) are ambiguous as the results have not been repeated and were not undertaken using current standard ancient DNA protocols (Addison & Matisoo-Smith, 2010; Gilbert, Bandelt, Hofreiter, & Barnes, 2005).

Recently genetic links have been established between inhabitants of both Near and Remote Oceania and an archaic hominin group from southern Siberia, titled the Denisovans after the location of the initial excavation in Denisova Cave (Bustamante & Henn, 2010; Reich et al., 2010; Reich et al., 2011). The cave has been occupied by hominin populations from 230,000 BP, but the material analysed dates to 30-50,000 BP. Denisovan genetic material is closely related to Neandertal populations. These genetic links with Oceanic populations are much stronger with modern populations inhabiting Near Oceania (Melanesian and Australian Aborigine populations) than Remote Oceania (Polynesian populations), but with little or no relationship to other Asian populations. Therefore it would not seem to support this genetic material being introduced into Oceania by the movement of Polynesian ancestors from Northeast Asia to the Pacific.

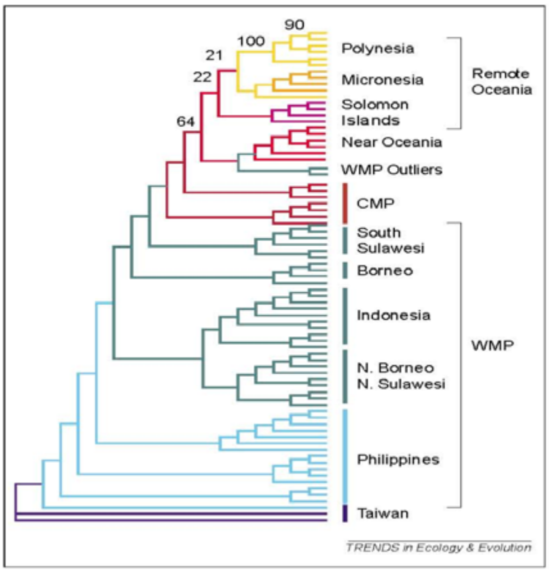
There is no easy model to explain these links. Melanesians and Australian Aborigine populations were the first occupants of the Pacific some 40,000 years ago (Jin & Su, 2000), and it would appear likely they acquired this Denisovan genetic material prior to their arrival in Near Oceania. This is more so given the appearance of the Denisovan material in Australian Aborigine populations, who have likely had little contact with other populations since their arrival in Australia. Admixture between Melanesian and Lapita populations passing through Near Oceania might explain how modern Polynesians populations acquired traces of this genetic material, but at lower frequency than Melanesian populations. Reich et al (2011) however, leans to the view that the Denisovan gene flow to Melanesian and Australian populations occurred in Southeast Asia indicating that Denisovan populations inhabited a wide area of Asia, from Siberia to Southeast Asia. There appears to be no archaeological evidence to support this conclusion.

3.4. Linguistics

Human migration throughout Island Southeast Asia and Oceania has been associated with the dispersal of Austronesian languages. Austronesian is one of the world's most diverse language groups covering an area ranging from Madagascar in the west to Easter Island in the east, as shown below in Figure 11.

Figure 11. Geographical span of Austronesian languages (Diamond, 2000).

Analysis of the Austronesian languages divides the 1200 Austronesian languages into 10 subgroups, of which nine (26 languages) are only spoken by Taiwanese indigenous groups with the 10th subgroup covering all other Austronesian languages outside Taiwan (Blust, 1999). This implies the origins of the Austronesian languages lie in Taiwan, with its subsequent dispersal throughout Island Southeast Asia through migration out of Taiwan (Diamond, 2000; Diamond & Bellwood, 2003; Gray et al., 2009; Gray & Jordan, 2000). The sequence of language dispersal, as shown in Figure 12 below, shows a strong eastward movement in line with the presumed dispersal of Austronesian speaking populations out of Taiwan, south to Island South East Asia and then east through Near Oceania to Remote Oceania.



TRENDS in Ecology & Evolution

Figure 12. Parsimony tree for 77 Austronesian languages. The tree is rooted with two indigenous Taiwanese languages (Hurles et al., 2003).

Phylogenetic analysis has identified a sequence of pulse-pauses in this expansion of Austronesian that can be linked to the settlement of the Pacific region, as well as technological and social innovations (Gray et al., 2009). These pulse-pauses correlate with the settlement pauses in the geographic expansion of Austronesian speaking populations out of Taiwan into Island Southeast Asia and from there into Near and then Remote Oceania. The first pause is found before the first movement from Taiwan to the Philippines, which may be due to the difficulties of crossing the 350 km Bashi channel (Blust, 1999; Pawley, 2002, pp. 261-263). Linguistic reconstruction suggests this first significant migration may relate to the development of the outrigger canoe (Pawley & Pawley, 1994, pp. 329-361; Pawley & Ross, 1993). The second pause is found after the settlement of Western Polynesia, around 2800 BP, before the movement into Central and East Polynesia, and coincides with the initial development of Polynesian culture (Blust, 1999; Gray et al., 2009).

Given the greater voyaging distances required to move into Central and East Polynesia, additional technological developments may have been required (Blust, 1999; Irwin, 1998). The language phylogenies confirm the rapid cultural developments by the Austronesian speaking populations as they voyaged from Southeast Asia into the Pacific, and confirms the close association between Austronesian and the development of the Lapita culture (Gray et al., 2009; Greenhill & Gray, 2005). Linguistic evidence for Austronesian expansion through Island Southeast Asia is considered congruent with the genetic evidence (Xu et al., 2012). These results show a corresponding pattern between linguistic and genetic expansion of Austronesian expansion through Island Southeast Asia, beginning around 4,000 to 3,000 years ago by reviewing the genetic admixture between populations of Asian and Papuan ancestry (Xu et al., 2012).

The most recent reconstructed time depth for Proto Austronesian is around 5,230 years, which ties in more closely with the express train model than the slow train, or entangled bank models (Gray et al., 2009; Gray & Jordan, 2000; Greenhill, Drummond, & Gray, 2010). In contrast the Papuan language families could be as old as 40,000 years (Foley, 1986, p. 9; Kirch, 1997, pp. 84-86). Austronesian languages remain spoken in various parts of Melanesia, mainly in coastal areas (Gray et al., 2009; Pawley, 2002, pp. 268-269).

Criticism of the comparative linguistic approach rests again on the argument that the level of interaction between the different population groups in Island Southeast Asia and Melanesia makes a simple model unreliable, particularly given the diversity of the language groups in this region (Terrell et al., 2001). Languages can be exchanged and adopted between different population groups without migration. Others argue for Island Southeast Asia as the centre of development of the Austronesian language, (Meacham, 1984, 1995; Oppenheimer & Richards, 2002, pp. 287-297; Solheim, 1984), or even Melanesia (Dyen, 1965), with migration, and/or language and culture dispersal back to Taiwan.

3.5. Archaeology

The first inhabitants to occupy Polynesia came out of Near Oceania, and are identified in the archaeological record by the Lapita Cultural Complex, best defined by its red-slipped dentate stamped pottery. The earliest Lapita sites are found in northern Island Melanesia, in the Bismarck and Solomon archipelagos, around 3600 BP (Kirch, 2000, pp. 88-91). These islands had already been occupied by indigenous Melanesian populations for more than 35,000 years at sites such as Yombon in New Britain, and Buang Merabak and Matenkupkum in New Ireland, however, these earlier inhabitants tended to occupy the interior areas of the islands (Kirch, 1997, pp. 29-34).

The emergence of the Lapita Cultural Complex represents a clear break from earlier Melanesian assemblages, including the arrival of the pig, dog, chicken and the Pacific rat (Spriggs, 1995, pp. 116-118). Other aspects of the culture included the development of stone and shell adzes, reef fishing and shellfish gathering, shell ornaments, stilt houses built over the water, highly decorated ceramic pottery, cultivation of tree and root crops, and use of obsidian (Green, 2003). The success of the Lapita people in colonizing new regions was based on their voyaging skills, and their portable subsistence economy (Kirch, 2000, p. 109).

Lapita culture began to expand from the Bismarck Archipelago within 2-300 years of the initial colonization, into the Santa Cruz group, Vanuatu, New Caledonia, Fiji, Tonga and Samoa by 3100 BP (Kirch, 2000, pp. 93-98). Tonga and Samoa represent the most easterly expansion of Lapita culture, with a distinctively Polynesian culture emerging around 2,000 years ago, followed by colonization from Western Polynesia into Eastern Polynesia (Kirch, 2000, pp. 230-238).

The earliest origins of Lapita culture can be found in Taiwan around 5,000 BP in the Neolithic Ta-p’en-k’eng and succeeding cultures, including fine red pottery, fishing gear, and polished stone adzes (Bellwood, 1995; Bellwood, Chambers, Ross, & Hung, 2011, pp. 321-354; Kirch, 1997, p. 48; Pawley, 2002, pp. 257-258). There was regular voyaging between

Taiwan and the Chinese mainland, with maritime trading links dating back before 7,000 BP (Chen, 2008; Rolett, Jiao, & Lin, 2002; Rolett, Wei-chun, & Sinton, 2000; Solheim, 2000).

This culture appears to have expanded into the Philippines by 4500 BP and then into the Sulawesi and Halmahera archipelagos (Kirch, 1997, pp. 48-49). Most of the archaeologically defining features of the Lapita culture can be found developing and spreading throughout Island Southeast Asia between 5,000 BP and 3,000 BP, including ceramics, ground stone adzes, fish hooks, shell ornaments, and horticulture (Kirch, 2000, pp. 91-93). Pottery nearly identical to that found in early Lapita sites has been found at the Uattamdi site in Halmahera dated to 3,300 BP (Kirch, 2000, p. 91).

Those arguing for a predominantly Melanesian origin for Lapita culture can point to elements of Lapita technology that pre-date the emergence of the Lapita Cultural Complex. These include lagoon fishing, trade in obsidian, and shell ornaments (J. Allen & White, 1989; Terrell & Welsch, 1997). There is also evidence of agricultural development in highland New Guinea however, this was markedly different from the agricultural economy which spread into Island Southeast Asia from China, and there is no sign of pre-Lapita agriculture in Island Melanesia (Pawley, 2002, p. 259).

The earliest record of human habitation on Taiwan shows an economy of fishing, shellfish, the cultivation of root and fruit crops, and a lithic industry of stone tools, dated to the period 15,000-5,000 BP (K.-C. Chang, 1995; Cheng-hwa, 2004, pp. 63-64). Fine burnished red pottery is found in early Neolithic sites (K.-C. Chang, 1969, pp. 197-200).

An early assessment of the Formosan people placed their likely origins as descended from two major prehistoric cultures, the northerly tribes originating from the Yuan-shan culture, based on the East China coastal area, as far north as Japan and Korea, and the southerly tribes, those often associated with Austronesian expansion, as originating from Lungshanoid agricultural populations who migrated to Southeast China from the north (K.-C. Chang, 1969; Ferrell, 1966). A possible cultural affinity with the Jomon of Japan can be identified (Cheng-hwa, 2004, p. 64). The Lungshanoid culture is seen as originating in North China, as an extension of the mongoloid Lungshan Neolithic culture, moving south due to population pressures, and facilitated by technological and agricultural advances, and characterized by geometric-stamped ceramics (K.-C. Chang, 1964).

3.6. Commensals

As humans migrated into Remote Oceania around 3,000 years ago, they carried with them animals as an important part of their subsistence economy. These animals, or commensals, had a symbiotic relationship with their human, being dependent on them for dispersal, and in return providing food (Matisoo-Smith, 2009). These animals included dogs, pigs, chickens and rats (Matisoo-Smith, 2009). Because of the large inter-island distances, their movements across the Pacific can only have been in association with human voyaging. As a result a number of studies have tracked the movement of these commensals through Oceania, to use the movement of these animals as a proxy for human migration.

The Pacific rat (*Rattus exulans*) is found throughout Island Southeast Asia, and its remains are present in early Lapita sites (Matisoo-Smith & Robins, 2004). Analysis of mtDNA lineages on the rat indicates their likely homeland regions. The lack of early archaeological evidence of the rat in Taiwan is considered to work against the express train model. Likewise the slow boat model is rejected due to the complex interaction of a number of different haplogroups. This suggests several introductions from a number of sources, consistent with post settlement contact and exchange, and would favour Green's VC Triple I model (Matisoo-Smith & Robins, 2004).

The pig is also found throughout Island Southeast Asia, with possible origins in Vietnam, and mtDNA analysis on ancient and modern pigs show they are linked to the main human migrations into Near and Remote Oceania, (Larson et al., 2007). Most likely domesticated pigs were acquired in Island Southeast Asia by the Austronesian speaking migrants moving south and then east into Near Oceania, where pigs begin to appear in the Northern Moluccas about 3500 BP, and then taken into Remote Oceania as part of the Lapita migration (Larson et al., 2007; Lum, McIntyre, Greger, Huffman, & Vilar, 2006). It is likely domesticated chicken were introduced along much the same geographical route (Liu et al., 2006).

Although not strictly speaking a commensal, studies on the human pathogen Helicobacter pylori, a bacterial parasite found in the human gut, lend support for two different human migration movements into the Pacific. The first and early migration into New Guinea and Australia, and a second much later migration wave out of Taiwan, through Island Southeast Asia and into the Pacific (Moodley et al., 2009).

3.7. Asian Dispersal and Climates in the Upper Pleistocene

The context for Asian migratory movements around China before 5,000 years ago is set by the first movement of modern humans into the Far East, out of Africa (see 2.5 above). Following the Eemian interglacial, which finished 110,000 years ago, climates around the world cooled until the lowest temperatures were reached during the Last Glacial Maximum (LGM) 18-21,000 years ago (Fagan, 2009, pp. 66-69).

The climate during these cooler periods was much more arid, with large areas of desert in Central and South-western Asia, and sea levels were much lower (Metspalu, Kivisild, Bandelt, Richards, & Villems, 2006). Because of the aridity, glaciers did not form in Northern Asia in the same way as Europe, but significant pockets of ice and extremely low temperatures would have been common, below current extremes of down to as low as minus 71ºC (Hanihara, 1986). The climate in Taiwan in the period 60,000 to 12,000 years ago was around 4º to 10º C lower than current temperatures, with a rapid rise in temperatures after this time to the current tropical/subtropical climate (K.-C. Chang, 1969, p. 193).

One of the earliest fossils of modern humans is found in Mongolia, dating back 30,000 BP, indicating that the northern region of mainland Asia was settled during one of the coldest periods of recent time (Etler, 1996; Goebel, 1999; Tiemei & Yinyun, 1991). As Southeast Asia and Australia have been settled by modern humans since at least 45,000 BP, and possibly much longer (Barker, 2005; Bowler et al., 2003), it has been suggested that Asia was settled by two routes, a southerly early route following the coast of Asia towards Southeast Asia and Australia (Kong et al., 2011; Metspalu et al., 2006; Normile, 2009; Shi & Su, 2009), and a later more northerly route, through Central Asia and southern Siberia, which carried the mtDNA haplogroup B (Maca-Meyer, Gonzalez, Larruga, Flores, & Cabrera, 2001; Zhong et al., 2011). Genetic differences indicate that it is likely different populations migrated along both the Northern and Southern routes before 30,000 BP (Sanchez-Mazas, Di, & Riccio, 2011). This premise is supported by both mtDNA analysis (Tanaka et al., 2004) and Y-chromosome analysis (Kivisild et al., 2003).

Clearly modern humans inhabiting this Northeast Asian region some 30,000 years ago, in one of the coldest periods of climate experienced by modern humans, and having migrated there through a cold northerly route, would be expected to exhibit cold adaptations. It is estimated that humans, even in warm clothing, can last only an hour in minus 50ºC temperatures (Hanihara, 1986, p. 78). The inhabitants of this time and region, often known as Archaic Mongoloids, likely had a number of cold adaptations. Modern day Mongoloid populations show concurrence with Bergman’s and Allen’s rules, with a large trunk and short limbs (Kazuro, 1986, pp. 79-80). Although less skin pigmentation is common in cold dry areas, these Asian populations have slightly darker skin as there are more ultraviolet rays in Northeast Asia than Europe (Hanihara, 1986, p. 79).

Pacific Northeast Asia is seen as the most likely place of origin for the emergence of agriculture and complex social organization in East Asia. In the far north a hunting-gathering-fishing culture evolved during glacial times, with the emergence of farming, pottery, animal husbandry and pit house villages in North China before 7,000 BP (Aikens & Rhee, 1992, pp. 3-8; Bettinger, Barton, & Morgan, 2010). Before 10,000 BP the warming of the climate lead to a rapid increase in population numbers in Northeast Asia, leading to the dispersal of Neo-Mongoloids to China, the Western Pacific, and North America (Arnaiz-Villena et al., 2010; Birdsell, 1951, p. 2; Hanihara, 1986, p. 79). These populations had the physical and cultural capability to survive in cold climates, and they would have been able to easily adapt to new environments (Hanihara, 1986, p. 79).

Analysis of paleontological, archaeological, and genetic data provides one scenario that these Northeast Upper Pleistocene populations form the basis of modern Mongolian, Korean, Japanese, Native American and Polynesian populations, as shown in Figure 13 below (Nei & Roychoudhury, 1993). A similar dispersal out of Africa to Northeast Asia by at least 30,000 BP is put forward by Oppenheimer (2012). This scenario is supported by genetic analysis of modern Mongolian populations (Kolman et al., 1996). Polynesians, along with indigenous Taiwanese, share a number of genetic affinities with Mongolian populations, including mtDNA haplogroup B, which is a significant component of the Polynesian genotype (Friedlaender et al., 2008; Maca-Meyer et al., 2001; Trejaut et al., 2005).

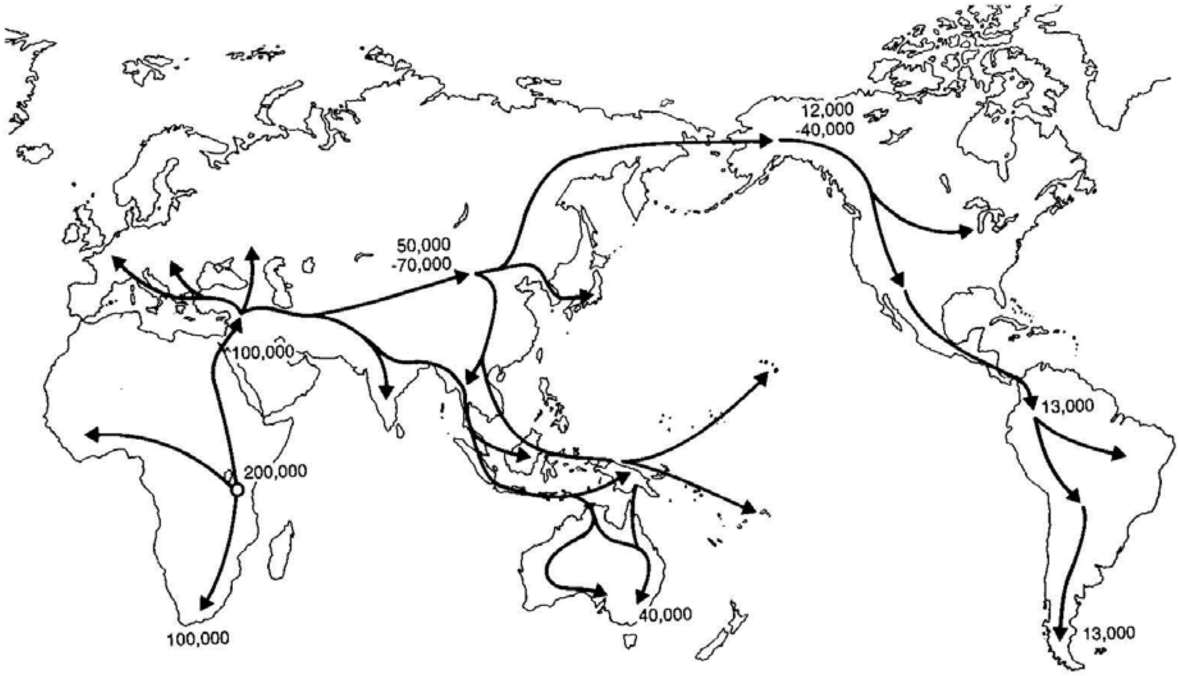


Figure 13. Scenario of the origins of major groups based on paleontological, archaeological, and genetic data (Nei & Roychoudhury, 1993).

The expansion of Neolithic Northeast Chinese populations, and the spread of the Lungshanoid agricultural and technological culture into South China have been linked with the emerging cultures in South China and Taiwan (K.-C. Chang, 1969, p. 250), and even with Polynesian cultures (K.-C. Chang, 1959). There is a similarity in the archaeological dates for the emergence of the Lungshanoid cultures in Taiwan and the dating for the emergence of proto-Austronesian language (K.-C. Chang, 1969, pp. 250-251).

There are a number of other studies that provide links between Northeast Asian and Southeast Asian populations, suggesting a southwards migration in the Upper Pleistocene. These include craniofacial and odontometric links between Polynesians and the Jomon people, who were the original indigenous inhabitants of Japan dating back 12,000 years ago (Brace, 1990; Brace, Brace, & Leonard, 1989; Brace & Nagai, 1982). Suggestions of a relationship between the Japanese language and Austronesian have been advanced since the 1920’s (Benedict, 1990, p. 1; Shichirō, 1976). Links between the cord-impressed pottery of the early Taiwan cultures, and the early Jomon pottery of Japan, dated more than 10,000 BP have been noted (K.-C. Chang, 1969, p. 221). Links between the indigenous Ainu people of Japan and Polynesians, with regard to physical characteristics, have also been postulated (Omoto, 1971-72). Craniometric similarities between the Ainu, American Indians and Polynesian populations have also been identified (Mayes, 2010).

Many of the physical characteristics of the Polynesians are similar to Asiatic Mongoloids (Howells, 1986; Katayama, 1996). Katayama (1996) terms Polynesian populations the *Hypermorphic Asiatic.* Polynesian origins are seen as Northeast Asian, as part of the prehistoric Mongoloid dispersals, with strong biological and cultural links between Polynesian and prehistoric Japanese populations (Katayama, 1990, 1996). These sea-based populations would have migrated down the East Chinese coast from North-east Asia to Taiwan.

3.8. Summary

The immediate ancestry of Polynesians lies with the Near Oceanic populations associated with the Lapita culture. The ancestral origin of these Lapita people is less clear-cut. Most of their cultural complex is derived from Island Southeast Asia, and a significant element of their genetic heritage is also associated with Southeast Asian populations, however, there was also admixture with indigenous Melanesian populations that had been living in this region for tens of thousands of years.

It is possible that there was more than one migratory event from Island Southeast Asia into Near Oceania, however, given the level of genetic homogeneity among Polynesians, it is likely that the ancestral origins of modern Polynesian populations derived from a relatively small founding population that represented only a subset of the genetic diversity among Near Oceanic populations associated with Lapita culture.

The majority of the evidence for the ancestral origins of the Lapita people points to Southeast Asia, in particular Taiwan, around 5,000 BP. Looking further back, there is a plausible scenario for the origins of these people being from Northeast Asia, where the environment would have reflected extremely cold temperatures for many thousands of years. If the Polynesians body morphology reflects an adaptation to a cold environment, then this is the most likely location where these adaptations would have evolved, sometime before 7,000 BP.

In order to test this theory, it is necessary to determine a research methodology that might help verify that the ancestral origin of Polynesian populations lies in a much colder environment. This methodology, a study of cold induced vasodilation response, forms the primary basis of this research.

Chapter 4. Cold Induced Vasodilation Response

4.1. Human Response to Cold

Human populations inhabit most regions of the world, encompassing nearly every environmental extreme. This is despite the fact that, in general, all humans are of similar physical characteristics; a linear build, large, hairless and sweaty (R.W. Newman, 1970). As mammals, humans are equipped with a plasticity of form that enables a limited adaptation to local environs. Whilst cultural adaptations have become more important to modern humans, evolutionary theory suggests that over time populations will have developed biological adaptations to their local climate (Steegmann, 1975, pp. 130-132).

Survival in a cold climate requires individuals to maintain their core body temperature, generally at around 37-38ºC (LeBlanc, 1975, p. 161). Failure to do so will lead to tissue damage, by way of frostbite, or eventually to death by hypothermia, if body temperature falls to a sufficiently low temperature, usually 31-32ºC (Beall & Steegmann, 2000, p. 164). Humans are not considered particularly tolerant to very cold conditions when compared with other mammals that inhabit the higher latitudes; in fact humans could be considered a predominantly tropical species (LeBlanc, 1975, p. 3).

Thermoregulation of the human body is governed by four subsystems that work together to maintain thermal equilibrium (Werner, 1987):

1. Passive traits such as subcutaneous fat, muscle tissue and body proportions.
2. Receptors located at varying intervals in the body that are triggered when tissue temperatures get too high or too low.
3. Neurons in the brain act as information processors to sense temperature changes and determine body responses.
4. Effectors carry messages to the parts of the body to initiate physical responses, including blood vessel constriction or dilation, muscle shivering, changes to respiration and metabolic rate, and sweating.

Human biological adaptations to climate can be developmental, with changes in physiology that occur during an individual's lifetime, providing acclimatization to environmental conditions. For example cold acclimatization can lower the core body temperature at which shivering is activated, whereas heat acclimatization can lower the core body temperature which activates sweating (Bruck, 1980). Interestingly, the cold acclimatization response would see the body reach a lower temperature before the heat generating shivering mechanism activates, possibly providing greater danger to the body in the short term, but conserving metabolic energy.

Alternatively human biological adaptations to climate can be a reflection of genetic traits that have evolved over many thousands of years. It is these genetic adaptations that form the basis of this study. Chapter 2 above covered human body morphology, which indicates adaptations to different environments in human populations found in varying climates. Other genetic adaptations concern the ability of the human body to maintain the temperature of peripheral extremities, such as cold induced vasodilation response.

4.2. Cold Induced Vasodilation Response

The primary reaction of the human body during exposure to cold is the conservation of core body temperature to protect vital organs by way of vasoconstriction, which restricts the flow of blood to the body's extremities, in particular the limbs, fingers and toes, as well as other mechanisms such as shivering (Daanen, 2003). Whilst vasoconstriction is an efficient mechanism to preserve core body temperatures, the extremities can rapidly lose heat to their environment, reaching a dangerously low temperature. This can result in a loss of dexterity, or tissue damage which can result in permanent impairment.

Cold induced vasodilation (CIVD) response is a secondary response of the human body preventing, or slowing the loss of temperature in the extremities. A CIVD response is generally only seen when skin temperatures fall below 12 ºC (Keatinge & Harman, 1980, p. 99). The blood vessels exposed to the cold, especially the small arteries, briefly dilate, allowing warm blood into the cold extremities. A CIVD response may occur after 5-10 minutes of cooling, with the body sending a brief flow of blood to the extremities in cycles, re-warming the fingers and maintaining their function.

The temperature response in the fingers subjected to extreme cooling (5ºC) over time can be seen in figure 14 below. A CIVD response can be defined as an increase of at least 1°C or more during exposure to cold (Hurlich & Steegmann, 1979; Little, Brooke, Mazess, & Baker, 1971; So, 1975). CIVD response has been observed in a number of animals including cats, birds, rats, monkeys and sheep (Folkow, Fox, Krog, Odelram, & Thorén, 1963; Gardner & Webb, 1986).

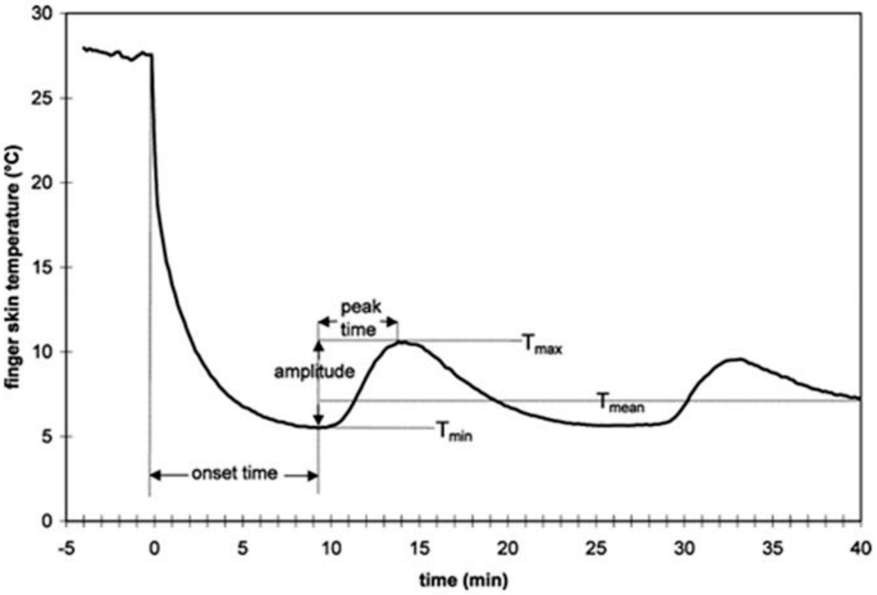


Figure 14. Parameters derived from a temperature profile of a fingertip immersed in cold water. (Daanen, 2003).

Figure 14 shows the parameters derived from a temperature profile of a fingertip immersed in cold water. The onset time is the time from immersion to the minimum temperature (T_{min}). The amplitude is the difference between T_{min} and the maximum temperature (T_{max}). Peak time is the time interval between T_{min} and T_{max}. The mean finger skin temperature (T_{mean}) denotes the finger skin temperature averaged over the immersion period, excluding onset time. Also observed is the frequency of waves or cycles during the test period (Daanen, 2003).

CIVD response was first described by Lewis (1930), who used the term *hunting response* to describe the alternating intervals of vasoconstriction and vasodilation that were observed when a finger was immersed in cold water with a temperature below 18ºC. The vasodilation response generally occurred within 5-10 minutes of immersion in cold water. Lewis (1930) considered this response a protective mechanism to keep the temperature of these exposed parts from falling too low and experiencing injury.

There are four possible responses when blood vessels are exposed to the cold (Purkayastha, Selvamurthy, & Ilavazhagan, 1992).

1. The hunting response as described by Lewis (1930).
2. A constant state of vasoconstriction.
3. Slow steady and continuous re-warming.

4. An initial period of vasoconstriction followed by an increase and maintenance of a constant temperature.

The majority of individuals will exhibit a CIVD response, with one study observing the hunting response in 210 out of 226 (93%) participants (Daanen, 2001, 2003).

Another study identified three possible responses (O'Brien, 2005).

1. Classic hunting response.
2. Sustained temperature after the first CIVD (proportional control).
3. No CIVD response.

In this study 30% of subjects had proportional control and 70% had the classic hunting response (O'Brien, 2005).

CIVD response can be enhanced to a degree through acclimatization to a cold environment; for example people working regularly with their hands in cold water, such as fishermen in cold climates. In cold stress tests on their fingers, Lapp, Norwegian and British fisherman show a more rapid onset of CIVD response compared with a control group, although the magnitude of response was not altered, suggesting that the acclimatization does not change the local vascular response (Krog, Folkow, Fox, & Andersen, 1960; Nelms & Soper, 1962).

In similar tests, Canadian fishermen showed a greater heat flow in their fingers, and a higher finger temperature, as well as less pain and numbness (LeBlanc, Hildes, & Heroux, 1960). In a Japanese study, workers in an ice chamber showed a greater CIVD response than workers in a cool room (Tanaka, 1971a). In contrast, studies of a short term exposure to cold conditions, such as a 2 week stay in the Arctic, tend to suggest a very slight decrease in CIVD response (Livingstone, 1976; Livingstone, Romet, Keefe, & Nolan, 1996).

Other factors that can affect CIVD response include;

- Age, with a tendency to a reduced CIVD and vasoconstriction response to cold in older subjects over 60 (Khan, Spence, & Belch, 1992; Sawada, 1996). One study on Chinese males aged 15-74 found the age of maximum CIVD response to be 25-29, and a CIVD response was to be found in babies as young as 3 days old (Yoshimura & Iida, 1952)

- Gender, with some studies showing a slight enhanced response in males (Cooke, Creager, Osmundson, & Shepherd, 1990; Reading, Roberts, & Prusaczyk, 1997), but with other studies showing little gender difference at all (Lund-Larsen, Wika, & Krog, 1970; Miller & Irving, 1962; Tanaka, 1971b; Yoshimura & Iida, 1952).

- Alcohol, studies show mixed results with alcohol delaying the onset of shivering and vasoconstriction, and vasodilation occurring slightly earlier (Daanen, 2003; Granberg, 1991).

- Tobacco smoking can temporarily cause peripheral vasoconstriction, and the vasodilation response is sluggish soon after smoking a cigarette, although the effect of tobacco smoke decreases over time and at 24 hours it has minimal impact (Cleophas, Fennis, & van't Laar, 1982). One study observed that regular smokers displayed a faster CIVD response time, and higher finger temperatures than non-smokers (Daanen, 2001, 2003).

- Diet, in particular high levels of protein, or vitamin C can enhance the CIVD response (Yoshimura & Iida, 1952).

- Vascular pathology. The most common disorder that would affect CIVD response is Raynaud’s disease, a vasopathic disorder in which extreme vasoconstriction of the peripheral blood vessels, particularly the fingers, causes tissue hypoxia and discoloration of the skin, is generally caused by emotional stress or cold, and is more common with women than men (Jobe, Goldman, & Beetham, 1985). Suffers of Raynaud’s disease exhibit a reduced CIVD response (Jobe et al., 1985). Those with frostbite cold injuries to their hands or feet show little or no sign of CIVD response (Meehan, 1955b).

- Cold resistance training. Studies have shown it is possible to show minor enhancement in the CIVD response of peripheral extremities with repeated immersion in very cold water, as well as a reduction in pain sensation (Glaser, Hall, & Whittow, 1959; Glaser & Whittow, 1957; Yoshimura & Iida, 1952).

- Altitude, in particular hypoxia, will reduce the magnitude of the CIVD response, although acclimatization to altitude will show a gradual improvement (Daanen & Van Ruiten, 2000; Mathew, Purkayastha, Selvamurthy, & Malhotra, 1977).

- Core body temperature. A higher core body temperature will generally enhance the CIVD response, as well as a higher mean skin temperature (Daanen, Van de Linde, Romet, & Ducharme, 1997).

Experiments on the reproducibility of CIVD response show that results with repeated testing of individual subjects are consistent within a range of between 0.5ºC and 1.0ºC, with mean values over time more consistent than minimum temperatures (Daanen et al., 1997; Meehan, 1955a; O'Brien, 2005; Yoshimura & Iida, 1952). This is despite a lack of standardization of testing procedures. Reproducibility is higher in experiments with whole hand immersion as opposed to single finger immersion (Sendowski, Savourey, Besnard, & Bittel, 1997).

A number of studies have noted the high levels of pain experienced by individuals subjected to cold water testing on their hands, particularly during the initial vasoconstriction phase (Heus, Daanen, & Havenith, 1995; LeBlanc, 1975, pp. 128-129). There is a significant correlation between the strength of the vasoconstriction and the degree of pain experienced by the subject, which may suggest the contractions of the skin vessels are a component of the pain (Anton, Gilly, Kreh, & Handwerker, 1982; Kreh, Anton, Gilly, & Handwerker, 1984).

4.3. Physiology of CIVD Response

Most researchers use the hands to quantify the CIVD response, and in particular the finger skin temperature, which reflects the blood flow, and therefore the amount of heat conveyed to this area. Skin is made up of two layers, the outer layer, or epidermis, which is the waterproof layer, and the inner layer, or dermis, which contains the blood vessels, lymphatics, sensory nerves and receptors, and hair follicles (Roddie, 2011, p. 285).

The arterio-venous anastomoses (AVAs) are thought to play a significant role in CIVD response (Grant, 1930; Roddie, 2011, p. 286). AVAs are the small blood vessels that connect the arteries and veins in the finger to allow these arteries and veins to service the same volume of tissue (Hale & Burch, 1960). They are controlled by the sympathetic nervous system, and contain a good supply of non-myelinated fibres on their thick muscular, deeply enervated walls, allowing almost compete closure of the blood vessel (Daanen, 2003; Roddie, 2011, p. 286). They are the first vessels to open at the onset of the CIVD response (Keatinge & Harman, 1980, p. 102).

AVAs are found mainly on the inside of the hands and feet, as well as ears and nail beds, with up to 500/cm² (Grant & Bland, 1931). Blood flowing through the dermal AVAs avoids the high resistance arterioles and capillaries and tends to flood the tissue with warm blood when they are fully open (Roddie, 2011, pp. 286-287). Skin temperature in the extremities is largely dependent on skin blood flow, as there is little tissue metabolic heat generated (Roddie, 2011, p. 287). Therefore skin temperature measurement is a good indicator of skin blood flow. The intensity of CIVD response in any particular part of the body is directly related to the density of AVAs (Grant & Bland, 1931).

A number of hypotheses have been advanced as to the underlying mechanism behind the CIVD response. Four of the most important are outlined by Daanen (2003).

1. Axon reflex

   Lewis (1930) in his original experiments on CIVD response concluded that the likely primary cause of the response was an axon reflex. An axon is a slim projection from a nerve cell, or neuron, which conducts impulses away from the neuron's cell body. An axon reflex occurs when cold stimulates the nerve endings of the neurons, with the impulses conveyed via the axon branches. The nerve endings release vasodilator substances which causes cutaneous vasodilation (Hornyak, Naver, Rydenhag, & Wallin, 1990). This could explain why there is no CIVD response when the nerves have been damaged, possibly by frostbite. However, experiments using electricity to stimulate an axon reflex in a hand immersed in cold water failed to generate a CIVD response, making the axon reflex an unlikely explanation (Daanen & Ducharme, 2000). In addition a CIVD response can occasionally be observed even after complete degeneration of the nerve supply (Keatinge & Harman, 1980, p. 103).

2. Dilating substance entering blood stream

   A CIVD response will generally only occur when the nerves are intact, which suggests that the vasodilator should be related to the nervous system. Cold exposure stimulates the release of nitric oxide, which is a powerful vasodilator. It may be that this substance plays a role in the CIVD response (Daanen, 2003)

3. Effect of cold on vascular smooth muscle activity

   When subjected to cold temperatures, the walls of the blood vessels contract, however, below a certain temperature, the contractile system relaxes and vasodilation occurs (Keatinge, 1970; Keatinge & Harman, 1980, pp. 99-102). It has been suggested that this reduced smooth muscle activity in the walls of the blood vessels, due to cold, is the main factor behind CIVD response (Folkow et al., 1963).

4. Decreased release of norepinephrine (noradrenaline) from adrenergic nerve endings

   In one experiment, no CIVD response was observed when norepinephrine was continuously perfused into rats' tails, while the tails were immersed in cold water (Gardner & Webb, 1986). They concluded that a CIVD response will only occur when norepinephrine is no longer released from adrenergic nerve endings. Following iontophoresis of norepinephrine from the skin of the fingers, CIVD response still occurred at reduced levels, but eventually becomes low enough to produce almost complete vasoconstriction (Keatinge, 1961; Keatinge & Harman, 1980, p. 104). Under cold stress, the sensitivity of α_2-adrenoreceptors for norepinephrine is increased, with the reduced levels of norepinephrine producing a fall in tissue temperature that leads to cold paralysis of the blood vessels, which is a major factor in CIVD response (Daanen, 2003; Freedman, Sabharwal, Moten, & Migaly, 1992; Keatinge & Harman, 1980, p. 105). Adrenoreceptors are more prominent in digital arteries than in more proximal ones, suggesting a greater role for distal arteries in thermoregulation, thus explaining the enhanced CIVD response found in fingers (Freedman et al., 1992).

Current thinking tends to lean towards hypothesis 4 above as the most likely explanation for CIVD response (Daanen, 2003). CIVD response is the likely result of a decrease in norepinephrine from the sympathetic nerves to the muscular coat of the AVAs during a period of localised cold. If an enhanced CIVD response has been subject to favourable selection in human populations inhabiting a cold environment in the past, then it must have provided some adaptive benefits for individuals to help deal with such a harsh climate.

4.4. Adaptive Features of CIVD Response in Hand

Efficient functioning in a cold climate requires the maintenance of a body temperature that allows the body to sustain mental and physiological capabilities. The extremities, especially the hands and feet, are particularly vulnerable to heat loss, which can cause a loss of movement and dexterity, which may put survival at risk. The hands and feet are superb heat exchangers by virtue of their large surface areas, lack of subcutaneous fat, and low metabolic heat production and this can result in a loss of manual dexterity, frostbite and tissue damage very quickly (Hanna & Brown, 1983).

A skin temperature below 15°C reduces manual dexterity, and below 10°C there is a complete loss of performance in motor skills (Heus et al., 1995). Below 12ºC there is a loss of tactile sensation (Lockhart, Kiess, & Clegg, 1975; Mackworth, 1953). There is a loss of manual dexterity in the hands under cold conditions even when whole body temperature is maintained (Gaydos & Dusek, 1958). In one study, which exposed fingers to extreme cold, freezing of the finger did not occur where there was a CIVD response; where there was no CIVD response finger freezing occurred every time (Wilson & Goldman, 1970). Any mechanism to assist the maintenance of finger temperature would enhance the chances of survival in a cold climate.

Hand or finger temperatures are an important and meaningful indicator of adaptation, as manual dexterity is a key factor in maintaining the ability to use tools and function in the extreme cold. A study on outdoor work temperatures in sub-arctic Canada in Winter showed temperatures in the range of -21ºC to -35ºC (Steegmann, 1977). Even at those temperatures finger temperatures of 14-19ºC were maintained by cold adapted inhabitants when engaged in activities such as hunting and wood gathering. Tasks requiring fine motor activities could only be completed with bare hands rather than the mittens generally worn. The incidence of frostbite was among this group was relatively rare.

The chances of survival by an individual inhabiting an extremely cold environment would likely be severely reduced by a decrease in dexterity, especially in the glacial environment of the Upper Pleistocene. It may be argued that CIVD response has an adverse effect in that it can reduce body temperatures by cycling warm blood through cold extremities (Keatinge, 1970, p. 102; Keatinge & Harman, 1980). The loss of heat from one hand in ice water can lead to a drop in core body temperature of 0.6ºC in less than 10 minutes (Roddie, 2011, p. 302). It could be argued, given that a CIVD response is maintained by the body even in the face of core body heat loss, that this demonstrates the selective advantage in maintaining hand functioning in the cold. Otherwise the CIVD response would likely have been selected against. In any event CIVD practically ceases when core body temperature falls to dangerous levels, so the increased risk from body heat loss is diminished at that point (Daanen, 2003).

If differences are to be observed in human response to cold, then these are more likely to be evident in extremity cooling (Steegmann, 1975). Extremities are more exposed, and therefore more difficult to protect from cold injury. Serious injury to extremities through exposure to cold can reduce the chances of survival either by way of death, or reduced ability to effectively hunt or gather food (Steegmann, 1975).

Any physiological adaptation that helps preserve hand temperature at a level consistent with maintaining functionality would be beneficial. This is exactly what CIVD response facilitates and, if genetic in origin, would be subject to natural selection in human populations that have traditionally inhabited a seasonally cold environment. It is therefore necessary to compare CIVD response between human populations who have traditionally inhabited different environments to identify whether it has been a physical trait that has been the subject of natural selection.

4.5. Differences in CIVD Response between Human Populations

One of the first studies to identify a possible genetic basis for a vascular adaptation to cold was Schuman's analysis of 716 frostbite injuries to American soldiers in the winter during the Korean War (Schuman, 1953). Winter conditions in Korea were severe, with many cold injuries, particularly frostbite, affecting the ability of soldiers to maintain active duty (Orr & Fainer, 1952). Detailed analysis of risk factors such as smoking, age, rank, State of origin, amongst others, showed that African American heritage was the single greatest risk factor. Schumann (1953) concluded that African Americans were more susceptible to cold related injuries due to their ancestral origins in tropical Africa.

African American soldiers sometimes had up to three times the number of frostbite injuries as European soldiers in similar circumstances (Orr & Fainer, 1952). Even African Americans raised in cold climates in the USA still had a significantly higher risk of frostbite than their European American counterparts; however, their risk was not as high as those African Americans from geographically warmer areas in the USA. This indicated there are both a developmental acclimatisation, and a genetic adaptation to cold environment identifiable in populations from different geographical locations and with varying ethnic heritage.

As a result of Schumann's study, Meehan (1955b) undertook a series of experiments using US Army personnel to investigate what he called individual and racial variation in CIVD response to a cold stimulus. The three subject groups were Caucasians, African-American and Alaskan natives. Alaskan natives maintained the highest finger temperatures during immersion in cold water while the African-American group maintained the lowest. The differences between the Caucasian and Alaskan native groups were not significant and may have represented either racial or individual adaptation, but there was a strong difference between the Caucasian and African-American groups indicating a genetic basis for the results. Similar results were produced in a number of follow up studies by the US military with varying participants including European, African American and Alaskan natives (Adams & Corvina, 1958; Iiampietro, Goldman, Buskirk, & Bass, 1959; M. T. Newman, 1967; R. W. Newman, 1969; Rennie & Adams, 1957).

These early studies all indicated that there was a measurable difference in CIVD response between human populations with differing geographical ancestry. Over the years a number of additional studies into the CIVD response of differing human populations have been completed. A brief summary of some of this research is outlined below.

- Comparison of hand blood flow and temperature between male Eskimo (*n*=22) and medical students (*n*=37) from Ontario subjected to cold water cooling at 5ºC over a 2 hour period. The hand blood flow of the Eskimo was twice that of the students, and skin temperature was greater (Brown & Page, 1952).

- Comparison between Alaskan Indian (*n*=9) and urban European males (*n*=8) subjected to a 30 minute hand immersion in 5ºC water. Finger and wrist skin temperatures were recorded. The Alaskan Indians exhibited higher finger temperatures during the cold immersion and less pain (Elsner, Nelms, & Irving, 1960).

- Comparison between male Norwegian Lapps (*n*=13) and North Norwegian fishermen (*n*=11), and a control group of expedition staff and Swedish students (*n*=12). Subjects’ hands were immersed in a variety of water baths with temperatures ranging from 20ºC to 2ºC, over a time period of between 20-30 minutes. The magnitude of CIVD response was similar among all three groups, but the onset of CIVD response was slower in the control group (Krog et al., 1960).

- Comparison between Canadian Gaspé fisherman (*n*=14) and control group from the same vicinity (*n*=14). Subjects hands were immersed in 2.5ºC water for 10 minutes. The fishermen maintained a higher finger temperature than the control group indicating evidence of acclimatization (LeBlanc et al., 1960).

- Comparison between Eskimo men, women and children, and 2 groups of European males, one of which was habituated to the cold. The tests were conducted in Alaska. Their hands were exposed to air temperatures of 3º to -7ºC for 30-45 minutes. The

Eskimo subjects maintained higher finger temperatures, with less pain, than the European groups, and the habituated European group maintained higher finger temperatures than the non-habituated European group (Miller & Irving, 1962).

- Comparison between British (Lancashire) fish filleters (*n*=11) and a control group (*n*=9) subjected to hand immersion in 0ºC water for 15 minutes. The fish filleters displayed an earlier onset of CIVD response, with a greater magnitude, again seen as evidence of acclimatization (Nelms & Soper, 1962).

- Comparison of finger temperature between groups of 6 male subjects, being Alaskan Indians, laboratory staff, and a habituated group of laboratory staff who immersed their fingers in cold water 6 times a day for 125 days, and a starvation group of staff who had no food for 5 days. Immersion was for 10 minutes in 0ºC water. The Alaskan Indian group maintained the highest finger temperature followed by the habituated group. Testing was conducted at an airforce base in Alaska (Eagan, 1963).

- Comparison between male (*n*=39) and female (*n*=33) Greenland Eskimo and male Norwegian lumberjacks subjected to 20 minute hand immersion in cold water at 0.5º and 1.5ºC. The Eskimo showed a significantly enhanced ability to maintain heat output. There were no differences in relation to gender or age (Lund-Larsen et al., 1970).

- Comparison between two groups of Quechua Indians, one from the Peruvian Andes (*n*=41), and one from the coast (*n*=10), and two groups of Europeans, US and British (*n*=8). Subjects exposed their hand to air temperatures of 0ºC for 60 minutes. There was no significant difference between the two Indian groups, but both exhibited higher finger and hand temperatures than the European participants, more so for the finger than the hand (Little et al., 1971).

- Comparison between male students living in New York State but whose ancestry is North Chinese (*n*=16), and South Chinese (*n*=13). Hand was immersed in 5ºC water for 30 minutes while finger temperature was recorded. The North Chinese, representing subjects with ancestry from a colder environment, maintained higher finger temperatures with an earlier onset of CIVD response (So, 1975).

- Comparison between Native American males in Northern Ontario from two different villages (*n*=11 for both) with the two villages representing varying degrees of European admixture. Subjected to hand immersion in 5ºC cold water for 30 minutes while skin temperature of the middle finger was recorded. The village with less European genetic admixture showed the greater CIVD response (Hurlich & Steegmann, 1979).

- Comparison between four groups of ten subjects each from South India, North India, Ghurkhas and high altitude Natives (HAN). Participants subjected to immersion of their hand in 4ºC cold water for 30 minutes while skin temperature of the index finger was recorded. The CIVD response was greatest in the HAN and lowest in the South Indian groups. The other two groups had a similar response, but greater than the South Indian group (Mathew, Purkayastha, & Nayar, 1979).

These studies show populations with ancestral origins in a cold environment exhibiting a stronger CIVD response than those from warmer environments. This indicates there is a strong genetic basis to CIVD response, and populations with ancestry in cold climate should display an enhanced CIVD response over populations with ancestry in warmer climates, even when the cold adapted populations are no longer subjected to cold conditions. Variation exists within these populations and it is the mean differences between each population that demonstrates a likely adaptation to a colder climate through an enhanced CIVD response.

4.6. Summary

Humans have been primarily a tropical mammal for most of their evolutionary history. Retention of body temperature at around 37-38ºC is essential for the preservation of life. Humans have developed limited biological adaptations for maintaining core body temperature when subjected to cold. These adaptations can be developmental or genetic.

One such adaptation is CIVD response. This assists the maintenance of hand and finger temperatures when subjected to extreme cold, which provides a survival advantage in terms of retaining manual dexterity. Studies indicate variation in CIVD response between human populations with differing geographical ancestry. Those populations with ancestry in cold climates exhibit an enhanced CIVD response compared with those with more tropical ancestry. This indicates CIVD response is a genetic adaptation to cold environments. CIVD response can be measured and comparisons made among different populations and this forms the basis of an important part of the present study.

Chapter 5. Methodology

5.1. Participant Selection

Ethics committee approval for research involving human participants was obtained from the University of Auckland Human Participants Ethics Committee on 11 December 2008, reference number 2008/468. Recruitment of participants was largely undertaken at the University of Auckland. Participants were sought by word of mouth, through posters positioned around the University, contact with student associations, and through a website. A number of talks were also given to groups of potential participants. All potential participants were advised to review the website to ascertain the criteria, and the requirements involved in participation

On occasion participants may have been rushing to get to the lab on time. To ensure this did not affect any results, each participant was seated and taken through the questionnaire first, and then the anthropometric measurements were taken. This process usually took around 30 minutes in an air conditioned lab. At this point all the participants would be in a stable rested state before the cold induced vasodilation response testing commenced.

Testing was carried out between February 2009 and August 2010 in Auckland. Auckland has a temperate climate, with an average annual daily temperature of 15.5°C, a daily minimum average temperature of 7.5ºC in July, being the coldest month, and a daily maximum average temperature of 24.1 ºC in February, being the warmest month (World Meteorological Organization, 2011). The lab used for testing was air conditioned, as are much of the University buildings. The likelihood of any effect on the CIVD response testing due to local climatic conditions is minimal.

In terms of other factors that may have affected testing, all participants were warned before arrival that they must not have taken alcohol, drugs, caffeine, eaten a large meal, or have smoked for four hours prior to testing. Participants were questioned on this on arrival to ensure their compliance.

A sample group of at least 50 European, 50 East Asian, 50 Polynesian, 50 Indian, 20 African, and 20 Melanesian participants was sought. The smaller sample size of African and Melanesian participants was due to the small numbers of these ethnic groups in Auckland and the difficulty of recruitment. In total 286 subjects participated in the study. Of the 286 participants, 277 (97%) were tested in the biology labs at the University of Auckland, 3 at the

Auckland University of Technology, and 6 at my residence. One participant, of Arab origin was excluded from the final analysis, as there seemed little point in having an ethnic group of just one participant, and no other Arabs participated in the study. This left a total of 285 participants. The same equipment was used in all test locations.

Each participant was asked a series of questions relating to their age, birthplace, countries they have lived in, history of occupations, gender, ancestry back to their grandparents, languages spoken by them or their parents or grandparents, medical history, fitness level, smoking history, last time of alcohol and caffeine consumption. This information, along with the anthropometric measurements taken from each participant, was recorded on an interview and data recording sheet, a copy of which is in appendix B. From this information each participant was categorised into an ethnic group.

The main purpose of this questionnaire was to:

1. Determine ethnicity for each participant.
2. To determine whether a participant qualified for either the anthropometric measurements survey, or the CIVD response testing.

Full details of the determination of ethnicity are covered in detail below. In terms of qualifying participants to participate in the testing procedures, no participant was disqualified from the anthropometric testing as none had any particular physical characteristics which may have affected these results. A number of participants, 11 in total, were excluded from the CIVD response testing and these were on the following grounds; failed to complete the CIVD response test satisfactorily (3 participants), on blood related prescription medications (4), age over 60 (1), previous frostbite finger injury (1), diabetic (1), finger drummer, with calluses on finger (1).

Every participant was questioned on their history of occupations, and the countries they had resided in for more than a 12 month period. None had been subjected to any significant period of intense cold, or high altitude. Therefore no participants were excluded from the CIVD response testing on the grounds of the likelihood of any significant developmental adaptations to cold.

All of the participants were residing in Auckland at the time of the testing, and the majority were students or staff at the University of Auckland, or friends of these. Table 3 below shows the average length of time of New Zealand residence for each participant group, by both detailed and broad ethnic grouping categorisation. In general Polynesians had on average resided in New Zealand for the longest period of time, followed by Europeans, particularly UK Europeans. Indians, Melanesians and Africans had resided in New Zealand for the shortest period, with the shortest average length of time being 4.8 years for the Indian group using the broad ethnic grouping categorisation (EG1), and 1.4 years for the PNG Melanesians by more detailed categorisation (EG2).

For the groups with the most likelihood of exposure to an extremely cold climate, being Asian and European participants, these groups on average had all lived in New Zealand for at least 8.5 years, and it is unlikely that these participants would have developed developmental adaptations to cold that would have affected their CIVD response testing.

Table 3. No of years participants had resided in New Zealand.

EG1	N	Mean	Std. Deviation
Polynesian	50	18.140	5.660
Other European	52	16.760	14.658
Other	22	13.136	8.281
Chinese	27	11.389	6.746
Korean	24	10.500	5.184
North European	13	9.038	14.364
Melanesian	25	5.560	6.264
African	21	4.929	3.497
Indian	51	4.775	5.774
Total	285	11.335	10.104

EG2	N	Mean	Std. Deviation
Mixed Melanesian	1	21.000	
Other Polynesian	10	19.600	4.300
Tongan	8	19.000	7.856
UK European	37	18.203	15.268
Samoan	32	17.469	5.477
Mixed European	9	16.611	12.077
Mixed Indian	3	14.333	6.807
Mixed Polynesian	6	12.833	7.731
Mixed Asian	12	12.333	9.411
South Chinese	21	12.214	7.054
Korean	24	10.500	5.184
North European	13	9.038	14.364
North Chinese	6	8.500	4.970
Island Melanesian	15	8.367	6.749
South European	6	8.083	13.192
East African	9	6.444	4.035
North Indian	28	5.554	6.071
South Indian	23	3.826	5.370
West African	12	3.792	2.667
PNG Melanesian	10	1.350	0.973
Total	285	11.335	10.104

Many of the participants (27%) were born in New Zealand, with the next most frequent country of birth being India, followed by Korea and China. A list of the ten most common birthplaces is shown in Table 4 below. A full list of countries of birth can be found in Appendix D.

Table 4. Top ten participant birthplaces

	N
New Zealand	77
India	46
Korea	24
China	20
Solomon Islands	12
Samoa	10
PNG	10
UK	9
Nigeria	9
South Africa	7

As outlined in Chapter 2, many years of research has clearly established there is no biological basis for racial groupings. However, it is necessary to use general terms when describing the ethnic groups, or human populations that participated in this research. During the testing phase of this research, six main groupings were used, but more detailed information was obtained from each participant so that they could be subdivided into more precise subcategories. The terms used for these groups generally relate to the geographical area from which they derive their ancestry.

- European

  This grouping is made up of three subcategories. UK Europeans derive their ancestry from the United Kingdom and Ireland, and this makes up the bulk of the group. North European consists of participants from north continental Europe including northern France, Netherlands, Germany, Poland, the Czech Republic, Russia and Scandinavia. South European included participants from Spain, Portugal, Croatia, and those from South America with Spanish or Portuguese ancestry.

- East Asian

  This is a very broad category mainly consisting of those participants from China, or with Chinese ancestry, including Hong Kong and Taiwan, with a few born in New Zealand, and also a small number from Malaysia. The boundary for the subcategories for South and North Chinese was Beijing, with those from Beijing and geographical areas north of Beijing considered North Chinese. Local dialect was taken into consideration when determining geographical ancestry.

Within this group is a significant subcategory, Koreans, all of whom were from South Korea. At an early stage in testing it was realised that the sub-categorization of Chinese into North and South Chinese was going to be relatively arbitrary, and therefore the identification of Koreans as an East Asian group from a clearly defined geographical region that was subject to extreme seasonal cold was going to be an important element in the research. Therefore the East Asian category was replaced by two separate categories; Koreans and Chinese.

- Indian

  These are participants deriving ancestry from the country of India. Most were born in India, with some from Sri Lanka, New Zealand and Fiji. South Indians were those from Bangalore south, and Sri Lanka. Like the Chinese, local dialect was taken into account in determining whether to classify Indians as from the north or south, but again it was difficult to gauge how accurate this was going back in time.

- African

  This included Africans from sub-Saharan Africa. In the end these participants fell into two distinctive categories. One group of Africans were largely from the western side of the continent, including Nigeria, as well as Ghana and Gambia. The other group of Africans were from Ethiopia, Zimbabwe and Sudan, a more eastern part of Africa.

- Polynesian

  The bulk of Polynesian participants were from Tonga and Samoa, with a few smaller islands included. No Fijians were included in this category due to the strong admixture between Melanesian and Polynesian influences in these islands. Likewise no Maori were included in the study due to the history of interaction with European populations.

- Melanesian

  The use of the term Melanesian is often criticised as it is not a satisfactory term to refer to a biological grouping due to the diverse nature of populations in this region. Melanesia is used here as a geographical term rather than as a biological basis for population grouping. To be more precise, Melanesian participants were from the Solomon Islands, Papua New Guinea, and Vanuatu.

- Other

  All other participants, including those with mixed ancestry were included in this category.

Overall an approximately equal split by gender was obtained, although some ethnic groups varied as to gender balance as shown in below. A further analysis by more detailed ethnic group is shown in Table 5 below, based on more specific analysis of the ancestral origins of participants, taking into account the genealogy for each participant. Although some of the sample sizes become statistically insignificant due to their small size, it does allow for analysis of the different environmental zones found in the geographical regions.

Table 5. Participants by gender and detailed ethnic group (EG2).

		Gender					
		Male		Female		Total	
		N	%	N	%	N	%
EG2	UK European	23	62%	14	38%	37	13%
	North European	7	54%	6	46%	13	5%
	South European	4	67%	2	33%	6	2%
	Mixed European	4	44%	5	56%	9	3%
	Korean	11	46%	13	54%	24	8%
	North Chinese	3	50%	3	50%	6	2%
	South Chinese	10	48%	11	52%	21	7%
	Mixed Asian	4	33%	8	67%	12	4%
	North Indian	15	54%	13	46%	28	10%
	South Indian	16	70%	7	30%	23	8%
	Mixed Indian	1	33%	2	67%	3	1%
	West African	9	75%	3	25%	12	4%
	East African	5	56%	4	44%	9	3%
	Samoan	11	34%	21	66%	32	11%
	Tongan	5	62%	3	38%	8	3%
	Other Polynesian	3	30%	7	70%	10	4%
	Mixed Polynesian	2	33%	4	67%	6	2%
	Island Melanesian	4	27%	11	73%	15	5%
	PNG Melanesian	3	30%	7	70%	10	4%
	Mixed Melanesian	1	100%	0	0%	1	0%
	Total	141	49%	144	51%	285	100%

Initially it was planned to categorize participants into the 6 ethnic groups outlined above, with a seventh category for those with mixed ancestry, for the purposes of statistical analysis, with some analysis using the more detailed categorization as per Table 5 above. There were a number of problems with this categorization. One problem was the very broad category provided by the East Asian grouping. Not only does this group cover a very broad geographic area, but it also covers a wide number of distinct ethnic groups within the Asian region. Therefore this category was divided into two groups, separating Asian into Chinese and Korean ethnic groups. Asian who are not Korean or Chinese are included in the Other category, which also includes participants of mixed ancestry.

This breakdown provides the basis for analysis using two distinctive Asian ethnic groups, taking into account the significantly different climates found in Asia. It was difficult to gauge the accuracy of the breakdown between North and South Chinese. A reasonable sample size of Koreans was the best example of a North Asian ethnic group from a significantly cold climate, as well as being a region close to that hypothesized as a possible location for Polynesian ancestral origins, as covered in section 1.3.

In addition early hypothesis testing for CIVD response showed significant differences between the three European categories, specifically between the Northern European and the other two European groups. There were no other significant differences between any of the other subcategories.

The detailed ethnic categorization was too detailed, with too many small sample sizes, uncertain geographical barriers, and little statistically significant differences between the groups for most variables. The broad categorization was not detailed enough, not highlighting some of the statistical differences that emerged. On this basis the categorization shown in Table 6 was chosen as the basis for most of the statistical analysis. This has the Asian category split into Chinese and Korean, and the European category divided into Northern European and Other European, as described above. There were no significant statistical or geographic reasons to further divide any of the other groups into subcategories, although these are used on occasion to test a particular point. This broad categorization is called ethnic grouping 1 (EG1) as displayed in Table 6 below and the more detailed categorization as shown in Table 5 above is called ethnic grouping 2 (EG2).

Table 6. Participants by gender and broad ethnic group (EG1).

EG1	Gender					
	Male		Female		Total	
	N	%	N	%	N	%
Other European	31	60%	21	40%	52	18%
North European	7	54%	6	46%	13	5%
Korean	11	46%	13	54%	24	8%
Chinese	13	48%	14	52%	27	9%
Indian	31	61%	20	39%	51	18%
African	14	67%	7	33%	21	7%
Polynesian	19	38%	31	62%	50	18%
Melanesian	7	28%	18	72%	25	9%
Other	8	36%	14	64%	22	8%
Total	141	49%	144	51%	285	100%

Analysis by age group, as per Table 7 below, shows a bias towards younger participants, as would be expected for a study conducted at a University, where participants were largely recruited on campus. This is also deliberate as it provided a population sample with likely fewer health issues. In relation to CIVD testing, there are a number of variables, including age and health, which can affect an individual’s response, and which makes a younger age group a more reliable sample group.

Table 7. Participants by age group and EG1.

EG1	Age Group					
	<20	20-30	30-40	40-50	50+	Total
	N	N	N	N	N	N
Other European	1	33	9	2	2	47
North European	0	8	3	7	0	18
Korean	2	18	4	0	0	24
Chinese	2	24	1	0	0	27
Indian	6	37	6	2	0	51
African	6	12	2	1	0	21
Polynesian	17	32	1	0	0	50
Melanesian	2	2	18	2	1	25
Other	2	18	2	0	0	22
Total	38	184	46	14	3	285

Finally a small proportion, around 6% of participants were smokers, with the group having the highest percentage of smokers being Polynesian.

Table 8. Percentage of participants who smoked shown by EG1.

	Smoking Habits				
	Non-smoker	Smoker	Total		
	N	N	N	% who smoke	95% Confidence levels
Other European	52	0	52	0.0%	0% - 5.6%
North European	12	1	13	7.6%	0.2% - 36%
Korean	21	3	24	12.5%	2.7% - 32.4%
Chinese	26	1	27	3.7%	0.1% - 19.0%
Indian	50	1	51	2.0%	0.05% - 10.4%
African	20	1	21	4.8%	0.1% - 23.8%
Polynesian	43	7	50	14.0%	5.8% - 23.7%
Melanesian	22	3	25	12.0%	2.5% - 31.2%
Other	21	1	22	4.5%	0.1% - 22.8%
Total	267	18	285	6.3%	3.8% - 9.8%

5.2. Anthropometric Measurement

On arrival for testing, participants were given a copy of the participant information sheet to read, and were then asked to sign a participant consent form. Participants were assigned an ID number, and their names and email addresses were recorded on a separate register. Participants were then asked to remove outer layers of clothing, and footwear.

The following measurements were taken for each participant. Anthropometric measurements were taken in accordance with standard guidelines as outlined in Cameron (1984).

- Height was measured against a wall mounted stadiometer. Participants were asked to stand with a straight back up against the wall with their feet flat on the floor, and their heels, buttocks and scapulae against the wall. The head was positioned so that the lower orbits of the eyes are in line with the ear canal. Height was read off the stadiometer.

- Sitting height was measured against a wall mounted stadiometer. Participants were asked to sit up with a straight back on a steel stool placed against the wall, with their buttocks and scapulae against the wall, and their thighs and calves at a right angle to each other. The head was positioned so that the lower orbits of the eyes are in line with the ear canal. Head height was read off the stadiometer. The stool had been measured as to its height against the stadiometer, and this height was deducted from the head height to provide sitting height, or trunk length. Sitting height ratio was then calculated as sitting height divided by height.

- Weight was measured on a standard set of Salter scales by kilograms to one decimal place. The participants were requested to wear a minimum of clothing. The weight of the clothing that was worn was estimated, based on measurements that had been made of clothing before the study commenced, and was taken off the total weight. Participants were asked to stand still and a reading taken.
- Bi-acromial and biiliac measurements were made using an anthropometer from the Lafayette Instrument Company, USA. The tips of the acromial processes were located from behind while the participant was seated, with the shoulders relaxed. The anthropometer blades were placed on the lateral tips of the processes and a reading taken.
- Biiliac measurements were made by locating the iliac crests. The blades of the anthropometer were then placed on the most lateral points of the iliac crests and pressed inwards firmly to counter surplus flesh on the crests. A reading was then taken.
- Wrists and finger measurements were taken using digital stainless steel callipers. The participant held their left wrist in a horizontal plane, and the callipers were applied against the styloid processes of the ulna and the radius. Pressure was applied to the callipers to compress the soft tissue around the wrist. *
- Finger width was measured by the participant holding their left index finger in a horizontal plane, palm up. The callipers were applied against the distal inter-phalangeal joint between the distal phalanx and middle phalanx, in line with the distal interphalangeal crease. Slight pressure was applied to the callipers to compress the soft tissue around the joint. *
- Mid biceps circumference was measured using a plastic tape measure. The mid-upper arm point is located by finding the midpoint between the acromion and the olecranon on the lateral side of the arm, with the arm flexed at a right angle. The participant then stood in a relaxed posture, with their left arm hanging loose by their side. The tape is then passed around the biceps and tightened so that the tape is touching the skin, but not compressing it, and a reading taken.

- Skinfold was measured using plastic Slim Guide skinfold callipers. Triceps and biceps skinfold measurements were taken at the mid-upper arm point. Abdominal skinfold measurement was taken 5cm to the left of the umbilicus.

- Blood pressure and pulse was taken using an Omron 1A1B electronic blood pressure monitor. *

- Body temperature was taken using an Omron in ear thermometer, MC-510. *

* It was decided to record these measurements shortly after the study had commenced, so they are not available for all participants.

5.3. CIVD Response Testing

Details on participant selection have already been covered in section 4. Additional criteria have been applied to the participant selection for CIVD response over and above that applied to the section on anthropometric measurement, with a further 11 participants excluded from the CIVD analysis, leaving 274 participants, as outlined in section 5.1. The revised breakdown of participants by EG1 and gender is shown in Table 9 below.

Table 9. CIVD response testing participants by EG1.

		Gender					
		Male		Female		Total	
		N	%	N	%	N	%
EG1	Other European	26	55%	21	45%	47	17%
	N. European	7	54%	6	46%	13	5%
	Korean	11	46%	13	54%	24	9%
	Chinese	12	46%	14	54%	26	9%
	Indian	31	61%	20	39%	51	19%
	African	13	65%	7	35%	20	7%
	Polynesian	19	39%	30	61%	49	18%
	Melanesian	7	30%	16	70%	23	8%
	Other	8	38%	13	62%	21	8%
	Total	134	49%	140	51%	274	100%

Testing of CIVD response has been undertaken by many researchers in the last 60 years. The methodology adopted in this study is largely based on the methods described in the comprehensive review of finger cold induced vasodilation response completed by Daanen (2003), and the test procedures recommended by Beall and Steegmann (2000).

The hands are an easy site on the human body to work with, and respond quickly to environmental changes. In particular, fingers have little insulation and react swiftly to changes in temperature. A number of studies relied on finger immersion only in cold water, however, reproducibility is higher in experiments with whole hand immersion as opposed to single finger immersion (Sendowski et al., 1997).

Previous studies have subjected the fingers and hands to the cold by using cold air or cold water. Heat transference in water is 20-25 times faster than in the air (Daanen, 2003). Where the water is agitated, the heat transfer in water may be 50 times faster than in the air (Schmidt-Nielsen, 1983, p. 266). In addition cold water testing is much easier to set up, involving less equipment, and is easier to monitor and control than cold air. Testing of CIVD response in 0ºC water is the equivalent of testing CIVD response in -18ºC air (Daanen, 2003).

Finger skin is the most frequently used site for CIVD response measurement. Finger skin temperature is a proxy for measuring blood flow, which is the basis for cold induced vasoconstriction, and vasodilation responses. Blood flow to the fingers is the only source of heat when the fingers are immersed in cold water.

Past studies have varied as to which finger and hand which has been used to monitor temperature and blood flow. Most commonly the index or middle fingers are used to measure changes in temperature during CIVD response, or sometimes both. For this study the palmar side of the distal phalanx of the left index finger was chosen as the site to use for the attachment of the thermocouple to measure changes in surface skin temperature.

Both Daanen (2003) and Beall and Steegmann (2000) recommended a water temperature of 5ºC, and this was a commonly used temperature in past studies. It is easier to maintain than a temperature of 0ºC, and there was less likelihood of severe pain, or risk of injury to the finger. Likewise an immersion time of at least 30 minutes was recommended by both Daanen (2003) and Beall and Steegmann (2000), and this was the immersion time used for all testing.

A small thermocouple was taped to the midpoint of the palmar side of the distal phalanx of the left index finger, using waterproof BSN medical plastic tape. The tape was firmly adhered to the skin to remove any air bubbles, and to prevent any chance of water being in contact with the thermocouple, see Figure 15 below.

The thermocouple was attached by a wire to a data recorder, a Gemini tinytag view 2 temperature logger. This was programmed to record a temperature from the thermocouple every 10 seconds. The logger also has a screen which allowed the viewing of the temperature of the probe, to ensure that no unusual readings were being obtained. The wire leading to the thermocouple was also attached with tape to the palmar side of the proximal phalanx with 3M micropore tape to ensure the thermocouple did not pull off the finger in the event of movement of the arm.

Figure 15. Attachment of the thermocouple to the left index finger.

(photo taken by author).

A cooling bath was prepared in advance. This consisted of an Evakool ice box. This is a highly efficient insulated ice box. The inner and outer skins are one piece moulded fibreglass with no joins or projections. They are bonded together by rigid insulation foam, with the insulation injected under controlled temperature and pressure, creating perfect lamination and bond of both inner and outer skins. These ice boxes are capable of staying cold for 5-15 days without external cooling.

The lid was removed and a small water pump was attached to the side of the ice box. A piece of plastic tubing was run from the outflow of the pump and connected to a plastic right angle joint fastened to the opposite wall of the ice box, thus allowing complete circulation of the water. Tap water was placed in the ice box and shaved ice added until the water temperature was 5ºC, as measured by a probe placed in the ice box and attached to a temperature gauge. The water temperature was maintained at 5ºC, plus or minus 0.2ºC by the addition of further ice as necessary.

The participants were advised as to the nature of the test, and were warned that immersion of their hand in the cooling bath would cause a sudden cooling of the hand, which would likely result in some discomfort for at least a few minutes. Once the participants were ready, they placed their hand into the cooling bath up to the wrist, with the water level around the height of the styloid processes of the ulna and the radius, as per Figure 16 below. This figure also shows the thermocouple attached to the left index finger and wired to the temperature logger.

Two small plastic caps (actually chair leg caps), about 2 cm in diameter, were glued to the bottom of the ice box at right angles to the flow of the water. This was for the participants to place their middle and ring fingers in to retain a consistent hand position for all participants, and to maintain the water flow against the palmar surface of the index finger to ensure a consistent water temperature of 5ºC on the skin surface being measured.

Figure 16. The hand immersed in the circulating cooling bath.

(photo by author)

The hand was held in the water in that position for a total of 30 minutes, with the water temperature being continuously monitored, along with the hand position, and the comfort level of the participants. After 30 minutes the participants were able to remove their hand, the thermocouple was removed and the participants given paper towels to dry their hands. The logger results were then uploaded onto a computer for analysis. This completed the CIVD response testing.

5.4. Participant Discomfort

A number of researchers have noted the intense pain associated with immersion of the hand in 5ºC cold water (Daanen, 2003). This pain may be associated with the degree of vasoconstriction (Kreh et al., 1984). Certainly the pain experienced by the participants in this study was, in general, severe. Several participants vomited, and a number were close to fainting. Almost without exception, participants vocalised their often extreme discomfort, with one comparing it to the pain of childbirth. All participants were advised before commencement of the test that they could remove their hand at any stage. Despite this, only one participant withdrew their hand and refused to continue, with one other withdrawing their hand and then re-immersing it to continue the test. For most participants, the pain was at its most intense for only about 3-5 minutes, and they were advised this before putting their hand in the water. A number subsequently remarked that it was this statement that largely kept their hand in the water.

The threshold for nerve conduction in tissue is 7-8ºC, (Vanggaard, 1975), and most participants reached below this temperature in less than 3 minutes. After this period of time the hand seemed to become numb, and less sensation of pain was experienced, which was a major factor in most participants completing a successful test.

As part of the study, each participant was asked to rank their pain sensation on a scale of 1-10 (10 being the most painful) after the following intervals; 2, 5, 10, 15, 20, and 25 minutes. Although these rankings are entirely subjective, they do provide an indication of the pain sensation experienced by each individual participant over the 30 minute immersion period.

5.5. Statistical Methodology

The purpose of this section is to summarise the statistical tools that were used to analyse the results from the CIVD response and anthropometric measurements in Chapter 6.

Data Collection and Cleaning

The anthropometric measurement data were collected using an information sheet which was then entered into a database using Microsoft Access software. The CIVD response was uploaded into an excel spreadsheet from which calculations for the different variables required were performed. This data was then entered into the Access database.

The data in the database was reviewed against expected limits to ensure no collection errors or unusual results were present. A review of the data at this stage found no unusual observations. This data was then transferred into an SPSS database. SPSS version 20 was used for the analysis of the data and the production of tables and graphs.

Analysis

Data was tested for normal distribution using the Kolmogorov-Smirnov, and Shapiro-Wilk tests as appropriate. Relationships between variables were explored using principal components analysis and Pearson correlation.

For the multivariate analysis there were three sets of variables; body size, body shape and CIVD response variables. For each dependent variable set, MANOVA was used to test for significant differences between the ethnic groups and between genders, as well as an interaction between ethnicity and gender. Pillai’s Trace was used for the multivariate analysis due to its robustness where there are unequal sample sizes (Pallant, 2011, p. 294; Tabachnick & Fidell, 2007, p. 252).

Discriminant function analysis was used to identify those variables contributing most to between group separations. Discriminant analysis is used to model the value of a dependent categorical variable based on its relationship to one or more predictors. The procedure automatically chooses a first function that will separate the groups as much as possible. It then chooses a second function that is both uncorrelated with the first function and provides as much further separation as possible. The procedure continues adding functions in this way until reaching the maximum number of functions as determined by the number of predictors and categories in the dependent variable.

In this analysis the results are displayed in a structure matrix. This is the canonical structure, also known as canonical loading or discriminant loading, of the discriminant functions. The structure matrix shows the correlation of each predictor variable with the discriminant function. It represents the correlations between the observed and the dimensions created with the unobserved discriminant functions (dimensions). The variables contributing the most to between group separation have the highest correlation with the functions that show the most separation between groups.

The multivariate analysis was followed up with univariate analysis using ANOVA (two way ANOVA where there were interaction effects with gender, and one way ANOVA where there were no interaction effects), ANCOVA and Tukey’s post-hoc comparison testing. For each relevant dependent variable, the ANOVA was used to identify statistically significant differences among ethnic groups using the ethnic grouping outlined in section 5.1. These tests are referred to as ‘test of between subjects’ effects’ in the results sections. P-values were identified for all statistically significant differences among groups.

Tukey’s HSD (honestly significant difference) post-hoc comparison test was used to identify which ethnic group mean differed significantly from the other groups’ means for each variable. This is a single step multiple comparison test used in conjunction with ANOVA to identify which means are significantly different from each other. Tukey's post-hoc tests are like a series of t-tests. The post-hoc tests are more stringent than the regular t-tests however, due to the number of tests performed. The results are displayed as homogeneous subsets of group means that do not differ from each other at $p<.05$. Subsets that do differ are shown in separate columns. The p-value (testing the null hypothesis of no difference between the means in the subset) for each subset is shown at the bottom of each column.

Effect size was calculated using eta^2. Effect size magnitude in this analysis is classified as follows: small (.01), medium (.06) and large (.14) (Cohen, 1988, pp. 284-287; Kirk, 1996). Where data had a non-normal distribution, the Kruskal-Wallis test was used to identify among group differences in the dependent variable.

Similarity of Phenotypic Differences and Genetic Differences

The test for similarity between phenotypic data and coancestry data was investigated using Mantel’s test (Mantel, 1967). Genetic distance information, in the form of pairwise F_{ST} “coancestry” distances, was taken from Friedlaender et al. (2008) for 8 ethnic groups corresponding to the ones in this study. The Korean ethnic group in this study was not represented in the genetic data, so the comparable Japanese ethnic group was substituted. Mantel’s test was used to compare the ‘distance’ between ethnic groups in terms of specific observed measures from the study, namely T_{av}, T_{index}, sitting height ratio and biiliac width, with genetic distance information identified for comparable ethnic groups in Friedlander et al (2008).

Mantel’s test is a statistical test of the correlation between two matrices. It follows a robust semi-parametric method for determining the similarity between two sets of distance information; it uses a ‘random permutation’ method to assess whether the similarity between the sets of distance information is greater than we would expect to see by random chance. It produces an empirical p-value, which can be interpreted as the probability of the two matrices being similar given the null hypothesis that there is no relationship between the two sets of measurements. The ‘ape’ package in the statistical language R was used to perform the tests by the Department of Molecular Medicine and Pathology at the Faculty of Medical and Health Sciences, University of Auckland. 100,000 permutations were used to perform each test on the basis that this many permutations should be used if the significance level approaches a critical value (Jackson & Somers, 1989).

5.6. Limitations of the Study

As with any study there are limitations that should be clearly understood in order to interpret the results. These are outlined in this section.

Sample bias: randomness and independence

Any study that involves human participants is subject to considerable variability. Statistics is concerned with estimation, being able to make generalizations about populations based on sample data (Whitlock & Schluter, 2009, pp. 1-16). An important factor is the extent to which the samples are representative of the target population. One assumption of the data is that it is randomly selected, that every member of the sample population has an equal chance of being selected. This is generally not the case when human populations occupy an entire world.

The second assumption is that the selection is of independent members who have no connection with each other. Again this is not always the case. In the case of the present study, word of mouth was an important factor in obtaining participants, many of whom would tell their friends. For example, many of the African participants knew each other through playing football.

In these limitations are also the problems associated with the bias of obtaining a sample of convenience, and volunteer bias. These tend to work against the assumptions of randomness and independence. Sample biases probably affect the body size sample assumptions more than the body shape and CIVD response, which are more genetic in origin. Body size has more of an environmental influence, especially in western culture, and has socio-economic implications which are not covered in this research. In targeting a particular segment of society, there are certain cultural biases which will occur.

As the research was undertaken at the University of Auckland, most of the participants were students living in Auckland. This attracted a certain age group, with a bias for a younger participant. As mentioned before, this does have the advantage of the participants generally having fewer health issues to confound the results. The only category that did not have many students was the Melanesian category; therefore this category has an older average age.

As the testing method for the CIVD response was extremely painful, initially it appeared that it would be difficult to attract a sufficiently large sample size. Many of the initial participants were students in the School of Biology who were interested in the study and prepared to participate, but eventually it became necessary to offer inducements for participants. A target of 50 participants was set for the larger ethnic groups, and 20 participants for the Korean, African and Melanesian groups. A total of 286 subjects participated in the study, reaching the target set at the outset, which was considered a good outcome. I am unaware of any previous CIVD response study larger than this.

In retrospect, a target of 50 for each group, including North European, Korean, African and Melanesian participants would have been possible if more money and time had been available, and if a clearer picture of likely between group differences had been known in advance, as well as the difficulty of categorization between anticipated sub-groups.

Ethnicity and categorisation

A major issue in participant selection was accurately determining their ethnicity. It was impractical to seek a genealogy further back than grandparents, particularly as all participants represented migrants to New Zealand at some time in the last two hundred years. In this respect New Zealand is a good place to do this research, as it has a diverse population mix, but conversely its population sometimes has limited knowledge about its origins.

In addition there is the issue of admixture, with European colonisation and trading links a factor in many regions, including Africa, Asia and the Pacific, since the Age of Exploration began in the 15th Century. Ethnicity was explored using a combination of family member birthplaces, migration movements, languages spoken, and the ethnicity they associated themselves with.

Determining ethnicity largely came down to geographic location of ancestry. Some of the regions used to categorise participants are very large, often with a multiplicity of different ethnicities found within its geographical boundaries. For example Europe, China, Africa and India are ethnically diverse, whereas a Polynesian island such as Samoa is not. A region like Korea probably lies somewhere in between. Some participants were clearly the product of migratory movements where their immediate ancestry had no relation to their ethnicity, for example Fijian Indians.

It might have been useful to have obtained genetic sample from each participant to aid in ethnicity determination. However, this is itself is not guaranteed to provide a clear result given the genetic differences between individuals, and no clear markers for the biological separation of ethnic groups. There are also no clear markers for the physical traits measured as part of this research, all of which are likely to be polygenic. In any event it is unlikely that all of the participants would have consented to this process, and the budget did not allow for this data collection and analysis. However, analysis of similarities between phenotypic data and coancestry was performed using data for comparable ethnic groups from a recent published paper.

Equipment

The main constraint for equipment was budgetary. The water bath was an ice box with an aquarium pump to circulate the water, and cooled by the addition of shaved ice. Temperature was monitored by a digital thermometer with an external probe. None of this equipment was specifically designed to do the job it was used for, but it was readily available and inexpensive. The effectiveness of the temperature monitoring was cross checked against the precise digital thermometer used for measurement of CIVD response. It performed well for this study, but purpose built circulating water baths with automatic temperature monitoring are available at a price.

The probe used to measure and record finger temperature was of a high quality. It would have been useful to have several of these to measure a variety of sites on the hand, and also to measure sites on the other hand for comparison, and possibly upper arm temperatures. There is equipment specifically designed for this type of research. A laser Doppler monitor will measure blood flow and temperature in finger tips, as well as performing extensive analysis; however, these are expensive.

To determine the reliability of the data, it would have been preferable to measure each participant two or three times as part of the study. This was impractical for a number of reasons. Firstly the CIVD response testing was extremely painful and few participants would have agreed to participate for a second time without considerable inducement. More money would have required for this, and even money would not have induced some participants to return! Time was also a factor. Each session for one participant took at least one hour. Few students wanted to devote a second or third hour to this study.

This time frame also limited the number of students who could participate in a day. Duplicate sets of equipment would have helped in allowing more participants per day. In the end two participants were tested for CIVD response twice, the author and a hardy female of German ancestry. Both sets of results were within less than 10% of each other, but it is hard to read too much into this small sample and the results have not been included in the analysis.

Based on the results of this study, and with a higher budget, improvements in the quality and scope of the research would be able to be achieved.

Research on Polynesian Origins

One important element of the present study is to understand the research that has been completed in relation to the origins of Polynesian populations. The main research focus of this thesis is to establish the cold adapted nature of Polynesian body morphology. The origins of that body morphology, without absolute evidence, can only be a source of conjecture, based on what has been published about the origins of the early populations that are ancestral to modern day Polynesians.

There is a great deal of research around the entry of populations into Melanesia and the subsequent colonization of the Pacific. This has been covered in Chapter 3. The consensus to date suggests these early voyagers who went on to colonize the Pacific came out of Taiwan around 5,000 years ago. However, there is very little published on where those origins may lie before this time.

The basis of the search for the origins of Polynesian body morphology, in a literal sense, is to suggest that if they come from Asia, and if they are cold adapted, and if these adaptations evolved over many thousands of years, then they must come from North Asia, as this is the coldest part of Asia. Furthermore, they must have been there for a long time before moving south. This is a logical conclusion, but contains several assumptions that cannot be tested. Without better supporting evidence from archaeological or genetic studies as to the likelihood of this hypothesis, it is ultimately unsatisfying, and is a limitation of this present study.

Ancestral Environments

Another limitation is the understanding of the ancestral environment of the different participants. We have a good understanding of our environment today, and of past environments. As outlined above the ethnic categorisation of participants has its own limitations. These are translated into similar limitations when trying to determine the different ancestral environments for each ethnic group. The different regions have a variety of climates, and these will have experienced variations in temperature over the past 20-30,000 years. For example China ranges from the tropics of Southeast Asia to the seasonally frozen north of Mongolia. Europe ranges from sunny Spain to Finland.

It would have been desirable to travel to specific locations in these regions, where populations have been known to reside for some considerable period of time, to better understand the likely ancestral environment. To be able to accurately determine these ancestral environments for each participant on the basis of the limited knowledge of their ancestral origins they were able to provide is difficult. Generalizations must be made in order to allow comparison between the different ethnic groups. The important factor is not that a particular environment has to be quantified, but that a reasonable basis for comparison between the different groups has to be identified.

BMI as a proxy for obesity

Finally when considering differences between ethnic groups for BMI, it is necessary to take into account the effect a higher sitting height ratio has on BMI. BMI has been adopted by the World Health Organization as the major criterion for determining rates of obesity, given its simplicity and cost-effectiveness (World Health Organisation, 2000). However, it does have its disadvantages, particularly with short and tall individuals, where it either underestimates the appropriate weight (short), or overestimates (tall) (Bagust & Walley, 2000). Likewise, because the trunk is proportionately heavier than the limbs, sitting height ratio produces a higher BMI in individuals with a higher sitting height ratio (Galloway, Chateau-Degat, Egeland, & Young, 2011).

This was highlighted in a recent study comparing body fat and BMI in Indian, Polynesian and European populations (Rush et al., 2009). Indians with a BMI of 24 (male) and 26 (female) had similar body fat levels to Europeans with a BMI of 30, and Polynesians with a BMI of 34 (male) and 35 (female). However, there are no alternatives to BMI available for global analysis, and no consensus on alternative methods to analyse results (Galloway et al., 2011).

Effects of Limitations

With regard to the limitations of the study outlined above, these are primarily designed to show how improvements could be made for future study. These limitations should not present any major barriers to the quality and understanding of the results presented in this present research.

With regard to sample bias and ethnicity, the University of Auckland is one of the largest institutions in New Zealand, with an ethnically diverse student population, many of whom have international origins. It is possibly the best place in New Zealand in which to find a wide and varied collection of individuals with a variety of ancestral origins. Because so many of the participants were international students, or first or second generation New Zealanders, this made it easier to identify their ancestral origins and categorise their ethnicity. It also reduces the number of generations over which admixture may have been a factor in their genetic heritage.

With regard to the relatively young age of participants, past studies have indicated that age is not a significant factor in CIVD response results until participants are much older, identified as over 60 in section 4.2 (Khan et al., 1992; Sawada, 1996). In addition chronic health issues such as obesity and diabetes also tend to occur later in life so the predominant 20-30 age range is considered an advantage for achieving consistent results.

The equipment, although basic, was thoroughly tested to ensure consistent results were being achieved. This was often through the author spending hours over a period of time with their hand in freezing water! The testing of all participants was done on an individual basis by the same researcher to ensure consistent methodology.

With regard to our understanding of ancestral environment and Polynesian origins, in fact the results in this present study were categorical and are outlined clearly in the results and discussion sections to follow. The most significant limitation is probably in the European categorization, where a greater number of participants with more narrowly defined ancestral origins may shed more light on the cold adapted nature of these populations. That would seem to offer a fruitful area for further study.

Chapter 6. Results

The results section is divided into five sections. The first section is brief and covers general environmental and physiological measurements that relate to the participants. The purpose of this section is to ensure the testing of participants was consistent in terms of any identifying any extraneous variables that might have influenced the results at all.

The second section coves the analysis of the body morphology variables and is itself divided into sections on body size and body shape. This is a somewhat arbitrary division as these variables are related, but it breaks up what is a long section of analysis with many variables into a more manageable structure. In addition the research in Chapter 2 suggests that variables relating to body shape are under stronger genetic influence than body size, and this difference forms an important part of the discussion of this analysis.

The third section covers the analysis relating to CIVD response variables. Again there are many variables to be analysed including temperature variables as well as time variables. An index is developed to consider the combined effect of a number of the most significant variables.

The fourth section covers analysis using a Mantel's test to compare genetic distances from a recent comparable study with an analysis of the between group distances for several of the more significant morphological and CIVD response variables from this present study. This comparable study calculated these genetic distances for a number of similar ethnic groups as part of research looking at the genetic structure of Near Oceania and Remote Oceania populations, and the relationship between these and other populations from different parts of the world.

The fifth and final section in this chapter is a brief summary of the results.

Each of the three main analytical sections for body size, body shape and CIVD response follows the same structure. The initial goal is to identify which of the variables contributes most to identifying differences between the ethnic groups. This is undertaken using principal components analysis and discriminant function analysis, as well as a comparison of means. Next the variables are examined as a group using MANOVA analysis to look at between group differences largely using the categorisation of ethnic grouping 1 (EG1) as outlined in section 5.1. Finally the identification and analysis of specific intergroup differences is made using ANOVA and Tukey's post-hoc comparison tests. Various sundry other tests are incorporated as necessary.

6.1. Environmental and Physiological measurements

A number of environmental and physiological measurements were made, as much to identify any issues arising from the background to the study, or individual participants, rather than any direct relationship with ancestral environment or any of the key dependent variables. A brief summary of these is as follows.

Table 10. Average room temperature during testing.

		Room Temperature				
		N	Mean	Standard Deviation	Maximum	Minimum
Test Location	UOA	276	21.8	1.0	24.5	18.4
	Albany	6	23.4	2.2	26.0	19.3
	AUT	3	22.1	0.5	22.5	21.6
	Total	285	21.8	1.1	26.0	18.4

(UOA = University of Auckland, AUT = Auckland University of Technology)

Testing was carried out in three locations, over a period of 18 months, but nearly all (97%) of all tests were completed in the labs at the School of Biological Sciences, University of Auckland. Air conditioning meant that the room temperature variance was reduced, with a mean of 21.8. The room temperatures would not be expected to affect the testing outcome at these levels.

Pulse, blood pressure and body temperature were also recorded, although the quality of the measurement instruments may account for some of the variance. Although Table 11 shows a variance in range in all three measurements, the means are within expected parameters. Although no participants were excluded from the anthropometric analysis on these factors, a number of participants were excluded from the CIVD analysis, as covered in 5.3 above. Full statistical tables showing more detailed results of the measurements can be found in Appendix B.

Table 11. Pulse, body temperature and blood pressure means of participants by EG1.

EG1	N	Pulse beats per minute (SD)	Body Temp ºC	BP systolic mmHg	BP diastolic mmHg
Other European	46	70 (12.2)	36.3 (.4)	126 (12.5)	80 (11.5)
North European	12	70 (14.7)	36.2 (.4)	123 (8.5)	79 (7.4)
Korean	24	75 (11.7)	36.4 (.3)	111 (15.3)	75 (8.5)
Chinese	25	73 (13.2)	36.5 (.6)	114 (15.3)	73 (14.6)
Indian	51	78 (14.7)	36.2 (.4)	115 (14.6)	75 (8.8)
African	21	74 (16.6)	36.4 (.4)	119 (11.1)	73 (11.9)
Polynesian	50	75 (13.2)	36.6 (.4)	122 (12.9)	79 (11.1)
Melanesian	25	73 (12.3)	36.5 (.2)	124 (19.8)	84 (13.9)
Other	21	79 (11.4)	36.6 (.3)	122 (13.2)	77 (10.3)
Total	275	74 (13.4)	36.4 (.4)	119 (14.8)	77 (11.4)

(Standard deviation (SD) given in brackets. BP = blood pressure)

Korean, Chinese, African and Indian blood pressure means are lower than other groups. Interestingly enough, the European groups have the highest mean blood pressure but the lowest mean pulse values. 6.3% of participants were smokers, as displayed in Table 8 above. The group with the highest percentage of smoking was Polynesians with 14%, and the lowest European with 1.5%. Body temperatures fall within a narrow range. These temperatures when measured through the auditory canal are not all that accurate and this may be reflected in these results.

A one way between-groups multivariate analysis of variance (MANOVA) was conducted using the dependent variables shown in Table 11 by ethnic grouping EG1 (excluding Others) as the fixed factor.

Pillai's Trace was also used for the multivariate analysis due to its robustness where there are unequal sample sizes (Pallant, 2011, p. 294; Tabachnick & Fidell, 2007, p. 252). There was a significant difference between groups, V = 0.35, F (28,968) = 3.29, p<.001. Effect size was medium at .087.

However, post-hoc analysis using a Tukey test showed few significant between group differences. Significance levels used are where p<.05. There were no significant between group differences for pulse. For body temperature the only significant differences were between Polynesian and Indian (p<.001), Polynesian and Other European (p=.024), and Melanesian and Indian (p=.043). For systolic blood pressure the only significant differences were between Other European and: Korean (p<.001), Indian (p<.001), and Chinese groups (p=.003), and between Polynesian and Korean (p=.035), and between Melanesian and Korean (p=.035). For diastolic blood pressure the only significant between group differences were between Melanesians and: Chinese (p=.01), Indian (p=.015), and African (p=.013).

Participants were asked to rate their fitness levels on a scale of 1-10, with 10 being the fittest. Although a very subjective measure, it does give an indication of how participants viewed their level of physical fitness. Most participants fell into a reasonably narrow range, between 5.6 and 7.0, with Europeans and Africans rating their levels of fitness higher than other groups as shown in Table 12 below. Melanesian and Polynesian groups rated themselves lower in fitness, which may relate to their weight and BMI.

Table 12. Participant's fitness self-rating.

EG1	N	Mean	Std. Deviation
European	65	6.85	1.1
Korean	24	6.54	0.9
Chinese	27	6.52	1.0
Indian	51	6.38	0.9
African	21	6.95	1.0
Polynesian	50	5.82	1.3
Melanesian	25	5.60	1.1
Other	22	6.05	1.1
Total	285	6.36	1.1

6.2. Anthropometric Measurements

A number of morphological measurements were taken from each participant. These measurements will be used to gauge the relationship between body morphology and geographical ancestry, as identified in Chapter 2, but also to test the relationship, if any, between body morphology and CIVD response, given that both may be viewed as independent adaptive responses to ancestral climate.

These anthropometric measurements have been divided into 2 categories. Body size is related to levels of body mass, including weight, skinfold measurement, and mid biceps diameter. Also calculated is the body mass index (BMI), being the participants weight divided by the square of their height. The BMI is a rough proxy for the measurement of body fat. Guidelines given by the US National Heart and Lung Institute suggest a normal human range for BMI is 18.5 to 25 (National Heart and Lung Institute, 2012).

Body shape is derived from bone measurements such as height, trunk height, body breadth, and those related to the wrist and hand. The sitting height ratio (SHR) is calculated from the trunk height divided by height. This gives a measure of the relative proportions of the body height contributed by the trunk and the legs respectively.

Because of gender differences in body shape and size, as well as the different proportion of males and females in each ethnic group, it is important to look at differences within each gender grouping, as well as by ethnic grouping. Full statistical tables showing detailed results of the anthropometric measurements can be found in Appendix C.

6.2.1. Body Size

The body size variable means for each ethnic group for males are shown in Table 13.

Table 13. Weight, total skinfold, mid biceps diameter and BMI means for males by EG1.

EG1 Males	N	Weight Kg (SD)	Total Skinfold mm	Mid Biceps diam mm	BMI
Other European	31	76.78 (7.5)	27.52 (11.0)	297.71 (30.0)	23.84 (2.0)
North European	7	78.89 (6.4)	36.43 (10.1)	298.00 (14.6)	24.40 (2.0)
Korean	11	72.90 (13.0)	33.09 (13.0)	293.45 (36.3)	23.76 (3.9)
Chinese	13	73.73 (11.8)	33.15 (11.4)	286.38 (25.1)	24.21 (3.3)
Indian	31	75.07 (13.0)	40.71 (13.7)	296.58 (36.0)	24.99 (3.7)
African	14	70.39 (9.9)	30.21 (13.4)	283.36 (22.2)	23.50 (3.0)
Polynesian	19	101.74 (18.0)	49.21 (16.1)	355.05 (29.3)	32.14 (5.4)
Melanesian	7	90.23 (12.8)	38.86 (15.3)	328.00 (40.9)	30.34 (6.6)
Other	8	65.33 (11.1)	32.25 (9.9)	278.63 (37.6)	22.07 (2.3)
Total	141	78.67 (15.6)	35.84 (14.5)	302.82 (38.0)	25.46 (4.7)

(Standard Deviation (SD) given in brackets. kg = kilograms, mm = millimetres, diam = diameter, BMI = body mass index)

Polynesians were clearly the largest in size, having the highest mean in every category. Melanesians also scored highly in terms of size. Africans had the lowest mean in every category, except total skinfold, where Europeans were marginally lower. The body size means for each ethnic group for females are shown in Table 14.

Table 14. Weight, total skinfold, mid biceps diameter and BMI means for females by EG1.

EG1 Females	N	Weight kg (SD)	Total Skinfold mm	Mid Biceps diam mm	BMI
Other European	21	65.72 (17.7)	40.71 (13.4)	277.95 (43.4)	22.82 (5.1)
North European	6	63.98 (9.0)	41.33 (12.4)	277.83 (30.4)	22.42 (2.2)
Korean	13	51.45 (6.8)	37.69 (7.0)	247.31 (20.0)	20.28 (2.1)
Chinese	14	52.38 (7.0)	38.29 (11.6)	244.57 (21.7)	20.63 (2.1)
Indian	20	55.88 (10.1)	48.75 (16.0)	262.05 (36.0)	22.68 (4.6)
African	7	59.70 (3.1)	48.14 (6.4)	264.57 (23.9)	22.29 (1.9)
Polynesian	31	87.77 (21.5)	64.52 (19.6)	321.90 (45.6)	31.35 (7.7)
Melanesian	18	77.21 (12.3)	54.44 (16.8)	300.78 (39.1)	31.06 (5.0)
Other	14	64.14 (20.4)	44.14 (14.3)	273.36 (47.3)	24.88 (7.3)
Total	144	67.43 (19.8)	48.88 (17.6)	280.94 (45.9)	25.38 (6.9)

(Standard Deviation (SD) given in brackets. kg = kilograms, mm = millimeters, diam = diameter, BMI = body mass index)

Females show a similar pattern to males. The main difference is their smaller size with females being on average 14% lighter, 8% narrower in mid biceps diameter, with only a 0.3% lower BMI, but with a 36% higher total skinfold. Like the Polynesian males, Polynesian females had the highest means in all categories, and Melanesians were second in all categories. Unlike males, where Africans generally were smaller, Korean females were the smallest in all categories, except mid biceps diameter, where they were second smallest, marginally ahead of the Chinese.

A one-way between-groups ANOVA was used to explore differences between the genders for the four body shape dependent variables shown in Table 13 above. There was a significant difference between genders for weight; F (1,261) = 28.49, p<.001, effect size is medium at 0.10; for total skinfold, F (1,261) = 43.82, p< .001, effect size is large at .14; for mid biceps diameter, F (1,261) = 18.97, p<.001, effect size was medium at .07. There was no significant difference between genders for BMI (p=.76).

A two-way between-groups multivariate analysis of variance (MANOVA) was conducted for the four body size dependent variables using ethnic grouping EG1 (excluding Others) and gender as the fixed factors. A two way analysis was used due to the significant differences in body size between genders.

Pillai's Trace was also used for the multivariate analysis due to its robustness where there are unequal sample sizes (Pallant, 2011, p. 294; Tabachnick & Fidell, 2007, p. 252). There was a significant difference between genders, V = 0.60, F (4,244) = 93.06, p<.001. There was also a significant difference between groups, V = 0.82, F (28,988) = 9.20, p<.001. Effect size was large for both gender differences (0.60) and ethnic groups (0.20).

The interaction effect between gender and ethnicity showed as not significant (p=.80), indicating the relationship between body size and gender was similar for the different ethnic groups.

Discriminant analysis was conducted to investigate the relationship between ethnicity (EG1 excluding others) and body size variables. Predictor variables were weight, total skinfold, mid biceps diameter and BMI. Significant mean differences were observed for all the variables. While the log determinants were quite similar, Box's M indicated that the assumption of equality of covariance was violated. Given the large sample size, this violation is not regarded as serious.

The analysis revealed four discriminant functions. The first explained 66.9% of variance, the second 23.6%, the third 8.6% and the fourth 0.9% of variance. The relative contribution of each variable to each discriminant function is shown in the structure matrix in Table 15 below. BMI was the variable contributing the most to group separation, followed by weight.

Table 15.Discriminant function structure matrix for body size variables.

	Function			
	1	2	3	4
BMI	.976*	.183	-.092	.067
Weight	.743*	.592	-.311	-.043
Mid Biceps diameter	.666*	.533	-.184	.489
Total Skinfold	.685	.193	.694*	-.105

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.
*. Largest absolute correlation between each variable and any discriminant function

Further analysis was conducted on each body size variable using ANOVA and Tukey post-hoc comparison test starting with weight.

Weight

A two-way between-groups ANOVA was used to explore the differences between the mean weight for ethnic groups, and between males and females. There was a significant main effect for ethnicity *F* (15,247) = 17.01, *p* < .001. The effect size, using eta squared, was large at .51. There was a significant main effect for gender *F* (1,247) = 67.51, *p* < .001. The effect size was large at .22, but less than that for ethnicity. The interaction effect between ethnicity and gender was not significant (p=.59).

There were significant differences in mean weight among ethnic groups, and between genders. However, there were no significant differences for the interaction between gender and ethnicity, suggesting a similar pattern for mean weight among ethnic groups for both males and females. This is illustrated in Figure 17 below.

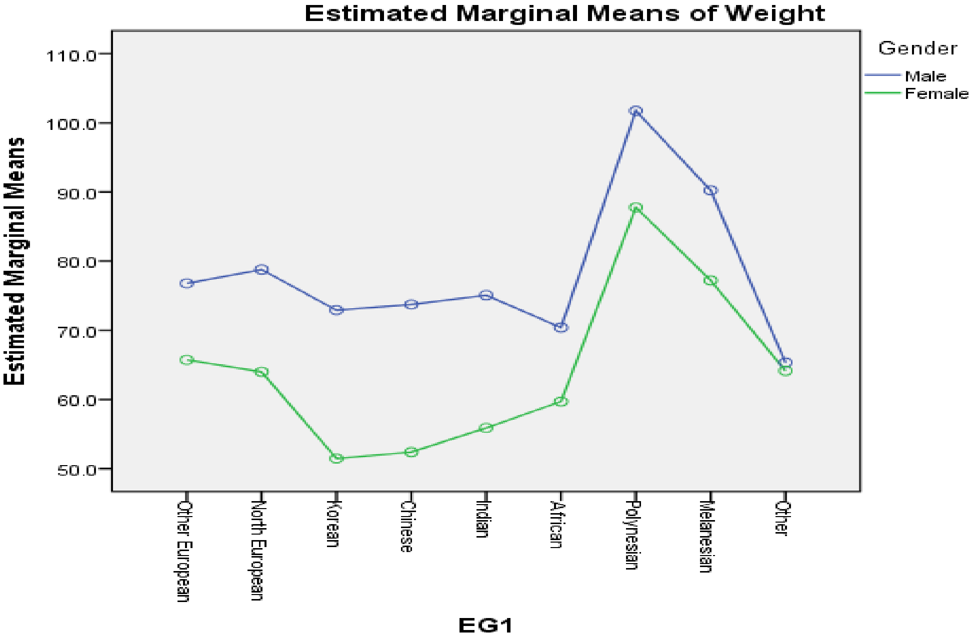


Figure 17. Estimated marginal means by gender and EG1 (kg).

Both males and females show a similar pattern of mean weight distribution by ethnicity. The largest gender differences are between Korean and Chinese participants. Post-hoc comparisons for the two-way ANOVA were completed using the Tukey HSD test as per Table 16.

Table 16. Homogeneous subsets of mean weight for males and females by EG1 using the Tukey HSD test.

EG1	N	Subset		
		1	2	3
Korean	24	61.283		
Chinese	27	62.659		
African	21	66.829		
Indian	51	67.547		
North European	13	71.954	71.954	
Other European	52	72.315	72.315	
Melanesian	25		80.856	
Polynesian	50			93.080
Sig.		.062	.244	1.000

Means for groups in homogeneous subsets are displayed in kg.

For weight there were significant differences between:

- Polynesian and all other groups at a significance of p<.001, except with Melanesian where p=.006.
- Melanesian and: Korean and Chinese (p<.001), Indian (p=.002), and African (p=.012).
- Other European and Korean (p=.023).

Note. There is a summary of significant differences between groups (EG1) for all body size and body shape variables in section 6.2.4.

Polynesians were clearly the group with the largest mean weight, with significant differences between them and all other groups. Melanesians were also significantly different from the four groups with the smallest means, being Korean, Chinese, African and Indian. The Asian grouping of Koreans and Chinese had the smallest mean weights.

The range of weight distribution within each group can be seen in the boxplot shown in Figure 18. This displays the minimum, maximum, first quartile, median, and third quartile, as well as outliers. Females were generally lighter than males, as would be expected, but for most groups females had a wider range of variability. The widest range of variability for males was found in Indian participants, but for females, the Polynesian group had a very wide range of variability.

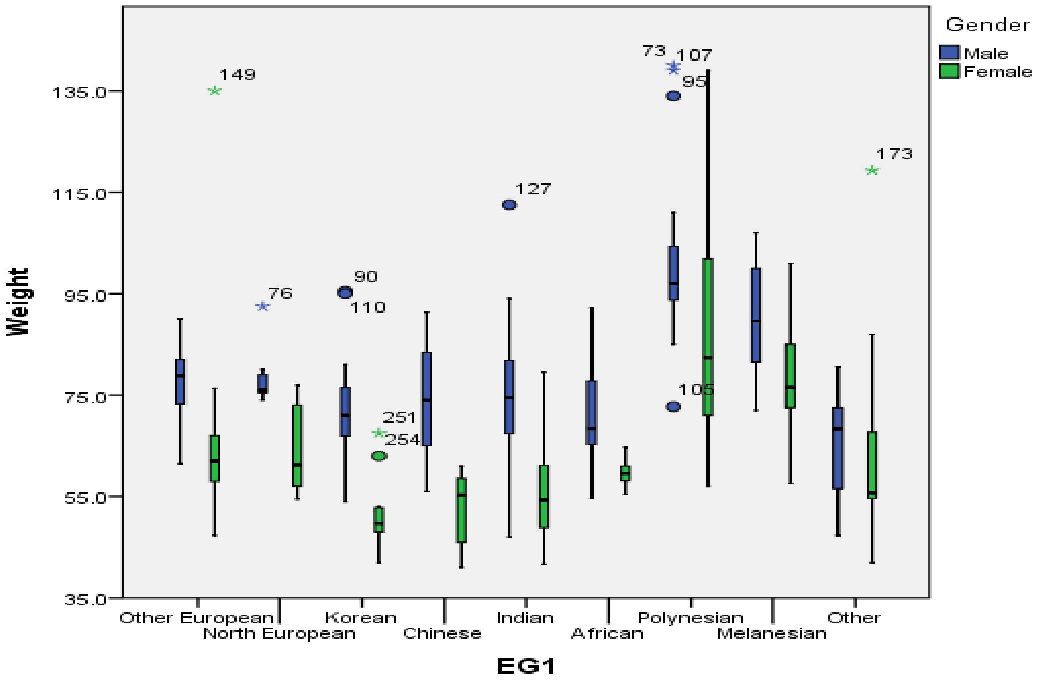


Figure 18. Weight means distribution by EG1 for males and females (kg).

The box plot also shows a number of outliers with a few participants having an extremely heavy body mass, both males and females. Six of the ten heaviest male participants were Polynesian, including the heaviest at 140 kg, with three Melanesian and one Indian making up the rest. Eight of the ten heaviest females were Polynesian, the heaviest being 139 kg, with a Melanesian and an Asian making up the balance.

Total Skinfold

A two-way between-groups ANOVA was used to explore the differences between the mean total skinfold for ethnic groups, using EG1 (but excluding the Other category) for males and females.

There was a significant main effect for ethnicity *F* (7,247) = 11.83, *p* < .001. The effect size was large at .25. There was a statistically significant main effect for gender *F* (1,247) = 27.75, *p* < .001. The effect size was medium at .10, less than that for ethnicity. The interaction effect between ethnicity and gender was not significant (p=.48).

Again there was no significant difference in the interaction effect between gender and ethnicity, suggesting a similar pattern for mean total skinfold among ethnic groups for both males and females. Post-hoc comparisons on mean total skinfold, using the Tukey HSD test, were completed as shown in Table 17.

Table 17. Homogeneous subsets of mean total skinfold for males and females by EG1 using the Tukey HSD test.

EG1	N	Subset		
		1	2	3
Other European	52	32.85		
Korean	24	35.58		
Chinese	27	35.81		
African	21	36.19		
North European	13	38.69	38.69	
Indian	51	43.86	43.86	
Melanesian	25		50.08	50.08
Polynesian	50			58.70
Sig.		.093	.073	.348

Means for groups in homogeneous subsets are displayed in mm.

For total skinfold there were significant differences between:

- Polynesian and other groups at a significance of p<.001, except with Melanesian (p=.21).
- Melanesian and: Other European (p<.001), Korean (p=.01), Chinese (p=.008), and African (p=.024),
- Indian and Other European (p=.003).

Polynesians had significantly higher mean total skinfold than all other groups except Melanesians. The results are very similar to the grouping for mean weight with one major difference; Other Europeans were at the high end of the mean weight grouping, but are the lowest when it comes to total skinfold. This is especially so for European males. This may partly reflect the taller height of Europeans, as described in section 2.4.

Mid Biceps Diameter

A two-way between-groups ANOVA was used to explore the differences between the mean mid biceps diameter for ethnic groups, using EG1 (but excluding the Other category) for males and females.

There was a significant main effect for ethnicity F (7,247) = 19.14, $p < .001$. The effect size was large at .35. There was a significant main effect for gender F (1,247) = 38.79, $p < .001$. The effect size was large at .14, but less than that for ethnicity. The interaction effect between ethnicity and gender was not significant (p=.74).

As with mean weight and mean total skinfold, there were significant differences in mean mid biceps diameter among ethnic groups, and between genders, but no significant differences for the interaction between gender and ethnicity, suggesting a similar pattern for mean mid biceps diameter among ethnic groups for both males and females. Post-hoc comparisons on mean mid biceps diameter, using the Tukey HSD test, were completed as shown in Table 18.

Table 18. Homogeneous subsets of mean mid biceps diameter for males and females by EG1 using the Tukey HSD test.

EG1	N	Subset		
		1	2	3
Chinese	27	264.70		
Korean	24	268.46		
African	21	277.10		
Indian	51	283.04	283.04	
North European	13	288.69	288.69	
Other European	52	289.73	289.73	
Melanesian	25		308.40	308.40
Polynesian	50			334.50
Sig.		.139	.128	.106

Means for groups in homogeneous subsets are displayed mm.

For mid biceps diameter there were significant differences between the following groups:

- Polynesian and all other groups at a significance of p≤ .001, except with Melanesians where p=.042.
- Melanesian and: Chinese (p<.001), Korean (p=.002), African (p=.045).
- Other Europeans and Chinese (p=.046).

Mid biceps diameter mean grouping is similar to the other body size variables, weight and skinfold. Polynesians and Melanesians are again the highest grouping for size, and Chinese, Koreans and Africans towards the lower end of the scale.

BMI

A two-way between-groups ANOVA was used to explore the differences between the mean BMI for ethnic groups, using EG1 (but excluding the Other category) for males and females.

There was a significant main effect for ethnicity *F* (7,247) = 24.26, *p* < .001. The effect size was large at .41. There was a significant main effect for gender *F* (1,247) = 7.09, *p* = .008. The effect size was small at .03, much less than that for ethnicity. The interaction effect between ethnicity and gender was not significant (p=.713).

As with mean weight, total skinfold, and mid biceps diameter, there were significant differences in mean BMI among ethnic groups, and between genders, but no significant differences for the interaction between gender and ethnicity, suggesting a similar pattern among ethnic groups for both males and females.

Post-hoc comparisons on mean BMI, using the Tukey HSD test, were completed as shown in Table 19.

Table 19. Homogeneous subsets of mean BMI for males and females by EG1 using the Tukey HSD test.

EG1	N	Subset	
		1	2
Korean	24	21.876	
Chinese	27	22.351	
African	21	23.099	
Other European	52	23.425	
North European	13	23.485	
Indian	51	24.085	
Melanesian	25		30.860
Polynesian	50		31.649
Sig.		.637	.998

Means for groups in homogeneous subsets are displayed.

For BMI there were significant differences between the following groups:

- Polynesian and other groups at a significance of p<.001, except Melanesian where p=.99.
- Melanesian and other groups at p< .001.

This table maintains the consistent pattern seen in other body size variables, with Polynesians and Melanesians grouping significantly larger than the other ethnic groups. Again Koreans, Chinese, and Africans are at the lower end of the scale.

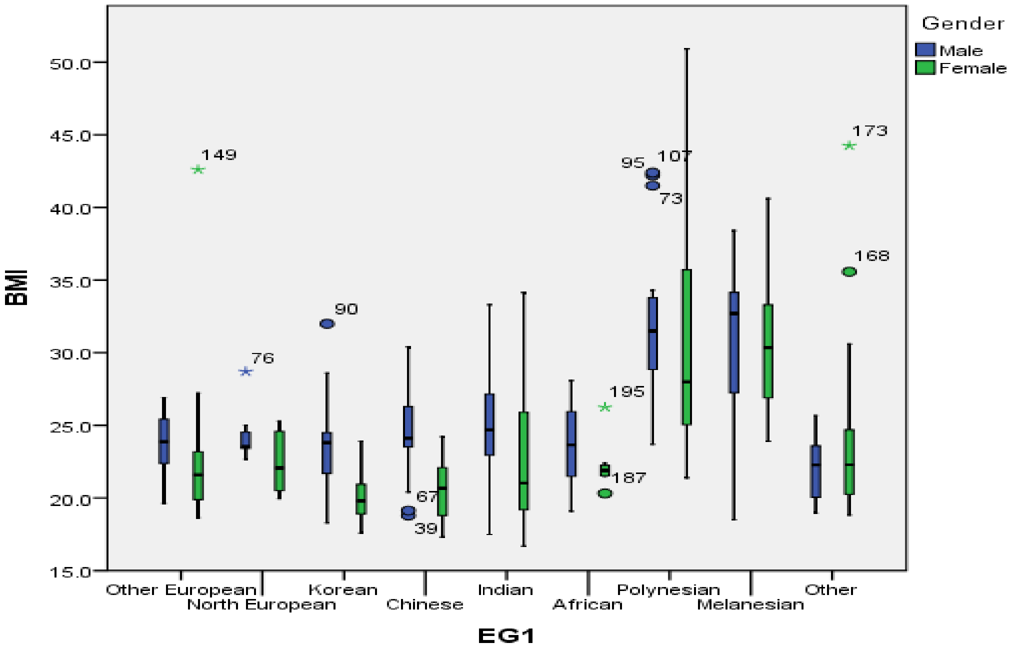
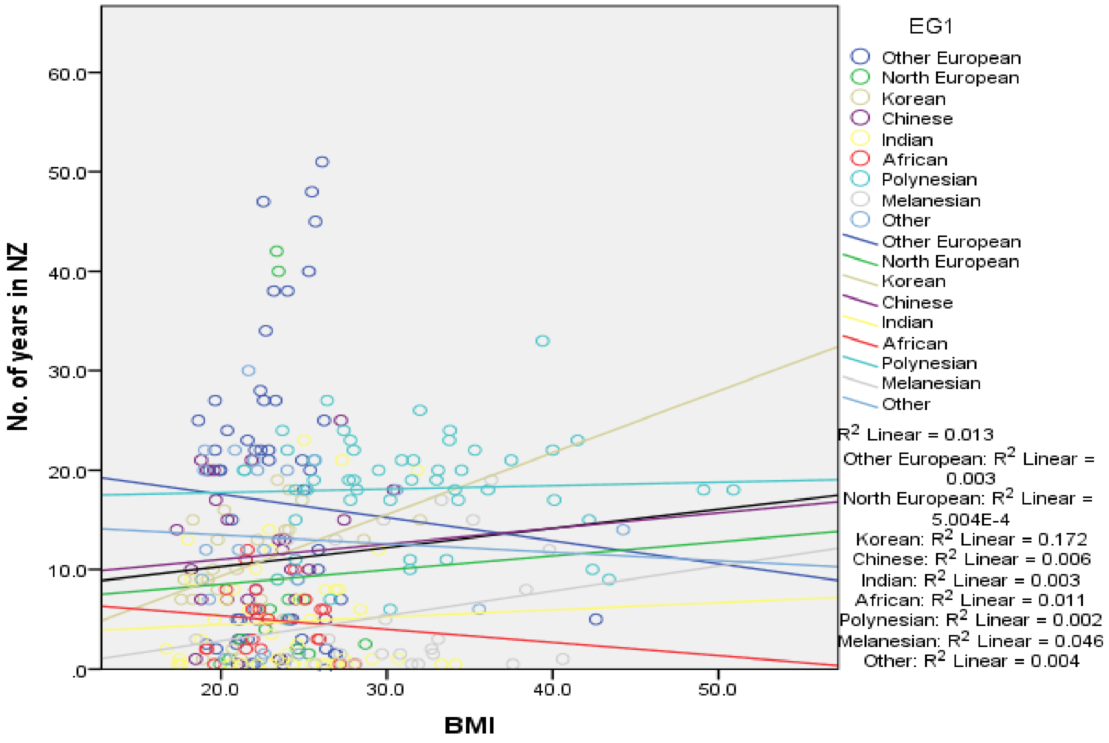


Figure 19. BMI means distribution by EG1 for males and females.

The variability of BMI among groups and gender is shown in Figure 19. Polynesians had the widest variability in BMI, particularly among females. Although Polynesian males have a narrower range, there are several significant outliers. Indians and Melanesians also have a wide range of variability. The relationship between BMI and the number of years a participant had resided in New Zealand is shown in Figure 20 below.

Figure 20. Relationship between BMI and no. of years residing in NZ.



Overall there was very little relationship between the number of years a participant had resided in New Zealand and their BMI, with r^2 =.013. The only group to show any significant relationship between BMI and years residing in New Zealand was the Korean group with r^2=.172.

Relationship between body size variables

When the relationship between the different variables of the body size are reviewed, as shown in the correlation matrices in Table 20, all variables were significantly correlated with the others. Total skinfold showed the lowest correlation with the other variables. BMI showed the highest correlation with the other variables.

Table 20. Correlation matrix between weight, total skinfold, mid biceps diameter, and BMI for males and females.

Male		Weight	Total Skinfold	Mid Biceps Diameter	BMI
Weight	Pearson Correlation	1	.691**	.813**	.895**
	Sig. (2-tailed)		.000	.000	.000
Total Skinfold	Pearson Correlation	.691**	1	.524**	.724**
	Sig. (2-tailed)	.000		.000	.000
Mid Biceps diam	Pearson Correlation	.813**	.524**	1	.800**
	Sig. (2-tailed)	.000	.000		.000
BMI	Pearson Correlation	.895**	.724**	.800**	1
	Sig. (2-tailed)	.000	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

Female		Weight	Total Skinfold	Mid Biceps Diameter	BMI
Weight	Pearson Correlation	1	.804**	.935**	.951**
	Sig. (2-tailed)		.000	.000	.000
Total Skinfold	Pearson Correlation	.804**	1	.811**	.842**
	Sig. (2-tailed)	.000		.000	.000
Mid Biceps diam	Pearson Correlation	.935**	.811**	1	.912**
	Sig. (2-tailed)	.000	.000		.000
BMI	Pearson Correlation	.951**	.842**	.912**	1
	Sig. (2-tailed)	.000	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

6.2.2. Body Shape

Means for body shape measurements for males are shown in Table 21.

Table 21. Height, biacromial and biiliac widths, and sitting height ratio for males by EG1.

EG1	N	Height Mm	(SD)	Biacromial mm	Biiliac mm	SHR
Other European	31	1793.90	(49.1)	410.97 (18.2)	294.87 (12.7)	.521 (.01)
North European	7	1797.57	(38.6)	409.29 (18.3)	296.71 (11.7)	.520 (.01)
Korean	11	1749.91	(49.2)	420.64 (17.3)	289.64 (16.8)	.539 (.01)
Chinese	13	1744.15	(67.3)	406.69 (17.7)	287.46 (14.9)	.536 (.01)
Indian	31	1731.68	(70.2)	409.55 (14.6)	282.61 (19.4)	.512 (.01)
African	14	1732.29	(93.0)	406.36 (17.5)	271.07 (17.3)	.509 (.02)
Polynesian	19	1779.74	(76.8)	434.79 (14.6)	320.32 (26.5)	.524 (.01)
Melanesian	7	1688.57	(67.0)	414.14 (19.0)	300.43 (18.9)	.522 (.02)
Other	8	1714.63	(74.2)	397.25 (19.5)	281.88 (12.5)	.528 (.02)
Total	141	1754.63	(72.4)	413.06 (19.1)	291.78 (22.1)	.522 (.02)

(Standard Deviation (SD) shown in brackets. SHR = sitting height ratio, mm= millimetres)

Polynesians had the largest biacromial and biiliac width means, and were second to Europeans in terms of height. They also had a relatively high sitting height ratio, behind Koreans and Chinese. Interestingly, although Koreans were amongst the lightest group, they had relatively large biacromial and biiliac breadth means, as well as the highest sitting height ratio. Africans scored at the low end of the scale for body shape, including the lowest sitting height ratio. Although the shortest, Melanesians had a relatively large biiliac and biacromial width. Means for body shape measurements for females are shown in Table 22.

Table 22. Height, biacromial and biiliac widths, and sitting height ratio for females by EG1.

EG1	N	Height mm (SD)	Biacromial mm	Biiliac mm	SHR
Other European	21	1692.81 (69.7)	369.95 (19.7)	285.14 (17.1)	.527 (.01)
North European	6	1686.50 (44.2)	356.67 (26.5)	274.67 (23.2)	.524 (.01)
Korean	13	1591.23 (51.1)	357.69 (14.6)	272.85 (12.4)	.542 (.01)
Chinese	14	1591.00 (50.7)	366.64 (17.1)	269.71 (16.1)	.541 (.01)
Indian	20	1573.60 (69.0)	353.95 (15.6)	273.90 (10.7)	.519 (.02)
African	7	1638.43 (47.2)	365.00 (11.6)	269.29 (16.6)	.525 (.02)
Polynesian	31	1674.10 (47.4)	397.74 (17.0)	311.39 (19.2)	.534 (.01)
Melanesian	18	1577.33 (40.8)	374.22 (14.9)	301.17 (17.2)	.523 (.02)
Other	14	1602.43 (75.1)	376.86 (24.5)	283.86 (27.4)	.531 (.01)
Total	144	1627.03 (73.4)	372.69 (23.0)	287.29 (23..5)	.530 (.02)

(Standard Deviation (SD) shown in brackets. SHR = sitting height ratio, mm= millimetres)

Again the main difference with male body shape means is the smaller size, with females being on average 7% shorter, 10% narrower in biacromial width, but only 2% narrower in biiliac width. Like their males counterparts, Europeans were clearly the tallest group for females, followed by Polynesians. Indians and Melanesians were the shortest. Koreans and Chinese females had the highest sitting height ratio, followed by Polynesians.

A one-way between-groups ANOVA was used to explore differences between the genders for the four body shape dependent variables shown in Table 21 above. There was a significant difference between genders for height; F (1,261) = 203.27, p<.001, effect size is large at .44; for biacromial width, F (1,261) = 263.07, p< .001, effect size is large at .50; for SHR, F (1,261) = 19.24, p<.001, effect size was medium at .07. There was no significant difference between genders for biiliac width (p=.10).

A two-way between-groups MANOVA was conducted using the four body shape dependent variables displayed in Table 21 above using ethnic grouping EG1 (excluding Others) and gender as the fixed factors. A two way analysis was used due to the significant differences in body shape between genders. Pillai’s trace was used for the analysis.

There was a significant difference between genders, V = 0.65, F (4,244) = 118.81, p<.001. There was a significant difference among groups, V = 1.15, F (28,988) = 14.21, p<.001. Effect size was large for both gender differences (0.65) and ethnic groups (0.29).

The interaction effect between gender and ethnicity was not significant (p=.08). This indicates that within each ethnic group, relationships between body shape distribution and gender were similar.

Discriminant analysis was conducted to investigate the relationship between ethnicity (EG1 excluding others) and body shape variables. Predictor variables were height, biiliac width, biacromial width and sitting height ratio. Significant mean differences were observed for all the variables. While the log determinants were quite similar, Box's M indicated that the assumption of equality of covariance was violated. Given the large sample size, this violation is not regarded as serious.

The analysis revealed four discriminant functions. The first explained 52.1% of variance, the second 30.4%, the third 14.8% and the fourth 2.6% of variance. The relative contribution of each variable to each discriminant function is shown in the structure matrix in Table 23 below. Biiliac width was the variable contributing the most to group separation, followed by sitting height ratio.

Table 23. Discriminant function structure matrix for body shape variables.

	Function			
	1	2	3	4
Biiliac	.690*	.376	.611	.091
SHR	.139	.704*	-.676	-.169
Height	-.185	.342	.712*	.585
Biacromial	.193	.171	.285	.923*

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions for both males and females.
Variables ordered by absolute size of correlation within function.
*. Largest absolute correlation between each variable and any discriminant function
(SHR = sitting height ratio)

Further analysis was conducted on each dependent variable using ANOVA and Tukey post-hoc comparison tests.

Height

A two-way between-groups ANOVA was used to explore the differences between the mean height for the ethnic groups, and for males and females.

There was a significant main effect for ethnicity *F* (7,247) = 15.06, *p* < .001. The effect size was large at .30. There was a significant main effect for gender *F* (1,247) = 204.84, *p* < .001. The effect size was large at .45, more than that for ethnicity. The interaction effect between ethnicity and gender was not significant, p=.124.

There were significant differences in mean height among ethnic groups, and between genders, but no significant difference for the interaction between gender and ethnicity, suggesting a similar pattern for mean height among ethnic groups for both males and females. Post-hoc comparisons on mean height, using the Tukey HSD test, were completed as shown in Table 24.

Table 24. Homogeneous subsets of height for males and females by EG1 using the Tukey HSD test.

EG1	N	Subset			
		1	2	3	4
Melanesian	25	1608.48			
Korean	24		1663.96		
Chinese	27		1664.74		
Indian	51		1669.69		
African	21		1701.00	1701.00	
Polynesian	50		1714.24	1714.24	1714.24
North European	13			1746.31	1746.31
Other European	52				1753.08
Sig.		1.000	.060	.129	.292

Means for groups in homogeneous subsets are displayed in mm.

For height there were significant differences between the following groups:

- Other European and: Korean, Chinese, Indian, Melanesian (p<.001), and African (p=.025), and Polynesian (p=.032).
- North European and: Korean (p=.003), Chinese (p=.003), Indian (p=.002), Melanesian (p<.001).
- Polynesians and: Melanesian (p<.001), Korean (p=.024), Chinese (p=.018), and Indian (p=.007).
- Melanesian and: Korean (p=.036), Chinese (p=.023), Indian (p=.001), African (p<.001).

Height grouped into four subsets, with Melanesian significantly shorter than all other groups. Other European, North European and Polynesian groups grouped taller than the other two subsets, particularly Other European who were significantly taller than all the other groups except North European.

Biacromial Width

A two-way between-groups ANOVA was used to explore the differences between the mean biacromial width for ethnic groups, using EG1 (but excluding the Other category) for males and females.

There was a significant main effect for ethnicity *F* (7,247) = 17.88, *p* < .001. The effect size was large at .69. There was a significant main effect for gender *F* (1,247) = 374.33, *p* < .001. The effect size was large at .60, much more than that for ethnicity. The interaction effect between ethnicity and gender was significant, p=.023.

There were significant differences in mean biacromial width among ethnic groups, and between genders, and significant differences for the interaction between gender and ethnicity. This suggests a dissimilar pattern among ethnic groups for both males and females. On this basis separate post-hoc analysis was completed for males and females. Post-hoc comparisons on mean biacromial width, using the Tukey HSD test, were completed as shown in Table 25.

Table 25. Homogeneous subsets of biacromial width for males and females by EG1 using the Tukey HSD test.

EG1 Male	N	Subset for alpha = 0.05	
		1	2
African	14	406.36	
Chinese	13	406.69	
North European	7	409.29	
Indian	31	409.55	
Other European	31	410.97	
Melanesian	7	414.14	414.14
Korean	11	420.64	420.64
Polynesian	19		434.79
Sig.		.404	.051

Means for groups in homogeneous subsets are displayed in mm.

EG1 Female	N	Subset for alpha = 0.05	
		1	2
Indian	20	353.95	
North European	6	356.67	
Korean	13	357.69	
African	7	365.00	
Chinese	14	366.64	
Other European	21	369.95	
Melanesian	18	374.22	
Polynesian	31		397.74
Sig.		.068	1.000

Means for groups in homogeneous subsets are displayed in mm.

For biacromial width for males there were significant differences between the following groups:

- Polynesian and: Other European, Chinese, Indian and African (p<.001), North European (p=.017).

For biacromial width for females there were significant differences between the following groups:

- Polynesian and all other groups at p<.001).
- Melanesian and Indian (p=.009).

Polynesians had significantly higher biacromial widths compared with other groups for both males and females except for male Koreans and Melanesians. The only other significant difference was between female Melanesians and Indians. The major difference between the genders was for Koreans, where males ranked relatively high for biacromial width compared to females.

Biiliac Width

A two-way between-groups ANOVA was used to explore the differences between the mean biiliac width for ethnic groups, using EG1 (but excluding the Other category) for males and females.

There was a significant main effect for ethnicity F (7,247) = 25.22, $p < .001$. The effect size was large at .42. There was a significant main effect for gender F (1,247) = 18.57, $p < .001$. The effect size was medium at .07, much less than that for ethnicity. The interaction effect between ethnicity and gender was not significant (p=.446).

There were significant differences in mean biiliac width among ethnic groups, and between genders, but no significant differences for the interaction between gender and ethnicity. This suggests a similar pattern among ethnic groups for both males and females. Post-hoc comparisons on mean biiliac width, using the Tukey HSD test, were completed as shown in Table 26.

Table 26. Homogeneous subsets of biiliac width for males and females by EG1 using the Tukey HSD test.

EG1	N	Subset			
		1	2	3	4
African	21	270.48			
Chinese	27	278.26	278.26		
Indian	51	279.20	279.20		
Korean	24	280.54	280.54		
North European	13		286.54	286.54	
Other European	52		290.94	290.94	
Melanesian	25			300.96	300.96
Polynesian	50				314.78
Sig.		.414	.143	.056	.079

Means for groups in homogeneous subsets are displayed in mm.

For biiliac width there were significant differences between the following groups:

- Polynesian and other groups at p<.001, except with Melanesian (p=.029).
- Melanesian and: Chinese, Indian, African and Korean all at p≤.001.
- Other European and: African (p<.001), Indian (p=.016), Chinese (p=.048).

Polynesian, other than with Melanesian, had significantly wider biiliac width than all other groups. Melanesian were also at the top end of the range. African, Indian and Chinese were at the bottom end of the range. A better picture of the range of distribution for biiliac width among ethnic groups, and gender can be seen in Figure 21 below.

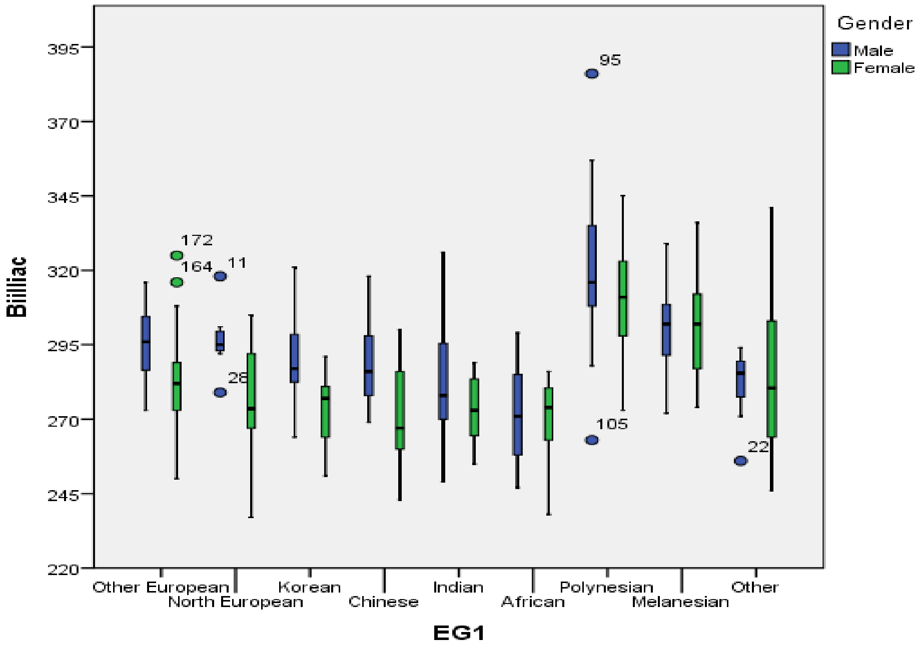


Figure 21. Billiac width means distribution by EG1 for males and females.

Sitting Height Ratio

Sitting height ratios are a key indicator of Bergmann's and Allen's Rules. When sitting height ratios were reviewed, as per Figure 22, a wide range of variability was seen, particularly within the African group. Interestingly, the sitting height ratio for females was higher than males in a number of ethnic groups.

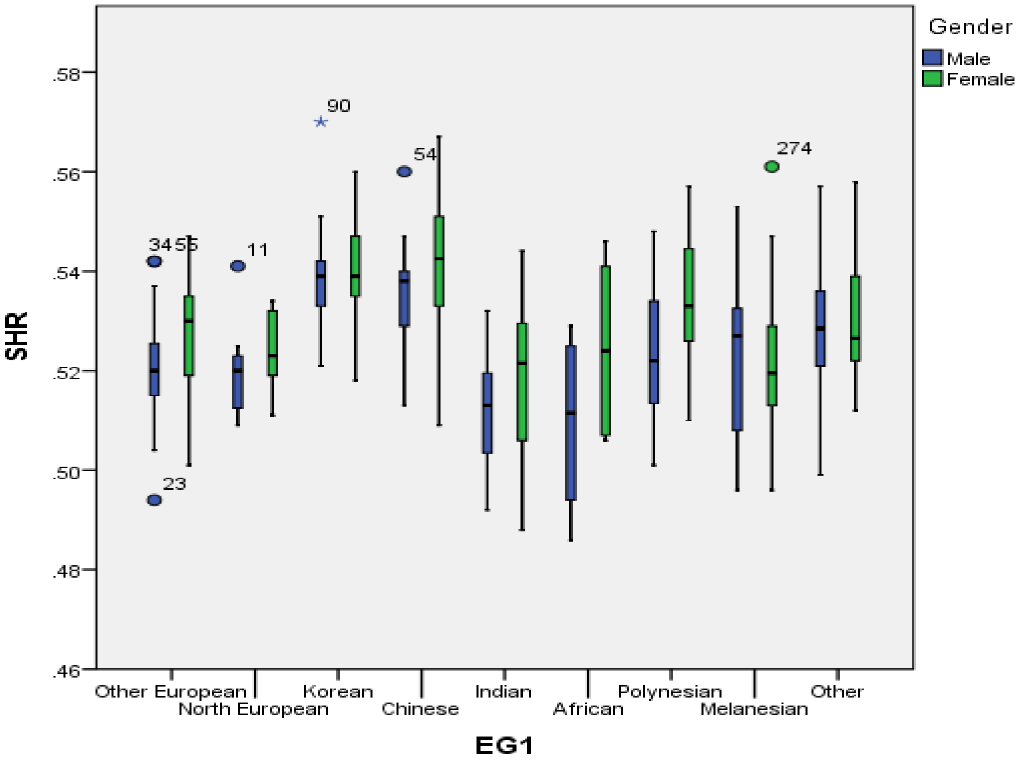


Figure 22. Sitting height ratio for males and females by EG1.

A two-way between-groups ANOVA was used to explore the differences between the mean sitting height ratio for ethnic groups, using EG1 (but excluding the Other category) for males and females.

There was a significant main effect for ethnicity *F* (7,247) = 13.76, *p* < .001. The effect size was large at .28. There was a significant main effect for gender *F* (1,247) = 10.84, *p* = .001. The effect size was small at .04, much less than that for ethnicity. The interaction effect between ethnicity and gender was not significant (p=.682).

There were significant differences in mean sitting height ratio among ethnic groups, and between genders, but no significant differences for the interaction between gender and ethnicity. This suggests a similar pattern among ethnic groups for both males and females. Post-hoc comparisons on mean sitting height ratio, using the Tukey HSD test, were completed as shown in Table 27.

Table 27. Homogeneous subsets of sitting height ratios for males and females by EG1 using the Tukey HSD test.

EG1	N	Subset		
		1	2	3
African	21	.5140		
Indian	51	.5148		
North European	13	.5218	.5218	
Melanesian	25	.5226	.5226	
Other European	52	.5233	.5233	
Polynesian	50		.5301	.5301
Chinese	27			.5386
Korean	24			.5405
Sig.		.186	.309	.094

Means for groups in homogeneous subsets are displayed.

For sitting height ratio there were significant differences between the following groups:

- Korean and: Indian, African, Other European and Melanesian (p<.001), North European (p=.002), and Polynesian (p=.041).
- Chinese and: Indian, African, Other European and Melanesian (P≤.001), North European (p=.006).
- Polynesian and: Indian (p<.001), and African (p<.001).

Korean sitting height ratio was the highest, and was significantly higher than all other groups except Chinese. Likewise Chinese sitting height ratio was significantly higher than all other groups except Koreans and Polynesians. These three formed the highest subset for sitting height ratio. African, Indian, Melanesian and the European groups formed the lowest subset.

Wrist Width

A two-way between-groups ANOVA was used to explore the differences between the mean wrist width for ethnic groups, using EG1 (but excluding the Other category) for males and females.

There was a significant main effect for ethnicity *F* (7,247) = 240.63, *p* < .001. The effect size was large at .45. There was a significant main effect for gender *F* (1,247) = 311.20, *p* < .001. The effect size was large at .56, larger than that for ethnicity. The interaction effect between ethnicity and gender was not significant (p=.591).

There were significant differences in mean wrist width among ethnic groups, and between genders, but no significant differences for the interaction between gender and ethnicity. This suggests a similar pattern among ethnic groups for both males and females. Post-hoc comparisons on mean wrist width, using the Tukey HSD test, were completed as shown in Table 28.

Table 28. Homogeneous subsets of wrist width for males and females by EG1 using the Tukey HSD test.

EG1	N	Subset			
		1	2	3	4
Chinese	27	50.942			
Indian	51	51.321			
Korean	24	52.204	52.204		
Melanesian	25	53.101	53.101	53.101	
African	21		54.065	54.065	
North European	13		54.186	54.186	
Other European	52			54.872	
Polynesian	50				57.365
Sig.		.119	.198	.332	1.000

Means for groups in homogeneous subsets are displayed in mm.

Significant differences were found between the following groups:

- Polynesian and; Melanesian, African, Indian, Chinese, Korean and North European (all at p<.001), and Other European (p=.011).
- Other European and; Indian (p<.001), Korean (p=.005), Chinese p<.001).
- North European and; Indian (p=.033), Chinese (p=.021)
- African and; Indian (p=.007), and Chinese (p=.006).

Polynesians had significantly larger wrist widths than all other groups. The two European groups also scored high. Chinese and Indians were at the lower end of the range.

Finger Width

A two-way between-groups ANOVA was used to explore the differences between the mean finger width for ethnic groups, using EG1 (but excluding the Other category) for males and females.

There was a significant main effect for ethnicity *F* (7,247) = 17.28, *p* < .001. The effect size was large at .35. There was a significant main effect for gender *F* (1,247) = 155.14, *p* < .001. The effect size was large at .47, larger than that for ethnicity. The interaction effect between ethnicity and gender was not significant (p=.153).

There were significant differences in mean finger width among ethnic groups, and between genders, but no significant differences for the interaction between gender and ethnicity. This suggests a similar pattern among ethnic groups for both males and females. Post-hoc comparisons on mean finger width, using the Tukey HSD test, were completed as shown in Table 29.

Table 29. Homogeneous subsets of finger width for males and females by EG1 using the Tukey HSD test.

EG1	N	Subset		
		1	2	3
Chinese	25	12.715		
Korean	24	13.177	13.177	
Indian	49	13.244	13.244	
North European	7		13.690	13.690
African	21		13.730	13.730
Melanesian	25		14.018	14.018
Other European	36			14.373
Polynesian	50			14.375
Sig.		.547	.054	.214

Means for groups in homogeneous subsets are displayed in mm.

Significant differences were found between the following groups:

- Polynesian and; Korean, Chinese and Indian (p<.001).
- Other European and; Korean, Chinese and Indian (p<.001).
- Melanesian and; Chinese (p<.001), Korean (p=.027), and Indian (p=.013).
- African and Chinese (p=.004).

Polynesian and Other European finger widths were significantly wider than Chinese, Korean and Indian groups. Chinese finger widths were the narrowest, much narrower than the other groups. Again Chinese, Indian and African groups ranked the lowest.

6.2.3. Relationship between Body Shape Variables

The correlations between the different variables for body shape are shown in the correlation matrices in Table 30. Sitting height ratio showed little significant correlation with any of the other variables except height and wrist width. Finger width had no significant correlation with biacromial width. For males, all the other variables showed significant correlation with each other. In general biiliac width had the highest correlation with the other variables.

For females, the major difference was a generally higher correlation between the variables, particularly with regard to finger width. Again there was little significant correlation between sitting height ratio and any other variables. Most of the other variables were significantly correlated with each other. Biacromial and biiliac width had the highest overall correlation with other variables.

Table 30. Correlation matrix between body shape variables for males and females.

Male		Height	Biacromial	Biiliac	SHR	Wrist Width	Finger Width
Height	Pearson Correlation	1	.459**	.521**	-.268**	.442**	.195*
	Sig. (2-tailed)		.000	.000	.001	.000	.031
Biacromial	Pearson Correlation	.459**	1	.545**	-.051	.463**	.168
	Sig. (2-tailed)	.000		.000	.545	.000	.064
Biiliac	Pearson Correlation	.521**	.545**	1	.039	.529**	.387**
	Sig. (2-tailed)	.000	.000		.648	.000	.000
SHR	Pearson Correlation	-.268**	-.051	.039	1	.062	.216*
	Sig. (2-tailed)	.001	.545	.648		.463	.017
Wrist Width	Pearson Correlation	.442**	.463**	.529**	.062	1	.563**
	Sig. (2-tailed)	.000	.000	.000	.463		.000
Finger Width	Pearson Correlation	.195*	.168	.387**	.216*	.563**	1
	Sig. (2-tailed)	.031	.064	.000	.017	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

Female		Height	Biacromial	Biiliac	SHR	Wrist Width	Finger Width
Height	Pearson Correlation	1	.510**	.393**	-.133	.549**	.364**
	Sig. (2-tailed)		.000	.000	.112	.000	.000
Biacromial	Pearson Correlation	.510**	1	.663**	.111	.653**	.521**
	Sig. (2-tailed)	.000		.000	.187	.000	.000
Biiliac	Pearson Correlation	.393**	.663**	1	.050	.648**	.656**
	Sig. (2-tailed)	.000	.000		.552	.000	.000
SHR	Pearson Correlation	-.133	.111	.050	1	.064	.046
	Sig. (2-tailed)	.112	.187	.552		.442	.603
Wrist Width	Pearson Correlation	.549**	.653**	.648**	.064	1	.707**
	Sig. (2-tailed)	.000	.000	.000	.442		.000
Finger Width	Pearson Correlation	.364**	.521**	.656**	.046	.707**	1
	Sig. (2-tailed)	.000	.000	.000	.603	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

6.2.4. Relationship between Body Shape and Body Size variables

Finally in reviewing the analysis of body shape and body size variables it is useful to look for relationships between these two different groups of variables.

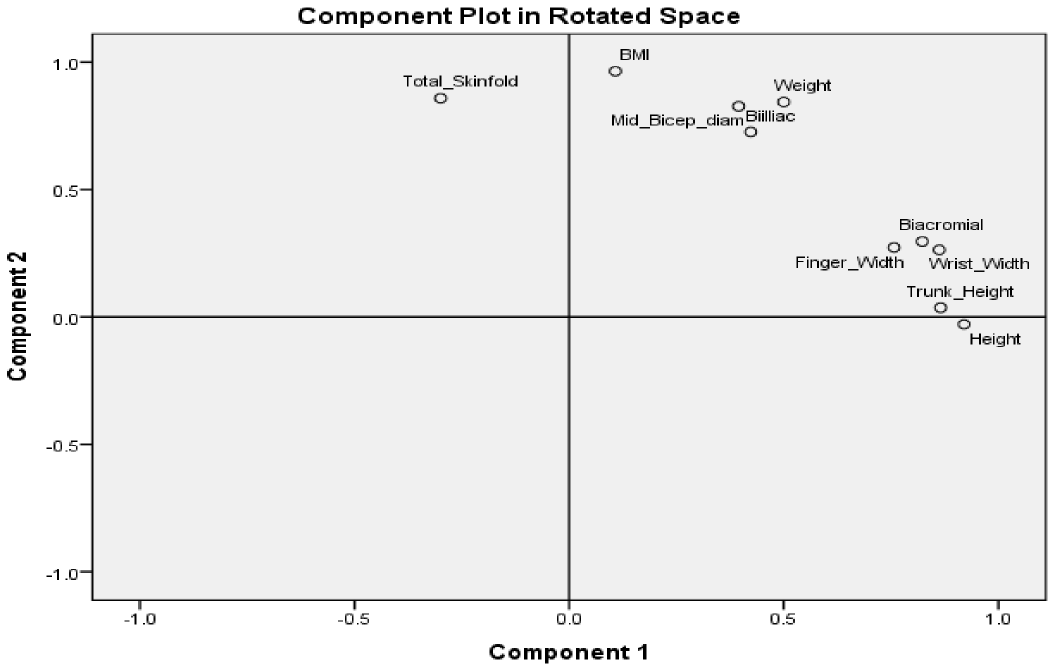


Figure 23. Analysis of principal component 1 against principal component 2 for body shape and body size variables.

Figure 23 above shows principal components analysis for all the body size and body shape, excluding sitting height ratio, which was off the scale for a two dimensional representation, and did not correlate closely with any other variables. There are two main clusters, one including height, trunk height, finger width, wrist width and biacromial width, which are all body shape variables. The second cluster includes weight, mid biceps diameter, and to a lesser extent, BMI and total skinfold, which are all body size variables. However, this grouping also includes biiliac width, the one variable that does not group within its category.

The principal component analysis (PCA) was conducted on the body shape and size variables with an oblique rotation due to the correlation between variables (Pallant, 2011, p. 185). Prior to performing the analysis, the suitability of the data for factor analysis was assessed. The Kaiser-Meyer-Olkin measure verified the sampling adequacy, KMO = .831, exceeding the recommended value of .6 ((Kaiser, 1970, 1974), and Bartlett's test of sphericity reached statistical significance, indicating the correlations between items were sufficiently large for PCA (Field, 2009, p. 671).

Principal components analysis identified two components which explained 56.51% and 24.49% of the variance between the groups respectively, a cumulative explanation of variance of 81.00%. The scree plot showed a clear break after the second component, and this is the number of components that were used for the final analysis, as shown in Table 31.

Weight was the variable explaining most of the variance between the groups, followed by mid biceps diameter. The next three variables contributing most to the variance were body shape variables including wrist width, biiliac width and finger width.

Table 31. Summary of exploratory factor analysis results from the component matrix for body size and shape variables.

	Component	
	1	2
Weight	.931	.310
Mid Biceps diam	.841	.366
Wrist Width	.824	-.366
Biacromial	.816	-.315
Biiliac	.796	
Finger Width	.750	
BMI	.713	.658
Trunk Height	.678	-.540
Height	.676	-.625
Total Skinfold	.336	.845

Extraction Method: Principal Component Analysis.
a. 2 components extracted.

The correlation between a number of body shape and body size variables is shown in Table 32. The highest correlation between a body size and body shape variable is between weight and biiliac width, at .798. The lowest correlation is between total skinfold and biacromial width. Excluding sitting height ratio, most of the variables are significantly correlated with each other.

Table 32. Correlation matrix for body shape and body size variables.

		Weight	Height	Biacromial	Biiliac	Total Skinfold	SHR	BMI	Mid Biceps	Wrist Width	Finger Width
Weight	Pearson	1	.464**	.658**	.798**	.558**	.009	.888**	.894**	.631**	.570**
	Sig. (2-tailed)		.000	.000	.000	.000	.875	.000	.000	.000	.000
Height	Pearson	.464**	1	.720**	.404**	-.225**	-.313**	.025	.334**	.710**	.564**
	Sig. (2-tailed)	.000		.000	.000	.000	.000	.668	.000	.000	.000
Biacromial	Pearson	.658**	.720**	1	.507**	.000	-.150*	.384**	.571**	.761**	.629**
	Sig. (2-tailed)	.000	.000		.000	.999	.011	.000	.000	.000	.000
Biiliac	Pearson	.798**	.404**	.507**	1	.484**	.018	.694**	.665**	.517**	.457**
	Sig. (2-tailed)	.000	.000	.000		.000	.764	.000	.000	.000	.000
Skinfold	Pearson	.558**	-.225**	.000	.484**	1	.163**	.736**	.529**	-.044	-.036
	Sig. (2-tailed)	.000	.000	.999	.000		.006	.000	.000	.454	.565
SHR	Pearson	.009	-.313**	-.150*	.018	.163**	1	.164**	.017	-.116	-.060
	Sig. (2-tailed)	.875	.000	.011	.764	.006		.006	.769	.050	.344
BMI	Pearson	.888**	.025	.384**	.694**	.736**	.164**	1	.842**	.360**	.373**
	Sig. (2-tailed)	.000	.668	.000	.000	.000	.006		.000	.000	.000
Mid Biceps	Pearson	.894**	.334**	.571**	.665**	.529**	.017	.842**	1	.548**	.523**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.769	.000		.000	.000
Wrist Width	Pearson	.631**	.710**	.761**	.517**	-.044	-.116	.360**	.548**	1	.779**
	Sig. (2-tailed)	.000	.000	.000	.000	.454	.050	.000	.000		.000
Finger Width	Pearson	.570**	.564**	.629**	.457**	-.036	-.060	.373**	.523**	.779**	1
	Sig. (2-tailed)	.000	.000	.000	.000	.565	.344	.000	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

A two-way between-groups MANOVA was conducted using the body size and body shape dependent variables weight, total skinfold, mid biceps diameter, BMI, height, trunk height, biacromial width, biiliac width, sitting height ratio, wrist width and finger width by ethnic grouping EG1 (excluding Others) and gender as the fixed factors. A two way analysis was used due to the significant differences in body shape between genders. Pillai's trace was used for the analysis.

There was a significant difference between genders, V = 0.76, F (11,211) = 59.27, p<.001. There was a significant difference between groups, V = 1.73, F (77,1519) = 6.46, p<.001. Effect size was large for both gender differences (0.76) and ethnic groups (0.25).

There was a significant interaction effect between gender and ethnicity (p<.001). This indicates that ethnic groups differed in the relationships between body shape and gender.

Test of between subjects effects again showed significant differences for ethnicity and gender, p<.05 for all body shape variables. The interaction effect between gender and ethnicity showed significant differences for trunk height (p=.024), and biacromial width (p=.014).

Discriminant analysis was conducted to investigate the relationship between ethnicity (EG1) and body size and body shape variables. Predictor variables were weight, total skinfold, mid biceps diameter, BMI, height, trunk height, biacromial width, biiliac width, sitting height ratio, wrist width and finger width. Significant mean differences were observed for all the variables. The log determinants were not similar, and Box's M indicated that the assumption of equality of covariance was violated. However, as before, reliance is on the large sample size for validity.

The analysis revealed seven discriminant functions. The first explained 38.7% of variance, the second 28.8%, the third 19.7%, the fourth 8.3%, the fifth 2.3%, the sixth 1.0%, and the seventh 0.3% of variance. The relative contribution of each variable to each discriminant function is shown in the structure matrix in Table 33 below. In general body size variables contributed more strongly to group separation than body shape variables, with biiliac width the one exception. BMI was the variable contributing the most to group separation, followed by biiliac width.

Table 33. Discriminant function analysis for body size and body shape variables.

	Function							
	1	2	3	4	5	6	7	8
BMI	-.741*	.152	.093	.162	-.033	.149	-.427	-.108
Biiliac	-.611*	.468	.373	.113	.322	.255	-.091	.259
Weight	-.582*	.225	.353	.367	-.051	.316	-.381	.049
Mid Biceps diam	-.530*	.173	.271	.357	.069	.213	-.076	-.105
Total Skinfold	-.515*	.083	-.074	.430	.339	-.229	-.387	-.325
SHR	.074	.639*	-.332	-.174	-.216	-.003	-.246	-.473
Trunk Height	.156	.542*	.497	.348	-.254	.453	-.134	.120
Height	.114	.164	.631*	.431	-.105	.431	.017	.375
Wrist Width	-.268	.245	.414	.360	-.543*	.281	.294	.231
Biacromial	-.190	.154	.131	.460	-.200	.699*	.071	.353
Finger Width	-.268	.095	.465	.088	-.355	.622*	.284	-.266

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.
*. Largest absolute correlation between each variable and any discriminant function

6.2.5. Summary of Analysis of Body Size and Body Shape Variables.

There were significant differences between genders for each of the variables but within each ethnic group these differences were similar, except for biacromial width.

There were significant differences identified among the different ethnic groups for all body size and shape variables. These are summarised in Table 34 below.

Table 34. Summary of significant differences between EG1 groups for body size and body shape variables.

EG1	Other European	North European	Korean	Chinese	Indian	African	Polynesian
Other European							
North European							
Korean	1,5,8,9,10	5,8					
Chinese	3,5,7,8,9,10	5,8,9					
Indian	2,5,7,9,10	5,9	8	8			
African	5,7		8	8,9,10	9		
Polynesian	1,2,3,4,5,6,7 9	1,2,3,4,6,7,9	1,2,3,4 5,7,8,9 10	1,2,3,4,5, 6,7,9,10	1,2,3,4,5 6,7,8,9 10	1,2,3,4 6,7,8,9	
Melanesian	2,4,5	4,5	1,2,3,4 5,7,8,10	1,2,3,4,5 7,8,10	1,4,5,7 10	1,2,3,4 5,7	1,3,5,7,9
Significant differences							
Weight	1						
Total skinfold	2						
Mid Biceps Diameter	3						
BMI	4						
Height	5						
Biacromial width	6						
Biiliac width	7						
Sitting height ratio	8						
Wrist width	9						
Finger width	10						

As can be seen the most significant differences were between Polynesians and all other groups. Polynesians had significantly higher values in most body size and body shape variables, suggesting their much larger average size than the other groups. Melanesians were also on average generally significantly larger than the other groups, but unlike Polynesians, were considerable shorter.

There were no significant differences in any variables between Chinese and Koreans, and between Other Europeans and North Europeans. There were only minor differences between Indians and Koreans and Chinese, and between Africans, Indians, Koreans and Other Europeans.

In terms of body size variables, BMI was the variable contributing most to group separation, followed closely by weight. For body shape variables, biiliac width was the variable contributing most to group separation. The highest correlation between a body size and body shape variable was between weight and biiliac width at .798, but a large number of variables were highly correlated, as might be expected.

6.3. CIVD Response Testing

This section covers the statistical analysis of some of the key variables obtained by having each participant hold their hand in water at a temperature of 5ºC for 30 minutes. This produces a number of temperature and time variables as displayed in Figure 24 below. The abbreviations used in this section for the different variables are reproduced again in Table 35 below for ease of reference.

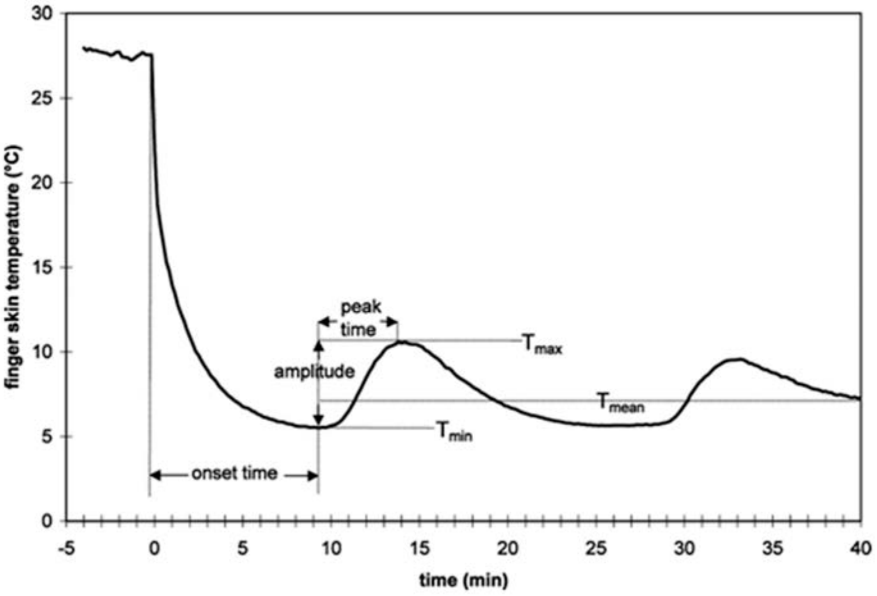


Figure 24. Parameters derived from a temperature profile of a fingertip immersed in cold water. (Daanen, 2003).

Table 35. Glossary of terms used in CIVD response analysis.

Glossary of terms used in CIVD response analysis	
T_{av}	Average temperature over 30 minutes of cooling
T_{mean}	Average temperature from Tmin to end of test
T_{max}	Maximum temperature achieved during 1st CIVD response
T_{min}	Minimum temperature during 30 minutes of cooling
T_{30}	Temperature after 30 minutes of cooling
$T_{pretest}$	Temperature prior to cooling
Amplitude	The increase in temperature from Tmin to Tmax
Onset time	The time from immersion to T min
Peak time	The time between Tmin and Tmax
Time to max	The time from immersion to Tmax
T_{freq}	The frequency of CIVD cycles during the test period
T_{index}	Index based on T_{av}, amplitude and onset time

Note. All temperatures are fingertip temperatures. 1st CIVD response is defined as the period between T_{min} and T_{max}, where T_{max} is the maximum temperature post T_{min} and prior to either a subsequent fall in temperature of 1ºC, or the end of the test, whichever is first.

As with the anthropometric variables, this section is designed to identify two important aspects; those variables that are most significant in terms of being able to define and measure the strength of a CIVD response, and to explore the differences in CIVD response between ethnic groups. This should then provide the basis for understanding the relationship between ancestral environment and CIVD response.

This section is divided into seven sections. The first section provides an overview of the relationship between the most important variables using principal component analysis and discriminant function analysis. The second section uses MANOVA to explore the significant differences between ethnic groups. The third section provides a more detailed analysis of average finger temperature over 30 minutes, or $T_{av,}$ which is the most significant variable in CIVD response.

The fourth section reviews a number of the other important CIVD response variables, although this is limited by the non-normal distribution for many of these variables. The fifth section develops an index utilising three of the most important CIVD response, including both time and temperature variables, to better understand the strength of an individual CIVD response. The sixth section reviews participant discomfort levels during testing and the seventh section provides a brief summary.

6.3.1. Overview of Variables

A principal component analysis (PCA) was conducted on the ten CIVD response variables shown in Figure 25 with an oblique rotation due to the correlation between variables (Pallant, 2011, p. 185). Prior to performing the analysis, the suitability of the data for factor analysis was assessed. The Kaiser-Meyer-Olkin measure verified the sampling adequacy, KMO = .688, exceeding the recommended value of .6 ((Kaiser, 1970, 1974), and Bartlett's test of sphericity reached statistical significance, indicating the correlations between items were sufficiently large for PCA (Field, 2009, p. 671).

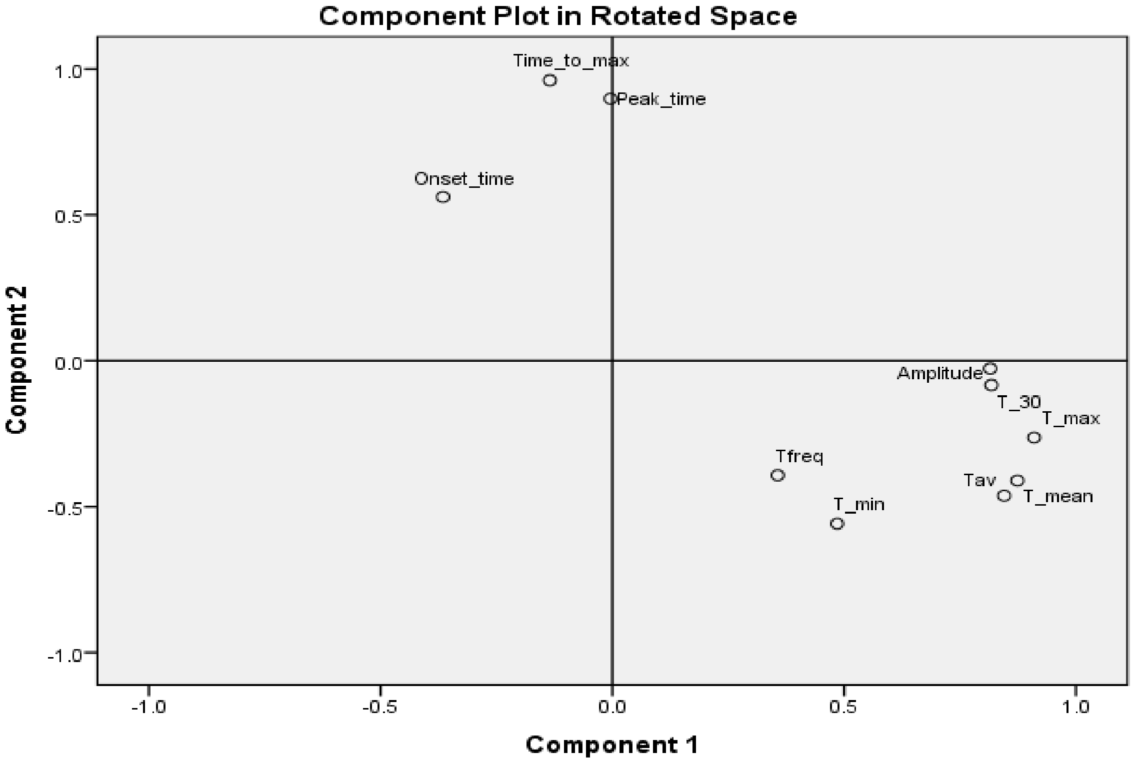


Figure 25. Principal components analysis of CIVD variables.

Figure 25 shows a number of CIVD variables clustering into two groups. The top group are time variables in a CIVD response. These are related, with a shorter time to begin a rewarming response, peak and then reach maximum temperature all contributing to a stronger CIVD response. Likewise the second cluster in the right hand side of the diagram displays temperature variables which are related, with a higher temperature in all facets generally representing a stronger CIVD response. T_{av} clusters in the middle of this group and is often considered to be the most consistent predictor of CIVD response. It is the variable most often quoted in previous research.

Principal components analysis identified two components which explained 55.37% and 15.84% of the variance respectively, a cumulative explanation of variance of 71.21%. The scree plot showed a clear break after the second component, and this is the number of components that were used for the final analysis, as shown in Table 36. Temperature variables loaded most strongly on component 1, with time variables loaded most strongly on component 2. Temperature variables, particularly T_{av} explained most of the variance.

Table 36. Summary of exploratory factor analysis results from the component matrix for CIVD response variables.

	Component	
	1	2
T_{av}	.955	
T_{mean}	.947	
T_{max}	.892	.327
T_{min}	.716	
T_{30}	.705	.388
Time to max	-.694	.678
Amplitude	.674	.481
Onset time	-.634	
T_{freq}	.520	
Peak time	-.560	.702

Extraction Method: Principal Component Analysis.
a. 2 components extracted.

6.3.2. Multivariate Analysis

Despite a number of the variables not showing a normal distribution, multivariate analysis was used to analyse between group differences for a number of variables. MANOVA is considered robust enough to analyse variables that violate the assumptions of normality and homogeneity of variance (Kinnear & Gray, 2009, p. 386).

The MANOVA analysis is based on the principal components analysis as shown in Figure 25. This analysis shows two clusters, one for temperature variables, and the other for time related variables. The first MANOVA uses the six temperature variables being Tav, Amplitude, T_{min}, T_{max}, T_{30} and $T_{mean.}$ Categorisation was by EG1 excluding the Other category. Results were analysed using Pillai's Trace.

There was a significant difference between ethnic groups, V = 0.55, F (42, 1332) = 3.22, $p<.001$. Effect size was medium (0.09). Test of between subjects effects showed significant differences between groups for all cold induced vasodilation response variables at $p<.001$ except amplitude ($p=.058$). There is a summary of significant between-group differences (EG1) for all cold induced vasodilation response variables on page 170.

Discriminant analysis was conducted to investigate the relationship between ethnicity (EG1 excluding others) and cold induced vasodilation response variables. Predictor variables were T_{av}, Amplitude, T_{min}, T_{max}, T_{30} and T_{mean}. Significant mean differences were observed for all the variables. The log determinants were not similar, and Box's M indicated that the assumption of equality of covariance was violated. However, as before, reliance is on the large sample size for validity.

The analysis revealed six discriminant functions. The first explained 75.4% of variance, the second 15.6%, the third 4.5%, the fourth 3.1%, the fifth 1.2% and the sixth 0.2% of variance. The relative contribution of each variable to each discriminant function is shown in the structure matrix in Table 37 below. T_{av} was the variable contributing the most to group separation, followed by T_{min} and T_{mean}.

Table 37. Discriminant function structure matrix for temperature CIVD variables.

	Function					
	1	2	3	4	5	6
T_{av}	.874*	.203	-.086	.384	.174	.096
T_{min}	.826*	.217	.279	-.342	.086	.261
T_{mean}	.787*	.283	-.133	.462	.241	.105
Amplitude	.261	-.034	.092	.838*	.421	.205
T_{max}	.603	.130	.218	.607*	.446	.066
T_{30}	.461	.468	.188	.587*	-.363	.237

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.
*. Largest absolute correlation between each variable and any discriminant function

Further analysis was undertaken on the time variables onset time, peak time, and time to maximum temperature using MANOVA. Categorisation was by EG1 excluding the Other category. Results were analysed using Pillai's Trace. There was a significant difference between groups, $V = 0.30$, $F(18,669) = 4.07$, $p<.001$. Effect size was medium (0.10).

Discriminant function analysis was conducted to investigate the relationship between ethnicity (EG1 excluding others) and the three cold induced vasodilation response time variables used in the above MANOVA. Predictor variables were onset time, peak time, and time to maximum temperature. Significant mean differences were observed for all the variables. The log determinants were not similar, and Box's M indicated that the assumption of equality of covariance was violated. However, as before, reliance is on the large sample size for validity.

The analysis revealed three discriminant functions. The first explained 86.5% of variance, the second 8.3%, and the third 5.2% of variance. The relative contribution of each variable to each discriminant function is shown in the structure matrix in Table 38 below. Onset time was the variable contributing the most to group separation, followed by peak time.

Table 38. Discriminant function structure matrix for time CIVD variables.

	Function		
	1	2	3
Onset time	.978*	.009	-.210
Peak time	.219	.964*	-.154
Time to max	.474	.809*	-.348

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions
Variables ordered by absolute size of correlation within function.
*. Largest absolute correlation between each variable and any discriminant function

Finally MANOVA analysis was conducted using the six CIVD response temperature variables, T_{av}, Amplitude, T_{min}, T_{max}, T_{30}, T_{mean} and the three time variables being onset time, peak time, and time to maximum temperature. Categorisation was by EG1 excluding the Other category. Results were analysed using Pillai's Trace.

There was a significant difference between groups, V = 0.764, F (80, 2104) = 2.78, p<.001. Effect size was small (0.01). Test of between subjects differences showed significant differences for ethnic groups for all variables at p<.001 except amplitude (p=.116), T_{freq} (p=.003), peak time (p=.138) and time to max (p=.002).

Discriminant analysis was conducted to investigate the relationship between ethnicity (EG1 excluding others) and the nine cold induced vasodilation response variables used in the above MANOVA. Predictor variables were T_{av}, Amplitude, T_{min}, T_{max}, T_{30}, $T_{mean,}$ onset time, peak time, and time to maximum temperature. Significant mean differences were observed for all the variables. The log determinants were not similar, and Box's M indicated that the assumption of equality of covariance was violated. Reliance is on the large sample size for validity.

The analysis revealed seven discriminant functions. The first explained 64.4% of variance, the second 15.8%, the third 11.6%, the fourth 4.8%, the fifth 2.3%, the sixth 0.9% and the seventh 0.1% of variance. The relative contribution of each variable to each discriminant function is shown in the structure matrix in Table 39 below. T_{av} was the variable contributing the most to group separation, followed by T_{min} and T_{mean}. Onset time was the time variable contributing the most to group separation.

Table 39. Discriminant function structure matrix for CIVD variables.

	Function						
	1	2	3	4	5	6	7
T_{av}	.765*	-.031	-.239	-.246	.235	.452	-.009
T_{min}	.716*	.103	-.234	-.429	-.367	.022	.081
T_{mean}	.689*	-.032	-.310	-.171	.298	.526	-.028
T_{max}	.524*	.066	-.165	-.318	.519	.465	-.198
Onset time	-.605	.692*	-.169	.074	.099	-.172	.005
Time to max	-.240	.533*	.028	.513	.203	-.394	.095
T 30	.393	-.056	-.488*	-.359	.374	.274	.409
Peak time	-.068	.408	.128	.531*	.116	-.275	.121
Amplitude	.228	.014	.000	-.148	.753*	.534	-.032

Pooled within-groups correlations between discriminating variables and standardized canonical discriminant functions

Variables ordered by absolute size of correlation within function.

*. Largest absolute correlation between each variable and any discriminant function

6.3.3. Average Finger Temperature over 30 minutes (T_{av}).

The first variable to be considered is that of T_{av}, given that it is a reflection of the CIVD response over the entire 30 minute test for each participant, and it was the variable contributing most to group separation as shown in section 6.3.2. Distribution of the data when tested using both the Kolmogorov-Smirnov and Shapiro-Wilk tests showed normal distribution, as seen in Table 40.

Table 40. Test of normality for T_{av}.

	Kolmogorov-Smirnov[a]			Shapiro-Wilk		
	Statistic	df	Sig.	Statistic	df	Sig.
T_{av}	.031	274	.200*	.995	274	.458

a. Lilliefors Significance Correction

*. This is a lower bound of the true significance.

This was confirmed in Figure 26, showing the frequency distribution for T_{av}. A comparison of the overall mean, 8.13 with the 5% trimmed mean, 8.12, shows they are very similar, indicating no significant outliers.

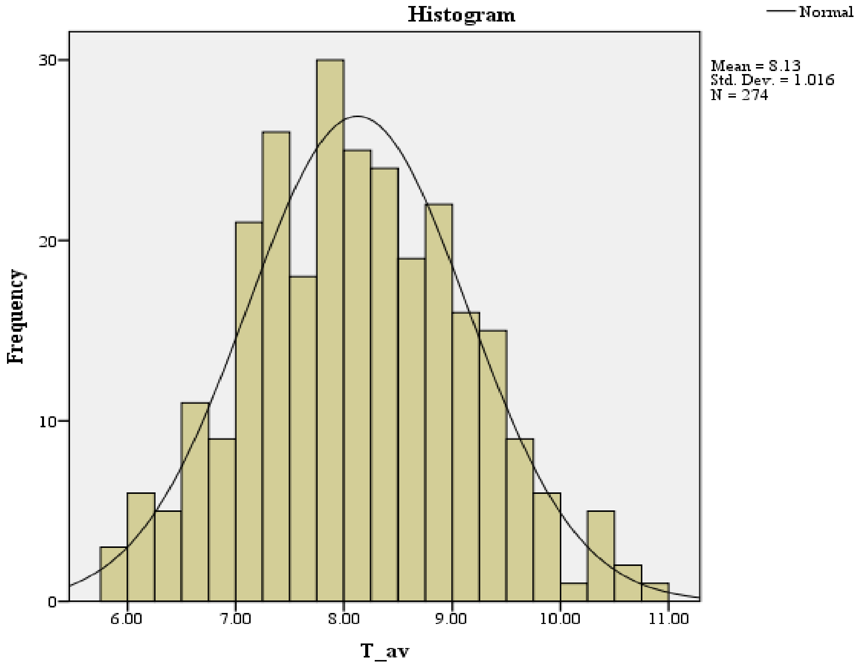


Figure 26. Histogram showed frequency distribution for T_{av}.

With normal distribution of T_{av} confirmed, it is necessary to determine whether there are significant differences between the two gender groups. The means for T_{av} by gender are shown in Table 41.

Table 41. Means for T_{av} by gender.

	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min.	Max.
					Lower Bound	Upper Bound		
Male	134	8.06	0.98	0.085	7.89	8.23	5.77	10.49
Female	140	8.19	1.05	0.089	8.01	8.36	5.99	10.80
Total	274	8.13	1.02	0.061	8.00	8.25	5.77	10.80

Means are shown in ºC.

The female T_{av} is higher than for males. A one-way between-groups ANOVA was used to explore the differences between the mean T_{av} for males and females. There was no significant difference, with p=.317 for T_{av} for the different genders, as shown in Table 42.

Table 42. One way ANOVA for T_{av} by gender.

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.039	1	1.039	1.005	.317
Within Groups	280.979	272	1.033		
Total	282.017	273			

Analysis by gender was also completed for each individual ethnic group. Again there was no significant difference, although Polynesian did come close with p=.057. For males, Korean had the highest T_{av}, higher than all other ethnic groups including Polynesian. Polynesian had the highest T_{av} for females. In two ethnic groups, the means for females were higher than males, being European and Polynesian.

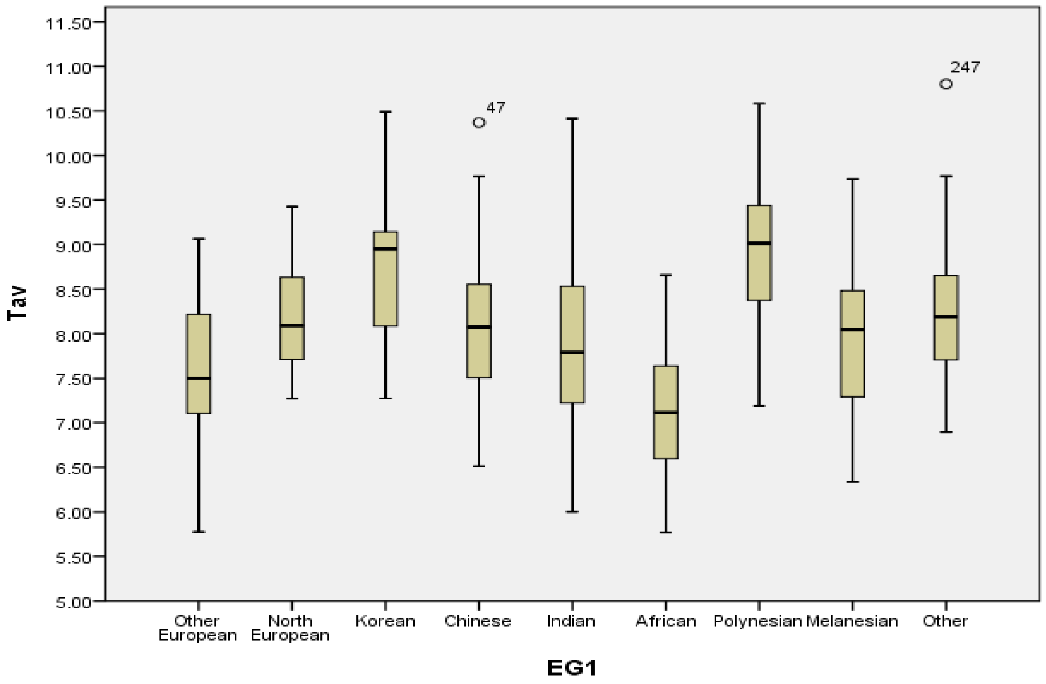
One this basis all analysis on T_{av} was done without separate analyses for males and females. First is an analysis by ethnic group. Means for EG1 are shown in Table 43.

Table 43. Means for T_{av} by EG1.

EG1	N	Mean	SD	Std. Error	95% Confidence Interval for Mean		Minimum	Maximum
					Lower Bound	Upper Bound		
Other European	47	7.64	0.816	.119	7.40	7.88	5.78	9.07
North European	13	8.18	0.652	.181	7.79	8.57	7.27	9.43
Korean	24	8.76	0.775	.158	8.43	9.08	7.27	10.49
Chinese	26	8.16	0.946	.185	7.78	8.55	6.51	10.37
Indian	51	7.84	1.025	.144	7.56	8.13	6.00	10.41
African	20	7.13	0.785	.176	6.77	7.50	5.77	8.66
Polynesian	49	8.94	0.833	.119	8.70	9.18	7.19	10.58
Melanesian	23	8.03	0.920	.192	7.63	8.43	6.34	9.73
Other	21	8.24	0.919	.201	7.83	8.66	6.90	10.80
Total	274	8.13	1.016	.061	8.00	8.25	5.77	10.80

Means are shown in ºC.

Polynesian had the highest average finger temperature, closely followed by Korean. African had the lowest T_{av}. The range for each ethnic group is similar as seen in Figure 27. The widest range in any one group was seen in the Indian group. The smallest range was seen in the African and North European groups.



Tav = average finger temperature, EG1 = ethnic grouping 1. Outliers are shown as circles.

Figure 27. T_{av} means distribution by EG1.

A one-way between-groups ANOVA was used to explore the differences in mean T_{av} among ethnic groups (EG1 excluding Other). There was a significant difference among the different ethnic groups, as seen in Table 44, with F (7,245) =14.279, p<.001. Effect size was large, with eta^2=.29.

Table 44. One way ANOVA for T_{av} by EG1.

ANOVA Table

			Sum of Squares	df	Mean Square	F	Sig.
Tav * EG1	Between Groups	(Combined)	76.732	7	10.962	14.279	.000
	Within Groups		188.075	245	.768		
	Total		264.806	252			

Measures of Association

	Eta	Eta Squared
Tav * EG1	.538	.290

Post-hoc comparisons for Tav by EG1 using the Tukey HSD test were completed as shown in Table 45.

Table 45. Homogeneous subsets of T_{av} by EG1 using the Tukey HSD test.

EG1	N	Subset for alpha = 0.05			
		1	2	3	4
African	20	7.1343			
Other European	47	7.6409	7.6409		
Indian	51	7.8440	7.8440		
Melanesian	23		8.0324	8.0324	
Chinese	26		8.1645	8.1645	
North European	13		8.1799	8.1799	
Korean	24			8.7572	8.7572
Polynesian	49				8.9358
Sig.		.077	.353	.065	.996

Means for groups in homogeneous subsets are displayed in °C.

Significant differences were found between the groups as follows:

- Polynesian and: Other European (p<.001), Chinese (p=.008), Indian (p<.001). Melanesian (p=.002), and Africans (p<.001).
- African and: Korean (p<.001), Melanesian (p=.021), Chinese (p=.003), Indian (p=.048), North European (p=.021)
- Korean and: Other European (p<.001), Indians (p=.001).

Polynesian and Korean grouped together as a subset, and their mean T_{av} was much higher than for all other ethnic groups. Polynesian had significantly higher T_{av} than all other groups except Korean and North European. Conversely African had significantly lower T_{av} than all other groups except Other European.

Means for T_{av} by the more detailed ethnic group categorisation EG2 (excluding Other) are shown in Table 46 below, ranked by mean T_{av}. Most ethnic subcategories within EG1 rank relatively closely to each other. The two exceptions are the differences between the UK, Mixed and South European groups, which group together, and North European which is separate from the other European groups. Likewise there is a similar but smaller gap between North and South Chinese.

Table 46. Mean T_{av} by EG2.

EG2	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean		Min	Max
					Lower Bound	Upper Bound		
Samoan	31	9.15	0.844	0.152	8.84	9.46	7.19	10.58
Other Polynesian	10	8.87	0.612	0.194	8.44	9.31	7.67	9.56
Korean	24	8.76	0.775	0.158	8.43	9.08	7.27	10.49
North Chinese	5	8.49	0.787	0.352	7.51	9.46	7.43	9.65
Tongan	8	8.19	0.624	0.221	7.67	8.72	7.21	9.35
North European	13	8.18	0.652	0.181	7.79	8.57	7.27	9.43
South Chinese	21	8.09	0.981	0.214	7.64	8.53	6.51	10.37
Island Melanesian	13	8.05	0.993	0.275	7.45	8.65	6.34	9.73
PNG Melanesian	10	8.01	0.868	0.275	7.39	8.63	7.02	9.71
South Indian	23	7.86	0.857	0.179	7.49	8.23	6.00	9.30
North Indian	28	7.83	1.160	0.219	7.38	8.28	6.12	10.41
South European	6	7.76	0.592	0.242	7.13	8.38	7.39	8.89
UK European	34	7.66	0.882	0.151	7.35	7.97	5.78	9.07
Mixed European	7	7.45	0.691	0.261	6.82	8.09	6.68	8.72
West African	11	7.40	0.743	0.224	6.90	7.90	5.99	8.66
East African	9	6.81	0.743	0.248	6.23	7.38	5.77	8.24
Total	253	8.12	1.025	0.064	7.99	8.24	5.77	10.58

A further analysis using a one way ANOVA was completed using the more detailed ethnic breakdown, EG2. A one-way between-groups ANOVA was used to explore the differences between the mean T_{av} for ethnic groups. There were a significant differences among the ethnic groups, as seen in Table 44, with F (15,237) =7.511, p<.001.

Effect size was large, with eta^2=.32. Post-hoc comparisons for T_{av} by EG2 using the Tukey HSD test were completed as shown in Table 47.

Table 47. Homogeneous subsets of T_{av} by EG2 using the Tukey HSD test.

		Subset for alpha = 0.05			
EG1	N	1	2	3	4
East African	9	6.8054			
West African	11	7.4036	7.4036		
Mixed European	7	7.4543	7.4543		
UK European	34	7.6590	7.6590	7.6590	
South European	6	7.7558	7.7558	7.7558	
North Indian	28	7.8292	7.8292	7.8292	
South Indian	23	7.8620	7.8620	7.8620	
PNG Melanesian	10	8.0103	8.0103	8.0103	8.0103
Island Melanesian	13	8.0494	8.0494	8.0494	8.0494
South Chinese	21		8.0880	8.0880	8.0880
North European	13		8.1799	8.1799	8.1799
Tongan	8		8.1939	8.1939	8.1939
North Chinese	5		8.4860	8.4860	8.4860
Korean	24			8.7572	8.7572
Other Polynesian	10			8.8737	8.8737
Samoan	31				9.1473
Sig.		.062	.198	.078	.138

Means for groups in homogeneous subsets are displayed in ºC.

Significant differences were found among the following groups:

- Samoan and: West and East African, North and South Indian, UK and mixed European (all p≤.001), Island Melanesian (p=.016), PNG Melanesian (p=.33), South Chinese (p=.003).
- Other Polynesian and: East African (p<.001), West African (p=.013), UK European (p=.013).
- Korean and: UK European (p<.001), Mixed European (p=.047), East African (p<.001), West African (p=.003), North Indian (p=.015), South Indian (p=.041).
- North European and East African (p=.028).
- South Chinese and East African (p=.024).

Although this analysis relies on different sample sizes, some of which are relatively small, it does generate some interesting results. Although most sub-groups of the EG1 ethnic groups grouped together, two do not. North Europeans grouped much higher than the other European Groups, and North Chinese grouped higher than South Chinese.

All Polynesian ethnic groups grouped with Koreans, both North and South Chinese groups, both Island and PNG Melanesian groups, as well as the North European ethnic group as having higher T_{av} means. The group at the lower end included both African groups as well as both North and South Indian groups and UK, Mixed and South European groups. Analysis of the North and South Chinese subgroups using a one way ANOVA did not show a statistically significant difference between these two groups, p=.409. This may reflect the homogeneity of the Chinese group in general in terms of cold induced vasodilation response, or may reflect the difficulty in accurately identifying ancestry for modern Chinese populations, particularly those living in New Zealand. Either way these two groups are treated as one in the present study.

Analysis of the four European ethnic groups using a one way ANOVA did not show a statistically significant difference between these four groups, p=.17. However, when UK, South and Mixed European ethnic groups were grouped together, and then compared with the North European group, there was a significant difference between the two groups at p<.05, with an effect size of eta^2=.08, a medium sized effect. North Europeans on the one hand, and the Other European groups on the other hand, were significantly different in terms of their cold induced vasodilation response and this was reflected in the categorization of EG1 as outlined in section 5.1.

Statistical analysis was performed on body size and body shape variables using EG1 categories to determine whether there were significant differences between the North European and Other European ethnic groups, but there were no significant differences. The correlation between $T_{av,}$ T_{index} and the body shape variables is shown in the correlation matrix in Table 48.

Table 48. Correlation matrix between T_{av}, T_{index}, and body size variables

		T_{av}	T_{index}	Weight	Mid Biceps Diam	Total Skinfold	BMI
T_{av}	Pearson	1	$.843^{**}$	$.359^{**}$	$.290^{**}$	$.395^{**}$	$.364^{**}$
	Sig. (2-tailed)		.000	.000	.000	.000	.000
T_{index}	Pearson	$.843^{**}$	1	$.296^{**}$	$.233^{**}$	$.295^{**}$	$.299^{**}$
	Sig. (2-tailed)	.000		.000	.000	.000	.000
Weight	Pearson n	$.359^{**}$	$.296^{**}$	1	$.894^{**}$	$.558^{**}$	$.888^{**}$
	Sig. (2-tailed)	.000	.000		.000	.000	.000
Mid Biceps	Pearson	$.290^{**}$	$.233^{**}$	$.894^{**}$	1	$.529^{**}$	$.842^{**}$
	Sig. (2-tailed)	.000	.000	.000		.000	.000
Total Skinfold	Pearson	$.395^{**}$	$.295^{**}$	$.558^{**}$	$.529^{**}$	1	$.736^{**}$
	Sig. (2-tailed)	.000	.000	.000	.000		.000
BMI	Pearson	$.364^{**}$	$.299^{**}$	$.888^{**}$	$.842^{**}$	$.736^{**}$	1
	Sig. (2-tailed)	.000	.000	.000	.000	.000	

**. Correlation is significant at the 0.01 level (2-tailed).

There was a significant correlation between all the body size variables and both T_{av} and T_{index}, the strongest being with Total skinfold. The correlation between T_{av}, T_{index} and body shape variables is shown in Table 49 below.

Table 49. Correlation matrix between T_{av}, T_{index}, and body shape variables.

		T_{av}	T_{index}	Height	Trunk Height	Biacromial	Biiliac	Wrist Width	SHR
T_{av}	Pearson	1	$.843^{**}$	.078	$.180^{**}$	$.143^{*}$	$.356^{**}$	$.137^{*}$	$.185^{**}$
	Sig. (2-tailed)		.000	.196	.003	.018	.000	.023	.002
T_{index}	Pearson	$.843^{**}$	1	.077	$.172^{**}$	.093	$.287^{**}$	.110	$.167^{**}$
	Sig. (2-tailed)	.000		.207	.004	.124	.000	.068	.006
Height	Pearson	.078	.077	1	$.845^{**}$	$.720^{**}$	$.404^{**}$	$.710^{**}$	$-.313^{**}$
	Sig. (2-tailed)	.196	.207		.000	.000	.000	.000	.000
Trunk Height	Pearson	$.180^{**}$	$.172^{**}$	$.845^{**}$	1	$.647^{**}$	$.422^{**}$	$.659^{**}$	$.234^{**}$
	Sig. (2-tailed)	.003	.004	.000		.000	.000	.000	.000
Biacromial	Pearson	$.143^{*}$	.093	$.720^{**}$	$.647^{**}$	1	$.507^{**}$	$.761^{**}$	$-.150^{*}$
	Sig. (2-tailed)	.018	.124	.000	.000		.000	.000	.011
Biiliac	Pearson	$.356^{**}$	$.287^{**}$	$.404^{**}$	$.422^{**}$	$.507^{**}$	1	$.517^{**}$	.018
	Sig. (2-tailed)	.000	.000	.000	.000	.000		.000	.764
Wrist Width	Pearson	$.137^{*}$	.110	$.710^{**}$	$.659^{**}$	$.761^{**}$	$.517^{**}$	1	-.116
	Sig. (2-tailed)	.023	.068	.000	.000	.000	.000		.050
SHR	Pearson	$.185^{**}$	$.167^{**}$	$-.313^{**}$	$.234^{**}$	$-.150^{*}$	.018	-.116	1
	Sig. (2-tailed)	.002	.006	.000	.000	.011	.764	.050	

**. Correlation is significant at the 0.01 level (2-tailed).
*. Correlation is significant at the 0.05 level (2-tailed).

T_{av} was significantly correlated with all body shape variables except height. Of the significant correlations for T_{av}, the strongest correlation was with biiliac breadth and the lowest with wrist width. T_{index} was less correlated with body shape variables than T_{av}, with significant correlations with trunk height, biiliac width and sitting height ratio. Again biiliac width was the strongest correlation.

A closer examination of the relationship between T_{av} and weight is shown in Figure 28.

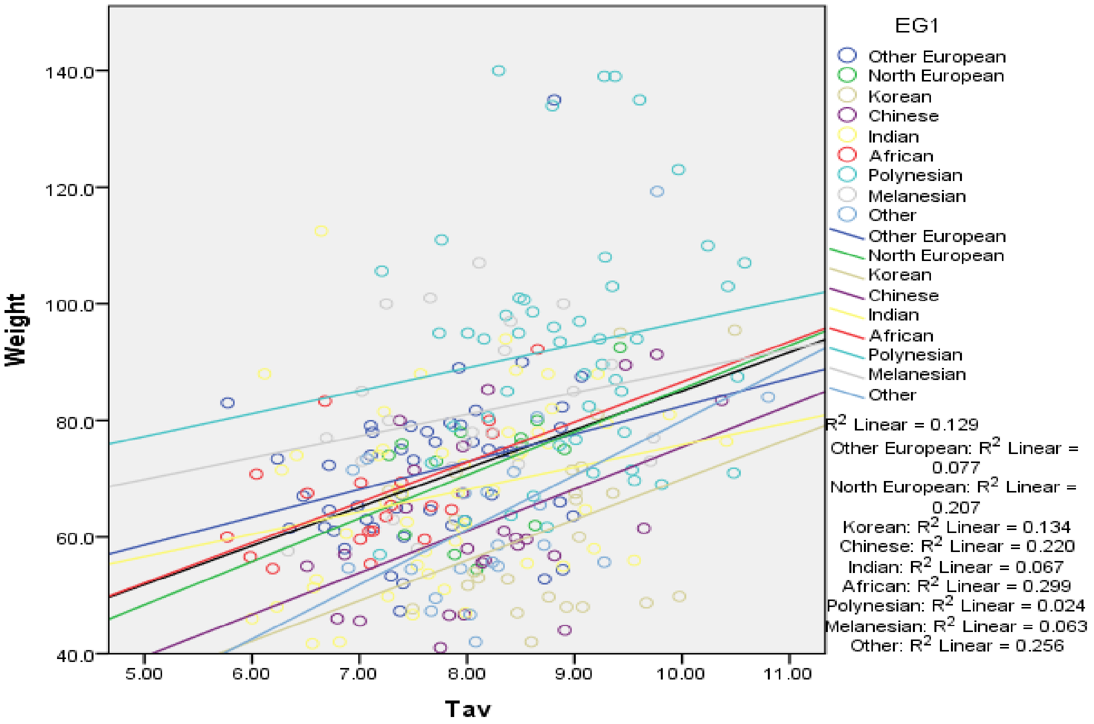


Figure 28. Relationship between weight and T_{av}.

The coefficient of determination, r^2, for the relationship between T_{av} and weight was .129, indicating that weight only accounted for 12.9% of the variability seen in T_{av}. Figure 28 also showed the correlation between T_{av} and weight for each ethnic group, including a separate breakdown for North and Other European ethnic groups. These ranged from a high of .3 for Africans to a low of .024 for Polynesians. Although Polynesians were the heaviest group, they showed the least relationship between weight and T_{av}.

A one way between-groups analysis of covariance was conducted to assess the effect of weight on T_{av}. T_{av} was the dependent variable, EG1 the independent variable, with weight the covariate. The analysis showed a significant difference for the effect of weight on T_{av} with F (1,244) = 20.024, p<.001, with a medium effect size of .076.

Weight accounted for 7.6% of the variation in T_{av}. The estimated marginal means for T_{av}, after excluding the effect of weight are shown in Table 50.

Table 50. Estimated marginal means for T_{av} after excluding the effect of weight for EG1.

			95% Confidence Interval	
EG1	Mean	Std. Error	Lower Bound	Upper Bound
Korean	8.944	.177	8.595	9.293
Polynesian	8.637	.138	8.366	8.908
Chinese	8.337	.170	8.002	8.672
North European	8.202	.234	7.741	8.663
Indian	7.934	.120	7.698	8.170
Melanesian	7.912	.178	7.561	8.262
Other European	7.674	.123	7.431	7.917
African	7.235	.190	6.861	7.609

a. Covariates appearing in the model are evaluated at the following values: Weight = 73.362.

In this analysis, Koreans now had the highest adjusted mean for T_{av}, with Polynesians remaining a close second, and the Chinese third. Africans remained at the bottom of the mean scores.

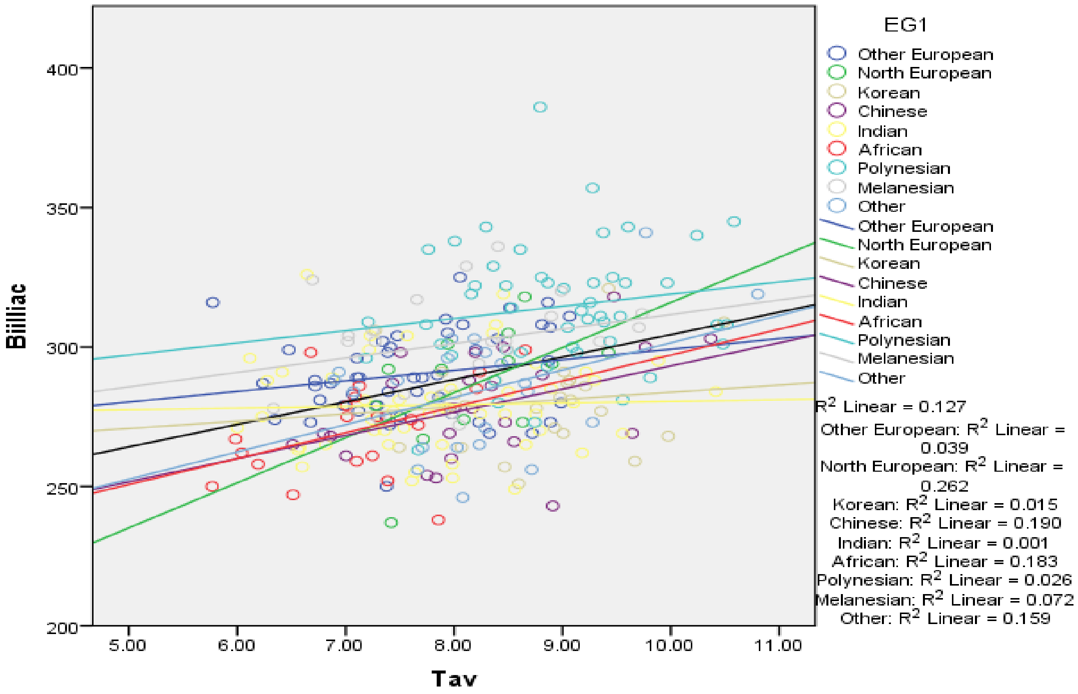


Figure 29. Relationship between biiliac width and T_{av}.

A similar result to that of weight can be seen in the relationship between biiliac width and T_{av}, shown in Figure 29, with r^2 at .127. Again the Africans show the strongest relationship between these two variables at r^2=.183, second only to North Europeans at r^2=262. None of these correlations were particularly strong.

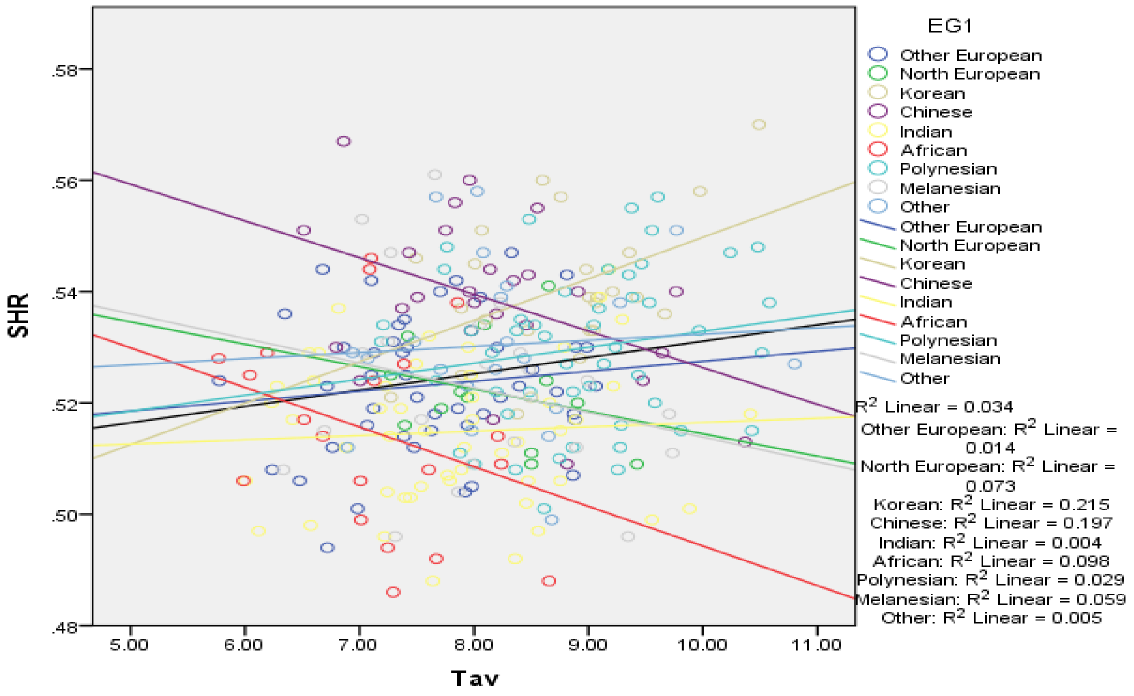


Figure 30. Relationship between sitting height ratio and T_{av}.

The relationship between sitting height ratio and T_{av} is shown in Figure 30 above. There was no clear pattern to the relationship between these two variables with r^2=.034. There were variable results for each of the ethnic groups, with three groups showing an inverse relationship between T_{av} and sitting height ratio being Africans, North Europeans, and Other Europeans. The groups displaying the strongest relationship between sitting height ratio and T_{av} were Koreans (r^2=.215) and Chinese (r^2=.197), neither of which were particularly strong.

Likewise, when the relationship between T_{av} and finger width and wrist width was examined, there was only a weak relationship. Analysis of T_{av} with wrist width and finger width showed wrist width r^2=.024, and finger width r^2=.006.

The relationship for T_{av} between smokers and non-smokers among different ethnic groups (EG1excluding Other) was examined using a one way ANOVA. There was a significant effect F (1,272) = 4.23, $p < .05$. The effect size was small .02. However, given that only 6.3% of participants smoked (see Table 8 above), and that smoking was highest among the Korean and Polynesian groups, who had the highest cold induced vasodilation response, this was not considered significant.

Age did not appear to be a factor, as shown in Figure 31 below. Although most of the participants fell into the under 30 years of age category, for those participants over this age there was no discernible relationship between age and T_{av}.

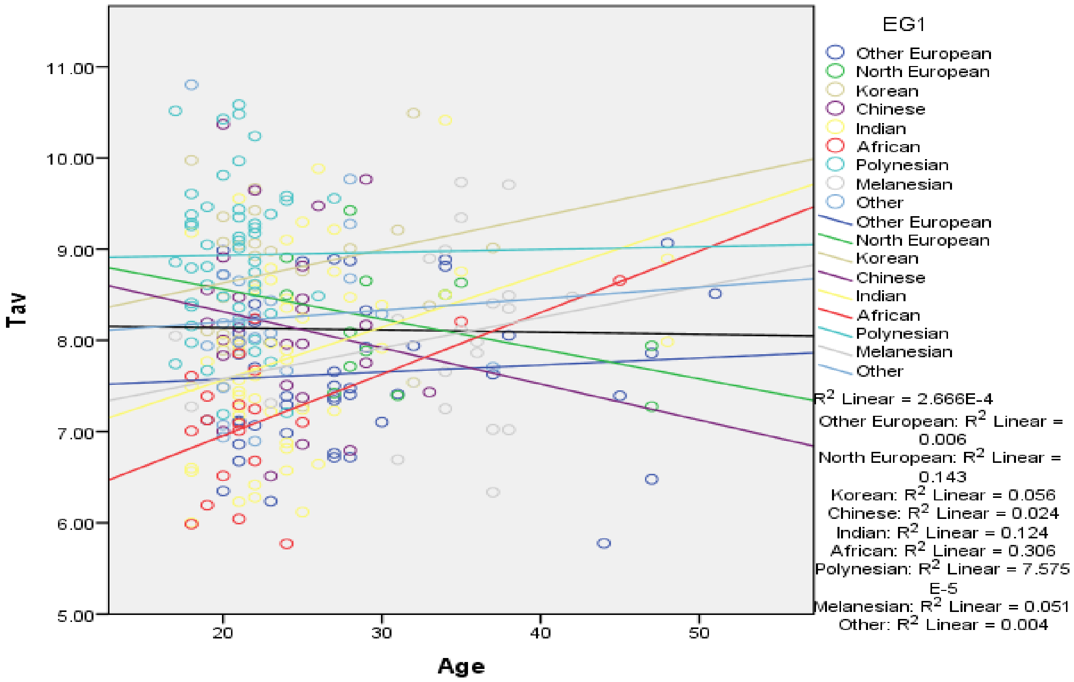


Figure 31. Relationship between age and T_{av}.

6.3.4. Other CIVD response variables

T_{mean} is the average finger temperature from T_{min} until the end of the test. It is effectively the same as T_{av} but excluding the initial cooling phase. This is the only other CIVD response variable (along with T_{av}) that has a normal distribution of data.

A one-way ANOVA was used to explore the differences between the mean T_{mean} for ethnic groups. There was a significant difference at the $p<.01$ in weight for the different ethnic groups. Effect size was large, with $eta^2=.25$. Post-hoc comparisons for T_{mean} by EG1 using the Tukey HSD test were completed as shown in Table 51.

Table 51. Homogeneous subsets of T_{mean} by EG1 using the Tukey HSD test.

		Subset for alpha = 0.05			
EG1	N	1	2	3	4
African	20	7.0936			
Other European	47	7.5554	7.5554		
Indian	51	7.6955	7.6955		
Melanesian	23		7.9422	7.9422	
Chinese	26		8.0309	8.0309	8.0309
North European	13		8.1749	8.1749	8.1749
Korean	24			8.6281	8.6281
Polynesian	49				8.7866
Sig.		.279	.245	.140	.071

Means for groups in homogeneous subsets are displayed °C.

Significant differences were found among the groups as follows:

- Polynesian and: Other European ($p<.001$), Chinese ($p=.015$), Indian ($p<.001$) and African ($p<.001$).
- Korean and: Other European ($p<.001$), Indian ($p=.001$), and African ($p<.001$).
- Between Chinese and African ($p=.013$).
- African and North European, ($p=.019$).

The results for T_{mean} are similar to those for T_{av}. Polynesian T_{mean} is significantly higher than all other groups except Koreans, North Europeans and Chinese. Koreans, Polynesians, North Europeans and Chinese T_{mean} are still higher than for all other groups, although only significantly higher than Africans. Africans are still the lowest, although they do group with Other Europeans and Indian groups in the lowest subset. Pearson correlation between T_{av} and T_{mean} was .989, r^2 was .978, and was uniformly high for all ethnic groups.

The rest of the CIVD response variables do not show normal distribution using the Kolmogorov-Smirnov test. Means for a number of the other variables are shown in Table 52.

Table 52. Means for Amplitude, T_{max}, T_{min}, T30, Tpretest, onset time and peak time.

EG1	N	T_{max} °C	T_{min} °C	T_{30} °C	$T_{pretest}$ °C	Amplitude °C	Onset time mins	Peak time mins
Other Euro	47	8.91 (1.30)	5.73 (.56)	7.85 (1.06)	27.80 (3.61)	3.23 (1.20)	5.39 (2.33)	7.97 (5.87)
North Euro	13	9.57 (.83)	5.95 (.72)	8.30 (.92)	28.05 (3.86)	3.62 (1.32)	4.88 (2.18)	7.48 (3.95)
Korean	24	10.02 (1.17)	6.60 (.69)	8.49 (.80)	31.55 (2.64)	3.41 (.81)	3.88 (2.03)	8.15 (6.06)
Chinese	26	9.30 (1.40)	6.22 (.87)	8.04 (.92)	29.89 (3.21)	3.09 (1.15)	4.13 (1.26)	6.94 (5.97)
Indian	51	9.12 (1.61)	5.94 (.56)	7.67 (1.04)	29.01 (3.93)	3.28 (1.53)	5.19 (2.03)	9.21 (5.84)
African	20	8.40 (1.45)	5.58 (.39)	7.59 (1.10)	27.33 (3.55)	2.82 (1.38)	8.45 (4.15)	10.83 (4.53)
Polynesian	49	10.52 (1.79)	6.64 (.58)	8.55 (.84)	32.38 (2.08)	3.88 (1.60)	3.98 (.88)	8.47 (5.77)
Melanesian	23	9.23 (1.35)	5.98 (.65)	7.80 (.88)	28.55 (2.92)	3.27 (1.10)	5.14 (1.46)	11.13 (5.32)
Other	21	9.63 (1.61)	6.15 (.84)	8.25 (.95)	29.17 (3.47)	3.49 (1.37)	4.38 (1.23)	9.79 (5.56)
Total	274	9.45 (1.59)	6.11 (.72)	8.05 (1.01)	29.52 (3.66)	3.37 (1.35)	4.95 (2.30)	8.80 (5.69)

(SD)

In terms of the strongest cold induced vasodilation response for these variables, Polynesian had the highest T_{min}, the highest T_{max}, and the strongest amplitude, reflecting a strong increase in temperature during the rewarming phase, and the highest temperature at the end of the test (T_{30}). Excluding the Other category, Koreans were second to Polynesians in all these categories. In terms of the onset time, Polynesians were second to Koreans with the quickest time to start rewarming. $T_{pretest}$ also showed a similar pattern.

Africans had the lowest T_{min}, T_{max}, T_{30}, and amplitude. They had the longest onset time by a very large margin. When exposed to cold water, African hands became very cold and took a long time to warm up, and didn't warm up as much as other groups. In terms of response to cold, the only variable they did not show the least response to was for peak time.

Peak time, being the time between T_{min} and T_{max}, when the strongest cold induced vasodilation response occurs, showed more variability. Melanesians had the longest rewarming time, followed by Africans, Indians and Polynesians. Europeans and Chinese had the shortest peak time.

Other Europeans had the second lowest T_{min} and T_{max}, and were at the lower end of most other variables in terms of strength of cold induced vasodilation response. However, in terms of amplitude, they were only behind the Koreans and Polynesians in their response.

Looking at the different temperatures at the start and finish of the test shows a similar result to T_{av}. A comparison of $T_{pretest}$ and T_{30}, along with T_{av}, is shown in Table 53.

Table 53. Comparison of T_{av}, $T_{pretest}$ and T_{30} means.

EG1	T_{av}	$T_{pretest}$	T_{30}
Polynesian	8.94	32.38	8.55
Korean	8.76	31.55	8.49
Other	8.24	29.17	8.25
North European	8.18	28.05	8.30
Chinese	8.16	29.89	8.04
Melanesian	8.03	28.55	7.80
Indian	7.84	29.01	7.67
Other European	7.64	27.80	7.85
African	7.13	27.33	7.59
Total	8.13	29.52	8.05

The ranking for pretest finger temperature ($T_{pretest}$) and finger temperature at the end of the test (T_{30}) is almost identical to that of T_{av}. Analysis of between group differences using a Kruskal-Wallis Test revealed a significant difference in both $T_{pretest}$ and T_{30}, as shown in Table 54.

Table 54. Kruskal-Wallis Test for $T_{pretest}$ and T_{30}.

	$T_{pretest}$	T_{30}
Chi-Square	61.944	31.226
df	7	7
Asymp. Sig.	.000	.000

a. Kruskal Wallis Test
b. Grouping Variable: EG1

Post-hoc comparison of $T_{pretest}$ using a Bonferroni correction showed that Polynesian were significantly different from all other groups except Koreans and Chinese. Africans were significantly different from Polynesian and Korean groups. Post-hoc comparison of T_{30} using a Bonferroni correction showed similar results.

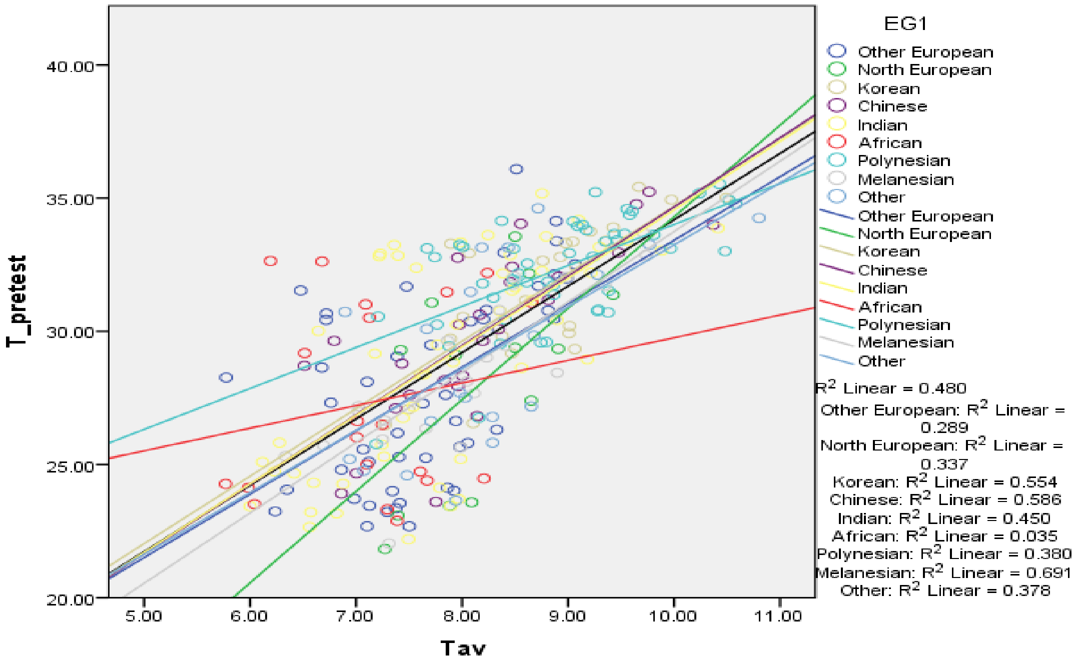


Figure 32. Relationship between T_{av} and $T_{pretest}$ for EG1.

As shown in Figure 32 there is a strong relationship between T_{av} and $T_{pretest}$ (r^2=.480), and this is the case for all groups other than Africans (r^2=.035). Those ethnic groups, who had the highest mean finger temperature before the test, also had higher mean finger temperatures during the test.

Also calculated was T_{freq}, being the number of waves of the CIVD response during the test period, whereby the finger temperature fluctuates through cycles of vasoconstriction and vasodilation. This is calculated using the definition of a CIVD response as an increase in finger temperature of 1°. Table 55 below shows T_{freq} recorded for individuals within each participant group. Only 30.3% of participants recorded more than one CIVD response during the 30 minute test period.

Table 55. Mean T_{freq} for EG1.

EG1					95% Confidence Interval for mean			
	N	Mean	Std. Deviation	Std. Error	Lower Bound	Upper Bound	Min	Max
Korean	24	1.96	1.160	0.237	1.47	2.45	1	5
Polynesian	49	1.67	1.107	0.158	1.36	1.99	1	5
North European	13	1.46	0.877	0.243	0.93	1.99	1	4
Chinese	26	1.42	0.643	0.126	1.16	1.68	1	3
Melanesian	23	1.35	0.714	0.149	1.04	1.66	1	3
Other European	47	1.28	0.540	0.079	1.12	1.44	1	3
Indian	51	1.27	0.493	0.069	1.14	1.41	1	3
African	20	1.25	0.444	0.099	1.04	1.46	1	2
Other	21	1.19	0.402	0.088	1.01	1.37	1	2
Total	274	1.43	0.782	0.047	1.33	1.52	1	5

As with most cold induced vasodilation response variables, Polynesians and Koreans had the highest mean for T_{freq}, and Africans the lowest among the different ethnic groups. Table 56 shows the percentage of participants who had more than one cold induced vasodilation response cycle.

Table 56. Participants with Tfreq >1 shown by EG1.

EG1	l N	T_{freq} >1	% of N	Mean	Std. Deviation	Max no. of cycles
Korean	24	13	54.2%	2.77	1.013	5
Polynesian	49	19	38.8%	2.74	1.147	5
Melanesian	23	5	21.7%	2.60	0.548	3
North European	13	4	30.8%	2.50	1.000	4
Chinese	26	9	34.6%	2.22	0.441	3
Other European	47	11	23.4%	2.18	0.405	3
Indian	51	13	25.5%	2.08	0.277	3
African	20	5	25.0%	2.00	0	2
Other	21	4	19.0%	2.00	0	2
Total	274	83	30.3%	2.41	0.797	

6.3.5. Index of CIVD response variables

To better understand the strength of an individual CIVD response, it is useful to consider the effect taking into account a number of variables. An index (T_{index}) for CIVD response was produced that calculated the overall impact of T_{av}, amplitude and onset time based on an index developed by Yoshimura and Iida (1950). This index takes the mean for these three variables and awards 2 points for a response within approximately one standard deviation of the mean (higher or lower) and 1 point or 3 points respectively for a response outside this range, as illustrated in Table 57 below.

Table 57. Calculation of multivariate CIVD response index (T_{index}).

Variables	Mean values	One point	Two points	Three points
T_{av}	7.76±.81	< 6.95ºC	6.95~8.57 ºC	>8.57 ºC
Amplitude	3.32±1.23	<2.09ºC	2.09~4.55 ºC	>4.55 ºC
Onset time	5.28±2.23	>7.51 mins	7.51~3.05mins	<3.05 mins

Mean values for T_{index} are shown in Table 58 below.

Table 58. Mean values of T_{index} by EG1.

EG1	N	Mean	Std. Deviation	Std. Error	95% Confidence Interval for Mean Lower Bound	95% Confidence Interval for Mean Upper Bound	Min	Max
Polynesian	49	6.96	1.020	0.146	6.67	7.25	5	9
Korean	24	6.75	1.073	0.219	6.30	7.20	5	9
North European	13	6.31	1.032	0.286	5.68	6.93	5	8
Other	21	6.29	0.902	0.197	5.87	6.70	5	8
Melanesian	23	6.17	1.029	0.215	5.73	6.62	3	8
Chinese	26	6.15	1.008	0.198	5.75	6.56	4	8
Other European	47	5.94	1.131	0.165	5.60	6.27	3	8
Indian	51	5.76	1.226	0.172	5.42	6.11	3	8
African	20	5.05	1.146	0.256	4.51	5.59	3	7
Total	274	6.18	1.193	0.072	6.04	6.32	3	9

These results were similar to the rankings of both T_{av}, as seen in Table 45, and the estimated marginal means for T_{av} after excluding the effect of weight as seen in Table 50. Polynesians had the highest mean followed closely by Koreans. Africans had the lowest mean.

The correlation between a number of cold induced vasodilation response variables can be seen in Table 59. All the variables were significantly correlated except T_{min} and amplitude. The correlation relationship between the temperature variables and the time variables was inverted; a shorter time to starting rewarming and to obtain maximum temperatures was inversely related to the strength of the temperature variables. The highest correlations were with T_{mean} and T_{index}, between T_{max} and T_{mean}, and between peak time and time to maximum temperature.

Table 59. Correlation between CIVD response variables.

		T_{av}	Amplitude	T_{index}	T_{freq}	T_{mean}	T_{30}	T_{max}	T_{min}	$T_{pretest}$	Onset time	Peak time	Time max
T_{av}	Correlation	1.000	.588**	.829**	.359**	.987**	.652**	.876**	.763**	.718**	-.677**	-.427**	-.545**
	Sig. (2-tailed)	.	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000	.000
Amplitude	Correlation	.588**	1.000	.692**	.242**	.656**	.504**	.837**	.103	.262**	-.213**	-.160**	-.203**
	Sig. (2-tailed)	.000	.	.000	.000	.000	.000	.000	.089	.000	.000	.008	.001
T_{index}	Correlation	.829**	.692**	1.000	.349**	.832**	.588**	.833**	.549**	.503**	-.569**	-.321**	-.444**
	Sig. (2-tailed)	.000	.000	.	.000	.000	.000	.000	.000	.000	.000	.000	.000
T_{freq}	Correlation	.359**	.242**	.349**	1.000	.342**	.333**	.317**	.341**	.239**	-.345**	-.392**	-.417**
	Sig. (2-tailed)	.000	.000	.000	.	.000	.000	.000	.000	.000	.000	.000	.000
T_{mean}	Correlation	.987**	.656**	.832**	.342**	1.000	.659**	.906**	.689**	.666**	-.615**	-.410**	-.511**
	Sig. (2-tailed)	.000	.000	.000	.000	.	.000	.000	.000	.000	.000	.000	.000
T_{30}	Correlation	.652**	.504**	.588**	.333**	.659**	1.000	.636**	.435**	.400**	-.420**	-.192**	-.280**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.	.000	.000	.000	.000	.001	.000
T_{max}	Correlation	.876**	.837**	.833**	.317**	.906**	.636**	1.000	.543**	.561**	-.500**	-.327**	-.410**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.	.000	.000	.000	.000	.000
T_{min}	Correlation	.763**	.103	.549**	.341**	.689**	.435**	.543**	1.000	.727**	-.751**	-.453**	-.563**
	Sig. (2-tailed)	.000	.089	.000	.000	.000	.000	.000	.	.000	.000	.000	.000
$T_{pretest}$	Correlation	.718**	.262**	.503**	.239**	.666**	.400**	.561**	.727**	1.000	-.564**	-.324**	-.388**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.	.000	.000	.000
Onset time	Correlation	-.677**	-.213**	-.569**	-.345**	-.615**	-.420**	-.500**	-.751**	-.564**	1.000	.514**	.684**
	Sig. (2-tailed)	.000	.000	.000	.000	.000	.000	.000	.000	.000	.	.000	.000
Peak time	Correlation	-.427**	-.160**	-.321**	-.392**	-.410**	-.192**	-.327**	-.453**	-.324**	.514**	1.000	.957**
	Sig. (2-tailed)	.000	.008	.000	.000	.000	.001	.000	.000	.000	.000	.	.000
Time max	Correlation	-.545**	-.203**	-.444**	-.417**	-.511**	-.280**	-.410**	-.563**	-.388**	.684**	.957**	1.000
	Sig. (2-tailed)	.000	.001	.000	.000	.000	.000	.000	.000	.000	.000	.000	.

**. Correlation is significant at the 0.01 level (2-tailed).

6.3.6. Participant Discomfort

Results of the discomfort levels experienced by participants, as described in section 5.4, are shown in Table 60. This table shows the average discomfort for the full 30 minute test, the first ten minutes, and for the second 20 minutes, based on a 1-10 scale, ten being the most painful.

Table 60. Participant discomfort means by EG1.

EG1	Discomfort average 30 mins	Discomfort Average 1^{st} 10 mins	Discomfort Average 2^{nd} 20 mins
Polynesian	4.60	5.51	3.69
North European	4.76	5.15	4.36
Melanesian	4.95	5.68	4.21
Korean	4.97	5.85	4.08
Other European	5.36	5.73	4.99
Chinese	5.50	6.19	4.81
Other	5.71	6.22	5.21
Indian	5.84	6.49	5.19
African	5.94	6.40	5.48
Total	5.30	5.94	4.66

Although an entirely subjective measure, the results are very similar to the rankings for T_{av}, but with an inverse relationship between response and discomfort. Polynesians show the least discomfort, Africans the most. This contradicts previous studies cited in 4.2 which suggested that pain was related to the intensity of the response. Although the pain is higher in the initial vasoconstriction phase over the first ten minutes, the level of discomfort was highest for those with the least cold induced vasodilation response, being African and Indian participants.

6.3.7. Summary of Analysis of cold induced vasodilation response

Polynesian and Korean groups consistently displayed the highest cold induced vasodilation response for most variables. There were no significant differences in any cold induced vasodilation response variables between Polynesian and Korean groups. Conversely the African group of participants consistently showed the lowest cold induced vasodilation response to cold temperatures. Among the remaining groups there were few significant differences, as seen in Table 61 below.

T_{av} was the variable contributing most to group separation as identified in the discriminant function analysis, followed by T_{mean}.

Table 61. Summary of significant differences between EG1 groups for CIVD response variables.

EG1	Other European	North European	Korean	Chinese	Indian	African	Polynesian
Other European							
North European							
Korean	1,2,4,5,7 11	4,11					
Chinese	4						
Indian			1,2,4,6,7 11				
African	8,10	1,2,8,12	1,2,4,5,6 810,11 12	1,2,4,8 12	1,8,12		
Polynesian	1,2,4,5,6 8,11,12	4,11		1,2,5 11	1,2,4,5 6,11,12	1,2,4,5 6,8,10 11,12	
Melanesian			11			1,8,12	1,11
Significant differences							
T_{av}	1						
T_{mean}	2						
Amplitude	3						
T_{min}	4						
T_{max}	5						
T_{30}	6						
T_{freq}	7						
Onset time	8						
Peak Time	9						
Time to max	10						
$T_{pretest}$	11						
T_{index}	12						

6.4. Analysis of similarity between phenotypic data and coancestry data

Despite the lack of genetic data obtained from participants, it was possible to perform an investigation to determine whether the observed phenotypic differences in body morphology and CIVD response among the ethnic groups in this study were similar to genetic differences among similar ethnic groups.

The test for similarity between phenotypic data and coancestry data was investigated using Mantel's test (Mantel, 1967). Genetic distance information, in the form of pairwise F_{ST} "coancestry" distances, was taken from Friedlaender et al. (2008) for 8 ethnic groups corresponding to the ones in this study. The Korean ethnic group in this study was not represented in the genetic data, so the comparable Japanese ethnic group was substituted.

Four measures were tested; T_{av}, T_{index}, SHR and biiliac width. The mean of each measure was calculated for each ethnic group, and the 'distance' between groups was calculated as the absolute value of the difference between the means. This produced a matrix of distances for each measure which could be compared with the genetic distance information. The results are shown in Table 62 below.

Table 62. Mantel's test for similarity between phenotypic and genetic distances.

	Empirical p-value
T_{av}	<0.0995
T_{index}	<0.0392*
SHR	<0.3347
Biiliac width	<0.0256*

* p-value is significant at the 0.05 level (2-tailed).
(T_{av} = average finger temperature, SHR = sitting height ratio, T_{index} = index of CIVD response variables)

The results indicate that for T_{index} and biiliac width there is some evidence suggesting there is a relationship between these phenotypic measures and genetic distance between comparable ethnic groups.

6.5. Summary

The results of this research clearly indicate that there are significant differences between the different ethnic groups in body shape, body size and CIVD response. In addition the Mantel's test indicated some similarity between comparable genetic distances and both morphological and CIVD response characteristics.

Having established there are significant differences in body shape, body size and CIVD response, it is important to understand the extent of these differences, how they apply to each ethnic group, and their relationship with ancestral environment. The differences among groups vary for each variable measured, and the relationship between these different variables and Bergmann’s and Allen’s rule needs to be analysed. Finally the likely origin of Polynesian body morphology needs to be reviewed in the light of these results.

These questions are discussed in Chapter 7.

Chapter 7. Discussion

This chapter is divided into four sections. The first three sections each covers one of the three research questions that the present study seeks to explore in relation to human adaptation to a cold environment using the data gathered and analysed in Chapter 6. The conclusion makes up the fourth section.

The first question relates to body morphology, its adaptation to extreme cold environments, and to what extent the results of the anthropometric measurements for the different ethnic groups might reflect different ancestral environments. This includes a review as to whether the results of the present study support the validity of Bergmann’s rule as outlined in Chapter 2.

The second question concerns CIVD response and whether variation in response between different ethnic groups reflects adaptation to different ancestral environments. Can CIVD response be regarded as an accurate predictor of ancestral environment, specifically exposure to a seasonally cold climate? The general characteristics of CIVD response are explored in relation to previous research presented in Chapter 4.

The third question brings together the results discussed in the first two questions specifically for the Polynesian sample. These are the relationship between ancestral environment, and firstly, Polynesian body morphology, and secondly, Polynesian CIVD response. These results are discussed along with current theories on Polynesian origins as outlined in Chapter 3, to explore the likely origins of the distinctive and robust Polynesian body morphology as described in section 2.7. The results of this review are compared with past theories put forward concerning the origins of Polynesian body morphology. A new hypothesis is put forward to explain the results.

7.1. Body Morphology and Environment

This section considers the relationship between body morphology and ancestral environment. To what extent does this present study support Bergmann’s rule? The prediction is that those populations from a cold ancestral climate should have a larger body mass, a higher sitting height ratio, reflecting a longer trunk and shorter legs, and a wider trunk.

7.1.1. Ancestral Environment

It is first necessary to look, as far as is possible given the significant world population movements over thousands of years, at the likely ancestral environments of the participants. Table 63 below shows the temperatures and latitude of a major city in each region relating to one of the ethnic groups as defined by the main grouping used, EG1. This can only be an approximation, as some of the groups cover a large geographical region, and one city does not necessarily represent an accurate representation of the total environment. The city chosen is based on a central location within a particular region.

Table 63. Average temperatures and latitude for major cities in participant regions.

EG1	City	Minimum Monthly Temp (ºC)	Average Monthly Temp (ºC)	Maximum Monthly Temp (ºC)	Latitude
Korean	Seoul	-6.1	12.5	29.5	37º 1’
North European	Berlin	-1.9	9.6	23.7	52º 32’
Chinese	Beijing	0.5	16.2	31.6	31º 10’
UK European	London	2.4	11.0	22.3	51º 32’
South European	Rome	3.7	15.5	28.7	41º 54’
Indian	Mumbai	16.8	27.2	33.6	18º 58’
Melanesian	Port Vila	19.3	24.9	30.3	17º 45’
African	Lagos	21.7	26.7	33.1	6º 27’
Polynesian	Apia	22.6	26.9	30.7	13º 50’

(Maps of the World; World Meteorological Organization, 2011)

The above table is ranked based on minimum monthly temperature; that is the coldest average monthly temperature for any month. This represents the degree to which each region experiences seasonally cold temperatures. By and large it corresponds to latitude except for the two Asian cities, Seoul and Beijing, which have a colder minimum temperature than indicated by their latitude. This suggests that Northern Asia is colder than comparable latitudes in Europe during winter. Seoul and Beijing have much higher maximum monthly temperatures than Berlin or London, indicating a wider range of yearly average temperatures. In fact both Northeast America and East Asia are considerably colder than comparable latitudes in Europe as illustrated in Figure 33.

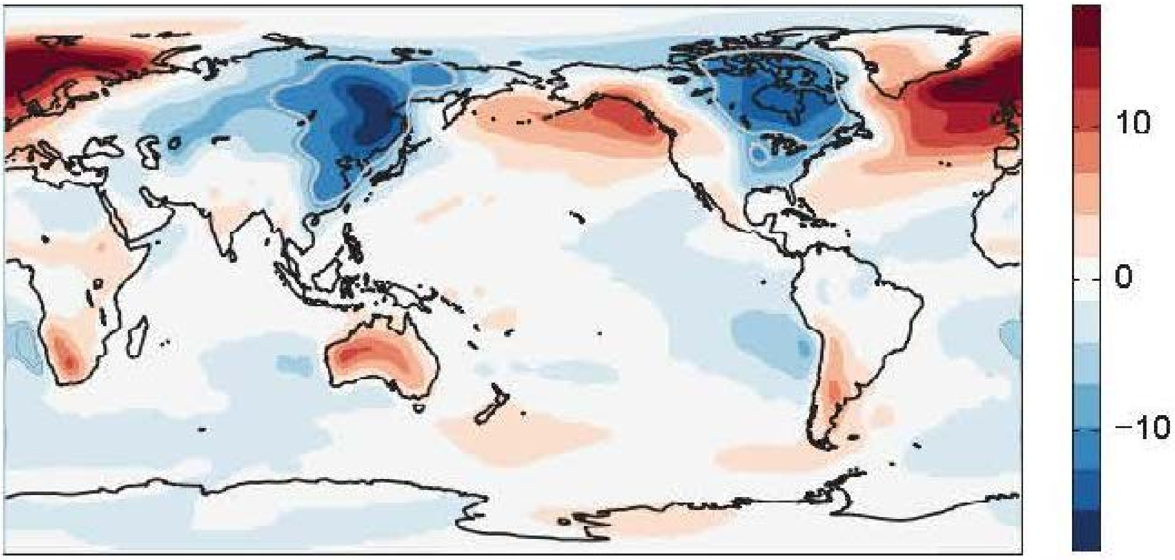


Figure 33. Surface temperature deviation from zonal mean December to February 1970 -2009 (Kaspi & Schneider, 2011).

This relatively warmer and restricted range of European temperatures is likely the result of several factors. One important factor is the warming effect of the Atlantic Gulf Stream, which delivers the equivalent of 27,000 times the energy of all Britain's power stations put together (Fagan, 2009, pp. 56-57). Europe, and particularly the UK, has a much milder climate than either the American or Asian continents for comparable latitudes, although there is speculation as to whether this is due to the Gulf Stream itself, or the associated warmer winds blowing in from the North Atlantic (Bischof, Mariano, & Ryan, 2003; Seager et al., 2002).

In addition to the Gulf Stream effect, Northeast Asia and Northeast America are cooled by heat released off the oceans just off their coast which draws cold arctic winds down into the regions just upstream from this heat source (Boos, 2011; Kaspi & Schneider, 2011). Warm ocean water contributes not only to the colder eastern boundary but also to a warmer western boundary.

This is not to suggest that these temperatures in Table 63 reflect the likely temperatures of the ancestral environments for these ethnic groups. These temperatures would have been much colder many thousands of years ago. (Fagan, 2009, pp. 66-67). Although the cooling of the Earth's temperature, commonly referred to as the Ice Age, commenced in earnest more than 2.5 million years ago, there have been a number of glacial and interglacial periods since that time, with the last glacial maximum occurring around 21,000 BP, following which temperatures then slowly warmed until the commencement of the current interglacial period around 12,000 BP (Fagan, 2009, pp. 66-67).

Global temperatures during the last glacial maximum averaged around 10ºC cooler than present temperatures, with some higher latitudes as much as 12ºC cooler, and the tropics 2-4ºC cooler (Erickson, 1990, p. 52; Fagan, 2009, p. 75). On this basis it would be expected that of the ethnic groups participating in this study, only Korean, North Chinese and European groups would have experienced an extremely cold seasonal environment.

However, much colder ancestral environments might have been, these modern day temperatures can serve as a proxy for grading the participants groups by the degree to which they experience seasonal cold temperatures, using the relative temperatures between the different places of origin for the different participant groups. What this research seeks to examine is which of the ethnic groups display cold adaptations, whether by way of body morphology, or cold induced vasodilation response, and to relate these adaptations to their likely ancestral environment.

As noted in section 2.2, adaptation is more likely to occur in habitats with extreme environmental conditions. Therefore it is only in those environments with extremely cold seasonal temperatures that would promote the development of cold adaptation in body morphology or CIVD response. Despite the definition of a CIVD response being defined as an increase in temperature of at least 1ºC (Hurlich & Steegmann, 1979; Little et al., 1971; So, 1975), all participant groups in this study had a mean amplitude greater than 1ºC, although there were some individuals in the African, Indian, and European groups who recorded an amplitude lower than this. On this basis most participants had a CIVD response.

Therefore, like the relative differences in seasonally cold temperature between the different regions, it is the relative magnitude of the development of CIVD response that appears to indicate a cold adaptation. Likewise it is the extent that body morphology conforms to Bergmann and Allen’s rules between the different groups. Therefore it is by way of comparison between the ethnic groups that should show whether temperature gradients reflect, or even predict differences in relative body morphology and CIVD response.

On the basis of Table 63 therefore, it would be predicted that participants from the most seasonally cold regions such as Korea, China and Europe should display the most developed cold adaptations. The rest of the ethnic groups are likely to have had little exposure to any extremes of cold. As Koreans inhabit what appears to be the coldest region, and they come from a small geographic region, with a relatively homogenous ethnic group, this group can effectively be seen as a control group for a cold adapted climate. The Korean Peninsula has been occupied by humans moving in from Northeast Asia since 40,000 BP (Derenko et al., 2007; Pope & Terrell, 2008).

Likewise, despite the Polynesian climate in Table 63 showing as marginally warmer than the African one, Africans can be seen as the control group for a population inhabiting a tropical ancestral climate. This is because in terms of ancestral movements of *Homo sapiens* out of Africa, as described in section 2.5, Africans are the only participant group that could not have been exposed to any ancestral climate other than a tropical or temperate climate due to the fact that the ancestors of these participants have remained inhabiting the African continent until recent times. They can only have been exposed to the African climate for many thousands of years, and nowhere in Africa is there a seasonally cold climate.

Therefore in relation to the premise behind this present study, if Polynesians are a cold adapted population, it would be expected that in terms of comparison of body morphology and CIVD response they would rank much closer to the Korean population than to the Africans. Conversely if they are indeed a population with a tropical ancestry then they should rank much closer to the Africans and the other ethnic groups from a tropical or temperate climate than those from the seasonally cold climates.

The relationship between the likely ancestral climate for the participant ethnic groups as outlined in this section, and the body size, body shape, and CIVD response results from Chapter 6, will be discussed next in this chapter. This relationship will be discussed on the basis that, in terms of ancestral environment, Table 64 below forms the ranking for the relationship between the different ancestral environments of participant groups from the coldest to the warmest.

Table 64. Relative seasonally cold temperatures of participant groups (EG1) based on current average minimum temperatures.

EG1	Ancestral Environment	
Korean	Coldest	1
North European		2
Chinese		3
Other European		4
Indian		5
Melanesian		6
Polynesian		7
African	Warmest	8

7.1.2. General Characteristics of Body Size and Body Shape

The starting point for this research was the large physical size of Polynesian populations, and the results confirmed this. Polynesians had the highest mean in every category for body size for both males and females by a considerable margin. Polynesians were significantly heavier than all the other ethnic groups. They had significantly higher means in total skinfold measurement, mid biceps diameter and BMI than all other groups except Melanesians.

Melanesians themselves were not small, with significantly higher mean BMI than all other groups except Polynesians. They had significantly higher means in weight, total skinfold, and mid biceps diameter than Korean, African and Chinese groups, who had the lowest means for all of the body size variables, except for total skinfold where Other Europeans had lower means.

Likewise in terms of body shape Polynesians had the widest mean for body width, had the second highest mean for height behind Europeans, had the largest wrist width and finger width means, and were only behind Koreans and Chinese in terms of mean sitting height ratio.

There were significant gender differences for all of the body size and shape variables except for BMI and biiliac width. This corresponds with the research outlined in section 2.4 where past research indicates no gender bias for biiliac width. Biiliac width is regarded as a key indicator of geographic ancestry, and under strong genetic control. BMI, along with weight, which is a key component of its calculation, is perhaps the factor under most influence by environment in a caloric rich society like New Zealand.

Discriminant function analysis indicated that for body size, BMI was the variable contributing most to group separation, followed by weight. For body shape, biiliac width was the variable contributing most to group separation. When the body shape and body size variables were correlated, biiliac width was the only one of the body shape variables to rank ahead of any of the body size variables in terms of variables contributing to group separation.

Clearly body size variables were more of a factor in differences between ethnic groups than body shape. This may emphasize the relatively short term and rapid impact of environmental differences, specifically differing caloric levels based on cultural or socio economic factors, being more significant in modern body size than genotype. Body shape variables may be under stronger genetic influence than body size variables, but body size variables are probably under stronger environmental influence, and this has more potential to generate rapid differences between ethnic groups depending on the environment, but more probably the culture they are living in.

Some participant groups had a higher percentage of recent migrants to New Zealand than others. This would have a significant impact on between group differences for body size depending on how long the participant had been living in New Zealand, and whether they had maintained their traditional diet or were consuming a high calorie westernized diet. As part of the study it was recorded how long the participant had been living in New Zealand.

In fact Polynesians had longest mean length of time residing in New Zealand, followed by Other Europeans, Chinese and Koreans. Although these results are only an approximate indication of environment and culture that the participant had been living in, this factor was compared with BMI. There was no strong relationship between BMI and years residing in New Zealand for any group except Koreans, which may suggest a greater change in diet for this group when moving to New Zealand than for other groups. Certainly the traditional diet in Korea is much different than New Zealand, as will be covered in more detail in section 7.1.3.

Perhaps of most interest is the lack of statistically significant differences between ethnic groups for body size and body shape variables. The ANOVA and MANOVA analyses consistently identified significant between group differences, but when these were closely analysed as to which groups were significantly different from others, there were not that many.

For body size, outside the differences outlined above between Polynesians and the other groups, and between Melanesian and the Chinese, Korean and African groups, there were few significant differences between the groups. If BMI is taken as the major indicator of body size, then the only significant differences were between the grouping together of Polynesians and Melanesians, and all other groups. There was no difference between Melanesian and Polynesian groups. There were no differences between any of the Indian, Korean, Africans, Chinese or either European groups.

For body shape variables, there were major between group differences for height, with the European groups significantly taller than most other groups. Polynesians were also significantly taller than the Asian and Indian groups. But for biacromial and biiliac widths, again Polynesians and, to an extent, Melanesians were significantly wider than other groups, but there were few significant differences among these other groups. For finger and wrist width, the major factor was the narrowness of Chinese, Indian and Korean fingers and wrist compared to the other groups. Again Polynesians had the widest of these variables.

The only variable that did not fall into this pattern was sitting height ratio. Koreans, and to a large extent Chinese, were significantly different from the other groups with the highest sitting height ratio. However, again, Polynesians were close behind these two in ranking with significant differences between them and the two lowest ranked groups in sitting height ratio, Africans and Indians.

This lack of between group variability, other than between Polynesian and the other ethnic groups, illustrates just how significantly different in body size and shape the Polynesian are from the other ethnic groups in the present study. There were few between group differences among the other ethnic groups. Polynesian were generally significantly different from most other ethnic groups in terms of size, and shape. Polynesian means were not just bigger than the other groups' means; they were significantly bigger in most variables measured, by a considerable margin.

Melanesians differed most from other ethnic groups in being short, which combined with their broad width, may contribute to their higher weight and BMI when consuming a high caloric diet.

7.1.3. Body Size and Geographical Ancestry

Bergmann's rule, predicts that, in general, the larger body size should correspond with the coldest climate. This was endorsed for modern human populations by Roberts (1953, 1978, 1981; 1976) as discussed in section 2.4. Katzmarzyk & Leonard (1998) concurred with the views of Roberts, but noted the strength of the relationship had declined, possibly reflecting secular changes such as changing diet and lifestyles which were increasing body mass. The results of this trend are confirmed in this study.

The relationship between the body size variables obtained from participants and environment is illustrated in Table 65 below. Column one shows the rankings of participant groups by environment from coldest at the top to warmest at the bottom for each participant group, as per Table 64. The rest of the columns show the rankings of body size averages for each participant group, with the group with the largest mean shown at the top of each column, and the group with the lowest mean at the bottom of each column. These rankings are based on the mean differences as ranked in the Tukey HSD test. Under Bergmann's rule these six ranking should be more or less much the same if the largest body size corresponds with the coldest climate.

Polynesians and Melanesians were clearly the largest in every body size category measured. Koreans and Chinese were, with the exception of total skinfold where Other Europeans had the lowest mean, the smallest in every category. If larger body size within species occur in the colder climates, this is almost the direct opposite of what might be predicted with regard to Table 64.

Table 65. Comparison of relative environments with rankings of body size means.

	Environment		Weight		Total Skinfold	
Cold/Large	Korean	1	Polynesian	7	Polynesian	7
	North European	2	Melanesian	6	Melanesian	6
	Chinese	3	Other European	4	Indian	5
	Other European	4	North European	2	North European	2
	Indian	5	Indian	5	African	8
	Melanesian	6	African	8	Chinese	3
	Polynesian	7	Chinese	3	Korean	1
Warm/Small	African	8	Korean	1	Other European	4

	Environment		Mid Biceps Diameter		BMI	
Cold/Large	Korean	1	Polynesian	7	Polynesian	7
	North European	2	Melanesian	6	Melanesian	6
	Chinese	3	Other European	4	Indian	5
	Other European	4	North European	2	North European	2
	Indian	5	Indian	5	Other European	4
	Melanesian	6	African	8	African	8
	Polynesian	7	Korean	1	Chinese	3
Warm/Small	African	8	Chinese	3	Korean	1

Even excluding Polynesians from the above rankings, on the basis that they have only inhabited a tropical environment for a relatively short period of time, clearly body size is no longer an accurate predictor for ancestral environment. European and Indian rankings in terms of body size variables tend to put them in the middle, which is what might be predicted, and Africans, excluding Koreans and Chinese, are towards the bottom, which again is consistent with Bergmann’s Rule. However, Koreans and Chinese are at the lower end of the scale for body size. They are consistently smaller in size for all variables despite inhabiting the coldest environments. Melanesians inhabit a tropical environment but are consistently at the high end for body size variables. This may in part relate to the high levels of humidity as outlined in section 2.4, where relative weight tends to be higher in more moist and humid climates (Hiernaux & Froment, 1976; Hiernaux et al., 1975).

Whatever is determining body size for a number of participant groups, it is not ancestral environment. Koreans and Chinese in their own countries have retained much of their traditional diet, which is low in fat and high in vegetables and fish, although both societies are starting to see an increase in overall levels of fat in their diet (Lee, Popkin, & Kim, 2002; Wu, 2006). Where societies have moved away from their traditional diet towards a modern westernized pattern of high fat intake, and low exercise, it is likely that diet is now the major determinant of body size, with exercise an important secondary element (Chakravarthy & Booth, 2004; W. P. T. James, 2008).

Whilst this may be related to the wealth of a country, this is not always the case. Some of the highest rates of obesity are found in Polynesia and Melanesia, which are not wealthy regions. The World Health Organization defines as overweight an individual with a BMI ≥25, and as obese an individual with a BMI ≥30. Data showing the percentage of population who are overweight and obese in a selection of countries from regions associated with the participant ethnic groups are shown in Table 66 below.

Table 66. Selection of global population overweight and obesity rates.

Country	% of population with a BMI ≥25	% of population with a BMI ≥30
Ethiopia	8.0	1.2
India	11.2	1.9
China	25.0	5.6
Nigeria	28.8	7.1
Korea	30.6	7.3
France	45.9	15.6
PNG	47.8	15.9
Italy	49.2	17.2
Germany	54.8	21.3
Spain	58.2	24.1
UK	61.5	24.9
Vanuatu	65.4	29.8
Solomon Islands	67.9	32.1
Samoa	85.6	55.5
Tonga	88.1	59.6

(World Health Organization, 2011)

The highest rates of obesity are in the Polynesian and Melanesian regions, with the lowest in African, India, Korea and China. This is largely the same result as in the present study as illustrated in Table 65 above, where Polynesian and Melanesian participants have the largest body size, and Korean, Chinese and African the lowest.

The participants surveyed were all living in New Zealand at the time they participated. This may affect their diet, and hence their rates of obesity, depending on whether have been raised in New Zealand, as opposed to being immigrants, or on study permits, as already described above in section 7.1.2. However, the obesity rate rankings in Table 66 do correspond very closely to the body size data rankings shown in Table 65, and do not correspond with the predictions of Bergmann's rule. The results of the present study are consistent with known geographical patterns of body size as illustrated in Table 66. Whatever the determinants of modern body size, they do not relate to climate.

7.1.4. Body Shape and Geographical Ancestry

Body shape is also regarded as correlated with ancestral climate, as described in section 2.4. Under Bergmann's and Allen's rules, cold adapted populations would be expected to have a longer and wider trunk, and shorter arms and legs. Unlike body size, body shape is regarded as less susceptible to secular changes, and more under genetic influence. In particular biiliac width (Ruff, 1994, 2002; Ruff & Walker, 1993) and sitting height ratios (Roberts, 1978) are considered to have the strongest relationship with ancestral climate.

The relationship between the body shape variables obtained in this study, and environment is illustrated in Table 67 below. Column one shows the rankings of participant groups by environment from coldest at the top to warmest at the bottom for each participant group, as per Table 64. The rest of the columns show the rankings of body shape means for each participant group, with the group with the highest mean shown at the top of each column, and the group with the lowest mean at the bottom of each column. These rankings are based on mean differences as ranked in the Tukey HSD tests from Chapter 6, except for biacromial width where there were significant differences in the interaction effect between ethnicity and gender. For biacromial width the weighted average of the male and female means are used.

Table 67. Comparison of relative environments with rankings of body shape means.

Rankings	Environment		Height		Biacromial Width	
Cold/large	Korean	1	Other European	4	Polynesian	7
	North European	2	North European	2	Melanesian	6
	Chinese	3	Polynesian	7	Other European	4
	Other European	4	African	8	Korean	1
	Indian	5	Indian	5	Chinese	3
	Melanesian	6	Chinese	3	African	8
	Polynesian	7	Korean	1	North European	2
Warm/small	African	8	Melanesian	6	Indian	5

Rankings	Environment		Biiliac Width		Sitting Height Ratio	
Cold/large	Korean	1	Polynesian	7	Korean	1
	North European	2	Melanesian	6	Chinese	3
	Chinese	3	Other European	4	Polynesian	7
	Other European	4	North European	2	Other European	4
	Indian	5	Korean	1	Melanesian	6
	Melanesian	6	Indian	5	North European	2
	Polynesian	7	Chinese	3	Indian	5
Warm/small	African	8	African	8	African	8

There was no strong correlation predicted between climate and either height or biacromial width, and this is the case in this results presented above. Of more interest are the results for biiliac width and sitting height ratio. With biiliac width, Africans had the narrowest measurement. Polynesians and Melanesians had the widest measurement, with Europeans and Koreans the next widest. Although not as strictly predicted by Bergmann's and Allen's rules, there is a little more relationship seen with climate than with any other body size or shape variables.

The African participants had the narrowest biiliac width and the lowest sitting height ratio, giving them the long lean narrow body predicted under Ruff's (1991, 1993, 1994) cylindrical thermoregulatory model. Polynesians had the widest biiliac breadth, which although not as predicted by their modern environment, clearly would tie in with the hypothesis that Polynesian exhibit the characteristics of a cold adapted population. Likewise European and Korean groups rank towards the higher end of the group ranking for biiliac width.

The confounding groups are the Melanesian and Chinese groups. Melanesians rank second widest in biiliac width, despite inhabiting a tropical climate for many thousands of years.

Under the predictions of Bergmann's rule and Ruffs (1991, 1993, 1994) model, Melanesians should have a narrower biiliac width. As will be seen in section 7.2.2, this is not the only anomaly associated with the Melanesian participant group. They do exhibit stronger cold adapted features in comparison with other groups than may be expected from their tropical environment. Likewise for the Chinese, if they are a cold adapted group, a wider biiliac width in comparison with other groups may be expected. However, the problems associated with categorizing a group as ethnically and geographically diverse as Chinese have been outlined in section 5.1, and therefore these results may reflect that diversity.

With sitting height ratio, we see a more definite relationship with what might be predicted under Bergmann's and Allen's rules. Cold adapted groups should have a higher sitting height ratio indicating shorter leg length and a longer trunk, providing less surface area to lose body heat, and more central body mass to generate heat, as described in Chapter 2.

Koreans and Chinese have the highest sitting height ratio, indicating a relatively longer trunk and shorter legs. This is as would be expected in relation to their seasonally cold climate. Next in the ranking come the Polynesian and Other European groups.

Africans have the lowest sitting height ratio, exactly as would be predicted given their tropical ancestry. Indian and Melanesian groups have the next lowest sitting height ratios, being the groups who also have a warm climate. North Europeans remain an anomaly, with a lower sitting height ratio than Melanesians. This corresponds with Roberts (1978, p. 20) findings that there was no clear distribution pattern for European populations for sitting height ratio, although they were at medium to high values. This also corresponds with the findings of Hubbe et al. (2009) who found different patterns for sitting height ratios for North European populations compared with comparable populations in Asia and America. In addition the sample size for North Europeans is small and from a wide range of geographical areas.

If you take out the Polynesian and North European results, the relationship with climate is as largely as would be predicted by Bergmann's and Allen's rules, with Koreans and Chinese with the highest sitting height ratio, followed by Other Europeans, Melanesians, Indians and Africans. Again this result supports the prediction that Polynesians are a cold adapted group, more so than any other result covered in this chapter so far.

When we look closer at the Tukey HSD post-hoc results, Koreans, Chinese and Polynesians formed a subset with the highest sitting height ratios, but with Koreans significantly different from all other groups except Chinese, and Chinese significantly different from all other groups except Koreans and Polynesians. Africans, Indians, Melanesians and both European groups formed the lower subset. With the exception of the Polynesians, this is close to what would be predicted under Bergmann's and Allen's rules. If Polynesians are accepted as being cold adapted, then these results fit closely with Bergmann's and Allen's rules. As suggested in Chapter 2Chapter 1, body proportions are more closely related to climate than body size.

With biiliac width we see a weak relationship with climate, with some groups from a colder ancestral environment having a wider biiliac width. With sitting height we see a much stronger relationship with ancestral climate. Those ethnic groups with ancestry in a seasonally cold environment have a higher sitting height ratio, indicating a longer trunk relative to limb length as predicted. The major exception is the Polynesians. However, if Polynesians are a cold adapted population then these results are what would be expected.

Based on these results, in terms of body shape, sitting height ratio, and to a much lesser extent, biiliac breadth would appear to be the only significant predictors for ancestral climate as outlined by Bergmann's and Allen's rules.

7.2. CIVD Response

This section is divided into two parts. The first part looks at the general characteristics of CIVD response over the total population sample. As this is one of the largest studies completed on CIVD response it is useful to look at the types of responses that characterise this sample, and how these compare with past studies.

The second part looks specifically at the differences in CIVD response between the different ethnic groups, and how this relates to ancestral climate. This will identify the degree to which CIVD response is a heritable physical trait associated with ancestry in a cold climate. The prediction is that those populations from a cold ancestral climate will exhibit a stronger CIVD response.

7.2.1. General Characteristics of CIVD response

The definition of a CIVD response, as given in section 4.2, is an increase in finger temperature between onset and peak time (amplitude in the present study) of 1° or more. On this basis, of the 274 subjects, 97% or 266 had an amplitude of 1° or more. There was a very large range in amplitude, from a low of .23° to a high of 8.95°, but with a mean of 3.37°, indicating most participants had a strong response based on the above definition.

This would indicate that an increase of 1° is either not a very good definition of a CIVD response, or that it is in fact an almost universal human response to severe localised cold, but with a wide range of variation in the strength of response. A better picture of human variation in CIVD response can be obtained by looking at the variation in the strength of the response rather than trying to set a fixed definition.

There are many variables that can be measured during the course of a 30 minute CIVD response test, as outlined in Figure 24 above in section 6.3. These consist of both temperature and time measurements, as well as combinations of these, and it is possible to calculate indices based on these variables.

There is a strong correlation between many of these CIVD response variables. In particular T_{av} is highly correlated with most of the other temperature variables, from a high of .987 with T_{mean} to a low of .359 with T_{freq}. In fact T_{freq} had the lowest incidence of correlation with the other temperature variables as well. Excluding T_{freq}, and T_{mean}, T_{av} had the strongest correlation with T_{max}, and T_{min}. This would indicate a strong CIVD response is not just the ability to maintain high average finger temperature over the test period, but also the ability to avoid low temperatures and achieve (relatively!) high temperatures. Amplitude, despite being a basis for the definition of a CIVD response in previous studies, had an overall lower correlation with the other temperature and time variables than T_{av}.

Similarly, T_{av} had the highest inverse correlation with the CIVD response time variables, more so with onset time and time to max, than with peak time. A strong CIVD response in terms of time variables has a short onset time, being the time at which cooling stops and rewarming starts, and a short time to get to maximum temperature. Onset time was the time variable that correlated most strongly with the temperature variables, except for T_{freq}, which correlated highly with time to max.

T_{av} also was the CIVD response variable contributing most to group separation, for both temperature and time variables, as shown in the discriminant function analysis. Onset time was the time variable contributing most to group separation. Likewise in the principal components analysis, T_{av} was the highest ranking variable in component one, which explained 55.37% of variance. These factors all indicate that T_{av} provides the most reliable single variable to gauge the strength of a CIVD response.

Overall a strong CIVD response can be characterised as having a high average finger temperature, short onset time, a high minimum temperature, a short peak time with a large amplitude, and a high maximum temperature. The participant's finger in this situation goes rapidly through the first CIVD response cycle whilst maintaining a relatively high finger temperature.

This response can be seen in the index developed by (Yoshimura & Iida, 1950), using T_{av}, amplitude and onset time. These variables are all strongly correlated (negatively in the case of onset time). T_{av} and T_{index} are probably the two variables that best describe the strength of a CIVD response. Correlation between these two was very strong at .829.

$T_{pretest}$ had a significant correlation with T_{av} (.718), with participants with higher $T_{pretest}$ generally having higher T_{av}. Body temperatures, which were all within a range of between 36.2-36.6ºC, did not seem to reflect these differences. Possibly these differences in $T_{pretest}$ may reflect the ability of extremities to lose heat, as well as to maintain temperature.

A further point of interest is the on-going process of vasoconstriction and vasodilation cycles during the test period, originally described by Lewis (1930) as the hunting reaction, whereby the finger temperature fluctuates through phases of vasoconstriction and vasodilation. Although this was viewed as a general characteristic by Daanen (2003), in fact only 30.3% of participants had more than one CIVD response cycle. This may also relate to the wide range of different ethnic groups sampled in this present study, including many participants from tropical climates. Many previous studies have focussed on participants from much colder climates, particularly Europe and North America.

The highest T_{freq} was seen in participants with the strongest CIVD response, and correlated most strongly with T_{av} and T_{index}, as well as time to max, indicating that the participants with the strongest CIVD response were also the most likely to have the most CIVD response cycles. Only one participant group, Korean, had T_{freq} higher than 1 for more than 50% of the group participants. Polynesian and Korean groups both had individuals with the highest number of cycles, i.e. 5. These were also the groups that highest overall CIVD response, showing the relationship between frequency of cycles and strength of CIVD response.

In terms of other factors that may have an influence in CIVD response, the small number of smokers at 6.3 % did not allow any significant analysis of the relationship between CIVD response and smoking. The groups with the highest smoking habit were Koreans and Polynesians, which were also the groups with the strongest CIVD response, which would add to the bias of any analysis. Age of the participant did not appear to have any discernible effect on the strength of CIVD response.

7.2.2. Intergroup Differences in CIVD response

As outlined in section 7.2.1 above, there is no basis for determining in absolute terms whether a participant has a CIVD response, or not. The only basis for comparison is the intensity of the response between participants, and between ethnic groups.

The results show that Korean and Polynesian groups had the strongest overall CIVD response, based on practically every variable, or combination of variables, measured during the CIVD response test. For most variables North Europeans and Chinese had the next strongest CIVD response. For most of the variables, Africans had the weakest CIVD response. The other ethnic groups tended to fall in the range between these groups.

$T_{pretest}$ showed a similar pattern to other CIVD response variables, with Polynesian and Korean groups having much higher, and Africans having much lower finger temperatures before testing, indicating that ethnic differences in finger temperatures are possibly prevalent at all times, not just when subjected to cold stress. There were significant differences between Polynesians and all other groups except Koreans, and between Korean and all other groups except Polynesians and Chinese.

As with body size and body shape above, it is pertinent to talk about not just what is in the results but what is not in the results. There were significant differences in T_{av} between Polynesians and every other ethnic group, with Polynesians having a significantly higher average finger temperature than all other groups except Koreans and North Europeans. Koreans had a significantly higher T_{av} than Africans, Other Europeans, and Indians. Conversely, Africans had a significantly lower T_{av} than all other groups except Other Europeans.

There were no other significant differences among groups. Polynesians and Koreans have a significantly stronger CIVD response; Africans have a significantly lower CIVD response. The rest of the groups have very little significant difference between them.

This in fact is what might be expected if Polynesians are cold adapted. Based on seasonally cold regional temperatures, the prediction was that only Korean, North Chinese and North European participants would be likely to have been subjected to extreme cold. There are sampling issues with Chinese in that it was difficult to separate North Chinese from South Chinese. Likewise with North Europeans, they are a small sample group. However, although not significantly different from any groups other than Africans, they were the only group other than Koreans that were not significantly different from Polynesians for T_{av}.

Likewise it was considered that only African participants would never have been exposed to anything other than a tropical or temperate climate. This is borne out by the results. Africans have a significantly weaker CIVD response than all other groups, except Other European, who represent a particular anomaly to be discussed in more detail further on in this section.

To a large extent the groups outside of the Korean and Polynesian grouping at one end of the CIVD response spectrum, and African at the other end of the spectrum, represent what might be expected from their ancestral environment, which is largely temperate or tropical without seasonally cold extremes. They have a CIVD response but it is not particularly strong. Not enough to be significantly different from each of the other groups. If the evolution of CIVD response is a slow and gradual process, and occurs only at the extremes of environment, then this is what might be expected.

The two groups that are speculated to have spent considerable time in the past in very cold conditions in Northeast Asia, being Koreans and Polynesians, show a significantly strong CIVD response in comparison with other groups. Conversely, Africans, who have never been exposed to anything but a tropical or temperate climate, show a much reduced CIVD response to all other groups. But all groups still do show some CIVD response. The present study indicates that it is a universal response.

The closest this present study could get to an examination of the genetic basis of these phenotypic adaptations to climate was through the use of the Mantel’s test using genetic data from comparable ethnic groups to compare genetic distances with distances calculated from two morphological variables and two CIVD response variables. These tests did indicate some relationship between the calculated genetic distances and the calculated group mean distances for the four variables.

As for body size and body shape above, a key question is to what extent these differences in CIVD response relate to ancestral environment. We will use the same method for assessing this question as for section 7.1 above using Table 64 as the basis for ranking relative ancestral climates.

If an enhanced CIVD response is an adaptation to a cold climate that is genetic in origin, then like body shape it suggests that the ethnic groups with the coldest ancestral environment should have the strongest response. A summary of the results of the study can be seen in Table 68 below.

Table 68. Comparison of relative environments with rankings of CIVD response variables by EG1.

Rankings	Environment		T_{av}		T_{index}	
Cold/strong	Korean	1	Polynesian	7	Polynesian	7
response	North European	2	Korean	1	Korean	1
	Chinese	3	North European	2	North European	2
	Other European	4	Chinese	3	Melanesian	6
	Indian	5	Melanesian	6	Chinese	3
	Melanesian	6	Indian	5	Other European	4
Warm/weak	Polynesian	7	Other European	4	Indian	5
response	African	8	African	8	African	8

Rankings	Environment		T_{av} adjusted for weight		T_{freq} (mean)	
Cold/strong	Korean	1	Korean	1	Korean	1
response	North European	2	Polynesian	7	Polynesian	7
	Chinese	3	Chinese	3	North European	2
	Other European	4	North European	2	Chinese	3
	Indian	5	Indian	5	Melanesian	6
	Melanesian	6	Melanesian	6	Other European	4
Warm/weak	Polynesian	7	Other European	4	Indian	5
response	African	8	African	8	African	8

There is a strong relationship between environment and the CIVD response variables, with the exception of the Polynesian and Other European groups. Koreans, Chinese and North Europeans have the coldest climate and the strongest overall CIVD response. Africans, Indians and Melanesians have the warmest climate and the weakest CIVD response.

Aside from the Polynesians, which represent a complete anomaly, the other unusual result is that of Other Europeans, being UK and South Europeans. UK Europeans come from high latitudes with a seasonally cold climate, yet, along with South Europeans, they display a CIVD response below all groups except Africans, and for some variables, Indians.

Looking firstly at Polynesians, they display a strong CIVD response, and have the largest body size. It would be natural to think that this large mass may be factor in their strong CIVD response. Body mass tends to generate heat, and they have a large hand size, both in terms of finger width and wrist width. Possibly this could explain why they are able to maintain finger warmth during the cold.

However, there was only a slight relationship between weight and T_{av} (r^2=.129) for all participants, and even less for Polynesians as a group (r^2=.024). When analysis of variance between groups was run, with weight as a covariate, Polynesians still had the second highest adjusted mean for T_{av}, behind Koreans, but ahead of all other groups. There was little relationship between T_{av} and either finger width or wrist width. The strongest correlation between CIVD response and body shape variables was the correlation between biiliac width and both T_{av} and T_{index}. Biiliac width is one of the body shape variables most strongly associated with populations from a seasonally cold climate. Furthermore, two other groups with a strong CIVD response were Koreans and Chinese, who had the lowest body mass after Africans, and their finger and wrist widths were at, or close to, the narrowest.

When the results of the other CIVD response variables are examined, the results are much the same as for T_{av}. Polynesians and Koreans had the strongest response in most of the variables, and Africans the weakest. On the basis of those results, CIVD response does appear to be a reliable indicator for ancestry from a seasonally cold climate.

With regard to the two most reliable indicators of ancestry from a cold climate identified in this research, i.e. sitting height ratio and CIVD response, Polynesians exhibit the characteristics of a cold adapted population. Following on from this, the logical conclusion is that the cold adapted body morphology, and cold adapted CIVD response of Polynesians are the result of exposure to a cold ancestral climate for a lengthy period of time sometime in their past. Despite inhabiting a tropical environment, Polynesians are a cold adapted population.

The other anomaly in terms of expected CIVD response is that of the Other European populations, who had a weak CIVD response. This is largely made up of UK Europeans, with a few other participants of Spanish and Portuguese descent. There were no significant differences in CIVD response between these UK and South European groups. As the UK European group have their ancestral origins in a region with a seasonally cold climate, and relatively high latitude, it might be expected that they would exhibit a much stronger CIVD response, but this was not the case.

In addition none of the European groups had a particularly high sitting height ratio, ranking in the middle, less than Koreans, Chinese and Polynesians, but higher than Africans, Indians and Melanesians. There were no significant differences between the European groups for sitting height ratio. This is consistent with the results from previous research as outlined in 2.4, where Europeans had sitting height ratios lower than East Asian populations, but higher than other groups.

There are two possible explanations in terms of adaptation to climate; either Europeans have not been exposed to as cold a climate as the East Asian and Polynesian groups, or their exposure to a cold climate has been for a shorter time, than these groups. There is some evidence to suggest both of these are possible.

As outlined in section 2.3, early European *H. sapiens* exhibit body proportions that are more linear, similar to tropical populations rather than cold adapted populations (Holliday, 1997a, 1999; Ruff, 2002). Over time these body proportions changed to reflect more of a cold adaptation. The earliest modern humans are seen in Europe from 35,000 BP (Trinkaus, 2005). Modern human fossils in East Asia are at least as old (Pope & Terrell, 2008; Trinkaus, 2005). Given the relatively close proximity of Europe to Africa in comparison to East Asia, it is likely that migration to East Asia may have taken many thousands more years than movement into Europe.

In addition, as outlined in section 3.7, it is likely this migration to Northeast Asia followed a northerly route across Asia. This would have exposed these populations to a seasonally cold climate for many thousands of years before actually arriving in Northeast Asia. As described in section 7.1.1, temperatures at similar latitudes are much colder in Northeast Asia than in Europe. Therefore it may well be that early populations of modern humans in Northeast Asia not only had a much longer exposure to seasonally cold temperatures in the last glacial maximum, in comparison with comparable European populations, but they had an exposure to much colder temperatures as well. This would have encouraged a greater degree of adaptation to a cold climate.

The closer proximity of Africa to Europe might also have allowed higher levels of continuing gene flow between these populations, with possible waves of migrations from tropical Africa into Near Asia and Southern Europe and then into North Europe, further mitigating against changes in body morphology towards cold adaptations.

Another factor that might be affecting the UK European results is the prehistoric and historic movement of gene flow between the UK and South Europe, as well as the seafaring nature of the UK in historic times. This is outside the scope of the present study but one example is the fact that in terms of North Europe, only the UK and France were to any significant extent part of the Roman Empire. It may be that factors of accessibility and climate had a part to play in greater gene flow with South Europe for the UK, as opposed to German, East European and Scandinavian Europe.

To a much lesser extent, Melanesians also show an unexpected CIVD response, with a stronger response than might have been expected, although still at the lower end of the rankings, and with no significant between group differences with any groups with lower CIVD response other than African. They do have a stronger response than Other Europeans, and on the T_{index} scale, stronger than Chinese. No amount of argument could suggest that the region of Melanesia has anything like a cold climate, nor are likely to have had for many thousands of years, if ever.

There are some possible explanations, although neither have any direct evidence as support. Section 3.3 covers the genetic relationship between Polynesian and Melanesian populations. Whilst there remains debate on the extent of this relationship, clearly there are genetic links between these two populations. Given the strong CIVD response associated with Polynesians, this genetic relationship could account for some of the variability in CIVD response found in the Melanesian sample. Another explanation may lie in the genetic links with the Denisovan populations. Finally it is worth considering Houghton’s original hypothesis. Inhabitants of Melanesia have been voyaging on the Ocean in canoes in Near Oceania for many thousands of years. However, it is hard to see the selective advantage, and most voyaging would have been a male dominated activity over relatively short distances.

7.3. Origins of Polynesian Body Morphology

This section considers the likely origins of Polynesian body morphology, and thus the likely origins of modern Polynesian populations before they entered the Pacific region more than 5,000 years ago. As demonstrated in sections 7.1 and 7.2, the results of this present study clearly indicate that modern Polynesian populations exhibit the characteristics of a cold adapted population in terms of both body morphology and CIVD response.

The next question to consider is how Polynesian populations might have acquired these cold adapted characteristics. The two hypotheses put forward some 20 years ago suggest they have acquired these characteristics after their movement into Oceania, either through voyaging in the cold maritime environment (Houghton, 1990, 1991a, 1996), or by way of sexual selection (van Dijk, 1991). Neither of these hypotheses can be ruled out by this present study, although the strong CIVD response of Polynesians would tend to militate against the sexual selection hypothesis and favour the cold maritime voyaging hypothesis.

As outlined in Chapter 3, the ancestors of modern Polynesian populations most likely came out of Taiwan around 5,500 years ago, moving fairly rapidly through Island Southeast Asia and Near Oceania, entering Remote Oceania around 3,000 years ago. Section 2.6 suggests the time scale for significant changes in human body morphology is likely to be many thousands of years. On this basis it is more likely than not that Polynesians ancestral populations were cold adapted before they moved to a temperate climate, which would predate their entry into Southeast Asia.

As outlined in section 2.2, these cold adaptations are only likely to have evolved in a climate subject to seasonally extremely cold temperatures. The only area of Asia that would provide the necessary seasonally cold environment for these adaptations to occur would be North Asia.

As seen in section 3.7, Pacific Northeast Asia is seen as a likely place of origin for the early emergence of agriculture and complex social organization in East Asia. Modern human populations have inhabited this region for at least 40,000 years, possibly much longer. Furthermore, if these areas were populated by a northerly route through Central Asia following the movement out of Africa, these populations would likely have been experiencing seasonally extreme cold for many thousands of years even before their arrival in Pacific Northeast Asia.

As outlined in section 2.8, if these early Proto-Polynesian populations originated in Northeast Asia many thousands of years ago, they would have adaptations to a cold environment that would assist survival in long and hazardous open water voyaging on the ocean. They may well have voyaged down the coast of China during their movement south on their way to reaching Taiwan. The physical and robust nature of the Polynesian physique would have been an important factor in the ability of the early Lapita populations to explore and colonise the Pacific.

Whilst Northeast Asia may be the most likely place of origin for the ancestors of Polynesian populations to have acquired their cold adaptations, as yet there remains no conclusive direct evidence for this hypothesis. There has been little in the way of research on the origins of the ancestors of Austronesian speaking populations prior to their emergence in the archaeological records of Taiwan, and much of the existing research is quite old. On top of this are the large scale population movements in Asia both in prehistoric and historic times, which complicate the picture. However, there are a number of genetic links between Pacific Island populations and Native American Indians, as outlined in Chapter 3. As these Native American populations originated in Northeast Asia before crossing to the Americas through Beringia sometime before 14,000 BP, it is possible these genetic links were established as a result of the ancestors of both Polynesian and Native American populations occupying this region before this time.

The identification of well-defined phenotypic characteristics in a population that have been subject to natural selection based on climatic extremes provides scope to look past the archaeological, linguistic and genetic evidence for population movements. Identifying the types of environments in which these populations likely spent thousands of years acquiring these characteristics provides clues as to the origins of these populations.

The Polynesians are possibly a good example of this. This present study confirms the cold adapted nature of Polynesian body morphology and CIVD response. This is in contrast to their current tropical environment that they have inhabited for the past 5,000 years. Given what research tells us about the movements of populations into Asia since the dispersal of *H. sapiens* out of Africa, there are limited environments with cold seasonal extremes that Polynesian ancestors may have occupied in the last 40,000 years which would provide the necessary cold extremes to develop their cold adaptations in body morphology and CIVD response.

The only extremely cold climates that humans have occupied since the dispersal Out of Africa are Northern Asia, Northern Europe and Northern America, excluding populations living at altitude. There is no evidence suggesting populations ancestral to Polynesians have ever occupied either of the European or American continents, or have ever inhabited a high altitude. Northern Asia is the only viable option, and Northeast Asia the most likely seasonally cold region these populations may have occupied prior to moving south towards Taiwan.

Therefore a new hypothesis is put forward. The basis of this hypothesis is that modern Polynesian populations exhibit the physical characteristics of a cold adapted population in terms of both body morphology and CIVD response. That these physical characteristics originate from populations ancestral to modern Polynesians who occupied a seasonally cold climate for many thousands of years before migrating to the Pacific region.

Following on from that hypothesis, the most likely region in which these characteristics were acquired is the Pacific Northeast Asia, and the most likely time period during which these characteristics were acquired is prior to 10,000 years ago.

7.3.1. Health Implications of Polynesian Origins

There are several distinguishing features with regard to Polynesian populations, as outlined in this present study. They are a particularly physically large and robust population, even after allowing for the effects of a modern western lifestyle, especially with regard to sitting height ratio. They are relatively homogenous, with little genetic variation between the different population groups within Polynesia. They also appear to be a cold adapted population, with origins in a much colder environment many thousands of years ago. This would make them one of the few populations who moved from a very cold to a very warm climate in prehistoric times. Much of the movement of *H. sapiens* has been out of Africa away from the tropics to inhabit more temperate climates.

On top of this are the very high rates of obesity found in Polynesian populations as outlined in section 7.1.3, and correspondingly high rates of diabetes. In 2010 the Micronesian island of Nauru ranked as the country with the highest per capita rate of diabetes mellitus in the world, with Tonga and French Polynesia both ranked in the top 15 (International Diabetes Federation, 2010).

It is reasonable to consider whether any of these factors are related to each other. Whilst health is not a primary feature of this thesis, this section will briefly consider some of these issues, which may form the basis for future research in what is becoming a major health concern for Polynesians.

The concept of the thrifty genotype was originally proposed by Neel (1962). Neel considered whether genetic factors which encouraged the efficient intake and storage of calories by the body, an advantage in times of nutritional stress, could become a disadvantage under a calorie rich diet, through higher rates of obesity and diabetes mellitus. This would most likely arise where a population moved from a traditional diet and lifestyle to a modern western diet high in calories and low in exercise. This is not unique to Polynesian populations; increasing rates of obesity and diabetes are common in many populations in this situation. What is unique to modern Polynesian populations is the extent to which this is seen occurring.

This thrifty gene concept has been the subject of research in Polynesian populations for some time. The colonization of Remote Oceania, which involved long oceanic voyages in canoes, and the limited environment of small islands, has led to the suggestion that efficient adipose tissue deposition may have been advantageous as a survival mechanism (Bindon & Baker, 1997; McGarvey, 1994, 1995; Zimmet, Dowse, & Finch, 1990). This is seen as unlikely for the same reasons that Houghton's Hypothesis is disputed – the swift and relatively risk averse mode of voyaging, as well as the limited time frame, does not suggest any great selective pressures on founding populations (Brewis, Irwin, & Allen, 1995; Irwin, 2010).

It is not proposed to revisit this idea. What may be of more significance is the relationship between Polynesians as a cold adapted population, and the high rates of obesity and diabetes mellitus. There are several advantages for individuals who can rapidly store fat in a cold climate. These are the ability to survive in times of food shortage, the insulative properties of fat to protect against cold, and the need for larger amounts of calories to maintain body temperature (Baker, 1995).

What may be advantageous in a cold climate may be deleterious in a hot climate, or where higher calorie levels are readily available. Abdominal insulative adipose tissue will restrict heat loss that may be preferable in a warm climate, and greater storage of fat for times of famine is of no advantage if there is no future famine. It may be that these genetic advantages for a cold climate have been of neutral or marginal value when Polynesian populations first moved to a tropical climate, only to become significantly deleterious when combined with a move to a western lifestyle with less physical activity and a much higher levels of caloric intake.

One study which looked at the high rates of obesity and diabetes among Polynesians concluded that the rates exceeded what might be expected from either Roberts (1953) analysis of body weight relationship with climate, or the results of modernization (Bindon & Baker, 1997). The study speculated this could possibly be the result of exposure to cold stress and cited Houghton (1990).

Increasingly it appears that there are population-specific differences in levels of insulin, glucose, blood pressure and lipids which may relate to the interaction between environment and genetics, and these are affecting the rates of diabetes and obesity among populations of differing ancestry (Jorgensen et al., 2003). Metabolic efficiency in the storage of excess calories in the form of fat is linked to the over-production of insulin, which increases fat tissue formation (Jobling et al., 2004, p. 362).

Research indicates Asian populations are more susceptible to diabetes at lower levels of obesity than European populations, leading to revised guidelines for a ‘normal’ BMI range (Chiu, Austin, Manuel, Shah, & Tu, 2011; Choo, 2002). There has even been the suggestion that a particular genetic variation found in high frequencies in Polynesian populations is responsible for their high rates of diabetes mellitus (Myles et al., 2007; Myles et al., 2011). This study found a relationship between one identified allele and high BMI rates in Tongan populations. This allele is absent in Africa, at low levels in Europe and the Americas, but is at its highest frequency in Polynesia, reaching .85 in Western Samoa, leading the study to conclude that it had been subject to positive selection at some point in the populations history. Although the study identified Houghton’s Hypothesis as a likely scenario for the selective advantage of this allele through cold stress, as outlined in this present study, it is more likely the exposure to cold stress in Polynesian populations dates back to prior to their entry into the Pacific.

There are a number of studies looking at the prevalence of obesity and diabetes amongst populations living in a cold climate, even where they maintain a traditional lifestyle and diet. A study of Mongolian nomads, where the mean annual temperature is -1.7ºC, identified high rates of excess fat, particularly abdominal fat, which would provide thermogenic and insulative protection against extreme cold (Beall & Goldstein, 1992). Studies on circumpolar indigenous populations indicate increasing levels of obesity and diabetes (Bjerregaard, Kue Young, Dewailly, & Ebbesson, 2004; T.K. Young, Schraer, Shubnikoff, Szathmary, & Nikitin, 1992). Inuit are seen as at higher risk for obesity than other populations globally based on BMI and waist circumference (T. K. Young, 2007).

Native Americans provide further evidence when considering other populations with high rates of diabetes. Native American populations have some of the highest rates of diabetes in the world; the Pima Indians have the distinction of having one of the world’s highest incidence of type II diabetes (Harjo, Perez, Lopez, & Wong, 2011; Knowler, Pettitt, Saad, & Bennett, 1990). Interestingly the rates of diabetes in Pima Indians in Mexico, where a more traditional lifestyle is still evident, are considerably lower than for U.S. Pima Indians, indicating the strong interaction between genotype and environment, even among populations with a stronger genetic propensity for diabetes (Bennett et al., 2006). As discussed in section 3.7, Asian and American circumpolar populations, along with American Indian populations, share a common ancestry and ancestral environment, originating in Northeast Asia in the Upper Pleistocene. It is likely that Polynesians share a similar ancestry.

One aspect under study for contributing to the development of insulin resistance in cold adapted populations is the prevalence of non-alcoholic fatty liver, which may be a factor in the thrifty genome scenario (Caldwell, Ikura, Iezzoni, & Liu, 2007). Fatty liver is a characteristic of non-hibernating cold adapted animals. A fatty liver serves as a secondary fat storage site, but also plays a role in thermoregulation. What may be an adaptive advantage in cold climates, and in situations of food deprivation, may be deleterious when confronted with caloric abundance and a warm, or controlled climate.

The development of obesity is also associated with the relationship between white adipose tissue, whose primary purpose is energy storage, and that of brown adipose tissue, which is involved in energy expenditure (Gesta, Tseng, & Kahn, 2007). Genetics is the dominant factor in the distribution of fat (Nelson, Vogler, Pedersen, Hong, & Miles, 2003). Brown adipose tissue is found in new born babies, but was considered to be relatively insignificant in human adults (Nelson et al., 2003), although more common in outdoor workers in cold climates (Huttunen, Hirvonen, & Kinnula, 1981). It is now thought to be more common, and play a role in energy expenditure and thermogenesis, and the maintenance of body temperature, and can be rapidly activated in cold conditions (Celi, 2009; Van Marken Lichtenbelt et al., 2009).

The activity of brown adipose tissue was inversely correlated with BMI and obesity, with a substantial increase in energy expenditure when exposed to mild cold. This suggests not only that the distribution of brown adipose tissue is related to cold climates, but that it may play a role in protecting against obesity (Cypess et al., 2009).

Another consideration is muscle type. Muscle fibre type plays a role in temperature maintenance through shivering (Haman, 2006). Houghton (1996, p. 242) speculated that Polynesians may have a preponderance of type II muscle fibres, which he thought may improve resistance to cold. There appears to be a correlation between individuals with a predominance of type II muscle fibre and obesity (Staron, Hikida, Hagerman, Dudley, & Murray, 1984; Wade, Marbut, & Round, 1990).

The relationship between Polynesian populations and their high rates of diabetes and obesity is only touched on in this section. The identification of Polynesians as a cold adapted population may serve to provide future opportunities for research in this area.

7.4. Conclusion

This research has examined the relationship between body size, body shape, CIVD response and ancestral environment. A range of variables covering body size, body shape and CIVD response was obtained from participants from a number of ethnic groups. Each ethnic group represents a different geographical region relating to ancestry. These geographical regions were then ranked by the degree to which they experienced seasonal cold. This was used as a proxy to rank the extent to which an ethnic group might have experienced seasonally very cold temperatures. Bergmann's and Allen's rules were used to establish the predictions for body morphology adapted to a cold climate.

There are significant differences between some of the ethnic groups for all of the variables studied. When these variables are related to ancestral climate, there was no significant relationship between any of the body size variables and a seasonally cold ancestral climate. With regard to body shape, there was a limited relationship between biiliac width and a seasonally cold ancestral climate. There was stronger relationship between sitting height ratio and a seasonally cold ancestral climate. There was no significant relationship between any of the other body shape variables and a seasonally cold ancestral climate. With regard to CIVD response, there was a significant relationship between CIVD response variables and groups from a seasonally cold ancestral climate. Therefore, on the basis of this research, CIVD response and sitting height ratio are the best predictors for ancestry from a seasonally cold climate for modern human populations.

The results of the Mantel's test in section 6.4 indicated similarity between comparable genetic distances and both morphological and CIVD response characteristics. Although using different data from another study for the genetic distances, these were comparable to the ethnic groupings of participants in this present study. This adds some weight to the suggestion that these phenotypic differences observed are based on heritable traits.

The major anomaly was the Polynesian group of participants. Despite inhabiting a tropical environment, they exhibited the characteristics of a cold adapted population. With regard to the variables that were the best predictors of ancestry from a seasonally cold ancestral climate, namely biiliac width, sitting height ratio and CIVD response, Polynesians are clearly a cold adapted population.

How the Polynesian group came to have these cold adaptations remains a source of conjecture. This research identifies these adaptations but cannot identify how or why they came about. This research does not rule out Houghton's hypothesis that these adaptations evolved during their time in the Oceanic region. However,, on the basis of past research outlined in chapters 2 and 3 relating to the time scale for the development of cold adapted characteristics, and the Asian origins of Polynesian populations, it is more likely that these adaptations date back to before the entry of Polynesians ancestors into Southeast Asia more than 5,000 years ago. If this hypothesis is accepted then the most likely region for these adaptations to have evolved in would be Northeast Asia.

These cold adaptations are also advanced as a possible factor in the ability of Polynesians to successfully colonize Remote Oceania, the most extensive and arduous maritime colonization in human prehistory, crossing the largest body of water on the planet, from Southeast Asia to South America. Despite humans populating Near Oceania for at least 40,000 years, it was only with the more recent emergence of populations ancestral to the Polynesians that humans began to move from Near Oceania to cross the Pacific Ocean. This occurred only a few thousand years after their appearance in Oceania more than 4,000 years ago. There were undoubtedly a number of factors in their successful colonization, but a robust and strong physique, as well as an ability to withstand cold temperatures whilst voyaging on the Pacific Ocean, must surely have been an important element in their success.

This research also does not explain why Polynesians are so large, and with such a high prevalence of obesity and diabetes. If it was purely a question of cold adaptation, then the most northern inhabitants of the Arctic Circle would be the largest people in the world. That would not appear to be the case. The movement of Polynesians from a very cold climate to a very tropical climate is put forward as a possible contributing factor, but one that would require more extensive research to establish a definite link.

The other anomaly was the weak CIVD response by UK Europeans, despite inhabiting a seasonally cold climate. Three possible explanations are advanced to explain this anomaly. The first is that the warming effect of the Gulf Stream reduces the cold temperature extremes found in Western Europe. At the same latitude, temperatures in Europe are much warmer than those in Asia. The second is the length of time *H. sapiens* have occupied Europe in comparison to early inhabitants of Northern Asia. The effects these factors may have had on the evolution of early European *H. sapiens* represent future areas of research that may be of interest. The third is the likelihood of continuing gene flow in both prehistoric and historic times between UK Europe and South Europe, more so than with other parts of North Europe, due to the accessibility and climate of the UK compared with these other parts of North Europe.

References

References

Adams, T., & Corvina, B. G. (1958). Racial Variation to a Standardized Cold Stress. *J Appl Physiol, 12*, 9-12.

Addison, D., & Matisoo-Smith, E. (2010). Rethinking Polynesians origins: a West-Polynesia Triple-I Model. *Archaeology in Oceania, 45*(1), 1-12.

Aiello, L. C. (1993). The Fossil Evidence for Modern Human Origins in Africa: A Revised View. *American Anthropologist, 95*(1), 73-96.

Aikens, C. M., & Rhee, S. N. (1992). The Emergence of Hunter-Fisher-Gatherers, Farmers, and Sociopolitical Elites in the Prehistory of Pacific Northeast Asia. In C. M. Aikens & S. N. Rhee (Eds.), *Pacific northeast Asia in prehistory: hunter-fisher-gatherers, farmers, and sociopolitical elites* (pp. 99-104). Pullman, Wash.: WSU Press.

Allen, J., & White, J. P. (1989). The Lapita homeland: some new data and an interpretation. *Journal of the Polynesian Society, 98*(2), 129-146.

Allen, J. A. (1877). The influence of physical conditions in the genesis of species. *Radical Review, 1*, 108-140.

Allen, J. A. (1982). Pre-contact Trade in Papua New Guinea. In R. J. May & H. Nelson (Eds.), *Melanesia : beyond diversity* (pp. 193-207). Canberra: Research School of Pacific Studies, Australian National University : distributed by ANU Press.

Anderson, A. (2002). *Initial human dispersal in Remote Oceania: pattern and exploration* Paper presented at the Pacific archaeology : assessments and prospects :proceedings of the international conference for the 50th anniversary of the first Lapita excavation, Noumea.

Anderson, A., & O'Connor, S. (2008). Indo-Pacific Migration and Colonization-Introduction. *Asian Perspectives, 47*(1), 2.

Anton, F., Gilly, H., Kreh, A., & Handwerker, H. (1982). Influence of vascular tone on pain induced by skin cooling. *Pflügers Archiv European Journal of Physiology, 394*(0), R58-R58. doi: 10.1007/bf02580807

Armelagos, G. J., & Van Gerven, D. P. (1980). Sexual dimorphism and human evolution: An overview. *Journal of Human Evolution, 9*(5), 437-446.

Arnaiz-Villena, A., Parga-Lozano, C., Moreno, E., Areces, C., Rey, D., & Gomez-Prieto, P. (2010). The Origin of Amerindians and the Peopling of the Americas According to HLA Genes: Admixture with Asian and Pacific People. [Article]. *Current Genomics, 11*(2), 103-114. doi: 10.2174/138920210790886862

Ashton, K. G., & Tracy, M. C. (2000). Is Bergmann's Rule Valid for Mammals? *American Naturalist, 156*(4), 390.

Auerbach, B. M. (2007). *Human skeletal variation in the New World during the Holocene: Effects of climate and subsistence across geography and time - Part I.* PhD, The Johns Hopkins University, Baltimore.

Auger, F., Jamieson, P., Balslev-Jogensen, J., Lewin, T., De Pena, J., & Skrobak-Kaczynski, J. (1980). Anthropometry of circumpolar populations. In F. A. Milan (Ed.), *The Human biology of circumpolar populations*. Cambridge [Eng.] ; New York: Cambridge University Press.

Bagust, A., & Walley, T. (2000). An alternative to body mass index for standardizing body weight for stature. *QJM, 93*(9), 589-596. doi: 10.1093/qjmed/93.9.589

Baker, P. T. (1995). Strong and weak linkages in the thrifty genotype hypothesis *Asia Pacific Journal of Clinical Nutrition, 4*, 337-338.

Barker, G. (2005). The archaeology of foraging and farming at Niah Cave, Sarawak. *Asian Perspectives: the Journal of Archaeology for Asia and the Pacific, 44*(1), 90(17).

Bateson, P., Barker, D., Clutton-Brock, T., Deb, D., D'Udine, B., Foley, R. A., . . . Sultan, S. E. (2004). Developmental plasticity and human health. *Nature, 430*(6998), 419-421.

Beall, C. M., & Goldstein, M. C. (1992). High prevalence of excess fat and central fat patterning among Mongolian pastoral nomads. *American Journal of Human Biology, 4*(6), 747-756.

Beall, C. M., & Steegmann, A. T. (2000). Human Adaptation to Climate: Temperature, Ultraviolet Radiation, and Altitude. In B. B. Sara Stinson, Rebecca Huss-Ashmore, Dennis O'Rourke (Ed.), *Human Biology: An Evolutionary and Biocultural Perspective*. New York: Wiley-Liss.

Bedford, S., & Spriggs, M. (2008). Northern Vanuatu as a Pacific Crossroads: The Archaeology of Discovery, Interaction, and the Emergence of the "Ethnographic Present". *Asian Perspectives, 47*(1), 95.

Bedford, S., Spriggs, M., Buckley, H. R., Valentin, F., & Regenvanu, R. (2009). The Teouma Lapita site, South Efate, Vanuatu. In P. J. Sheppard, T. Thomas & G. Summerhayes (Eds.), *Lapita : ancestors and descendants* (pp. 215-234). Auckland [N.Z.]: New Zealand Archaeological Association.

Bellwood, P. S. (1995). The Austronesians Prehistory in Southeast Asia: Homeland, Exansion and Transformation. In P. S. Bellwood, J. J. Fox & D. T. Tryon (Eds.), *The Austronesians : historical and comparative perspectives* (pp. 96-111). Canberra: Australian National University.

Bellwood, P. S., Chambers, G., Ross, M., & Hung, H.-c. (2011). Are ‘Cultures’ Inherited? Multidisciplinary Perspectives on the Origins and Migrations of Austronesian-Speaking Peoples Prior to 1000 BC. In B. W. Roberts & M. Vander Linden (Eds.), *Investigating Archaeological Cultures* (pp. 321-354): Springer New York.

Benedict, P. K. (1990). *Japanese/Austro-Tai*. Ann Arbor [Mich.]: Karoma.

Bennett, P. H., Esparza, J., Kidd, J. R., Kidd, K. K., Ravussin, E., Schulz, L. O., & Valencia, M. E. (2006, 2006/08//). Effects of traditional and western environments on prevalence of type 2 diabetes in Pima Indians in Mexico and the U.S. *Diabetes Care, 29,* 1866+.

Benoist, J. (1975). The ecological gradient of the weight/surface relationship among Israeli groups of various origin. *Journal of Human Evolution, 4*(6), 525-528.

Bentley, R. A., Buckley, H. R., Spriggs, M., Bedford, S., Ottley, C. J., Nowell, G. M., . . . Pearson, D. G. (2007). Lapita migrants in the Pacific's oldest cemetery: isotopic analysis at Teouma, Vanuatu.(Reports). *American Antiquity, 72*(4), 645(612).

Bettinger, R. L., Barton, L., & Morgan, C. (2010). The origins of food production in north China: A different kind of agricultural revolution. *Evolutionary Anthropology: Issues, News, and Reviews, 19*(1), 9-21. doi: 10.1002/evan.20236

Biggs, A. K. (2003). *The Long and the Short of it: Variation in Limb Segment Lengths and Proportions among Pacific Peoples.* Master of Arts, University of Auckland, Auckland.

Bindon, J. R., & Baker, P. T. (1997). Bergmann's rule and the thrifty genotype. *American Journal of Physical Anthropology, 104*(2), 201-210.

Birdsell, J. B. (1951). The Problem of the Early Peopling of the Americas as viewed from Asia. In W. S. Laughlin (Ed.), *Papers on the physical anthropology of the American Indian* (pp. 1-68). New York Viking Fund

Bischof, B., Mariano, A. J., & Ryan, E. H. (2003). The North Atlantic Drift Current. *Ocean Surface Currents*.

Bjerregaard, P., Kue Young, T., Dewailly, E., & Ebbesson, S. O. E. (2004). Review Article: Indigenous health in the Arctic: an overview of the circumpolar Inuit population. *Scand J Public Health, 32*(5), 390-395. doi: 10.1080/14034940410028398

Blackburn, T. M., Gaston, K. J., & Loder, N. (1999). Geographic gradients in body size: a clarification of Bergmann's rule. *Diversity & Distributions, 5*(4), 165-174.

Blust, R. (1999). Subgrouping, circularity, and extinction: some issues in comparative Austronesian linguistics. In E. Zeitoun & R. Li (Eds.), *Symposium Series of the Institute of Linguistics*, (Vol. 1, pp. 31-94). Taipei: Academia Sinica, Number 1.

Boas, F. (1940). Changes in Bodily Form of Descendants of Immigrants. *American Anthropologist, 42*(2), 183-189.

Bogin, B. (1999). *Patterns of Human Growth* (2 ed.). Cambridge: Cambridge University Press.

Bogin, B., Kapell, M., Varela, M. I., Orden, A. B., Smith, P. K., & Loucky, J. (2001). How genetic are human body proportions. In P. Dasgupta & R. Hauspie (Eds.), *Persepctives in Human Growth, Development and Maturation*. Dordrecht: Kluwer Academic Publishers.

Bogin, B., & Rios, L. (2003). Rapid morphological change in living humans: implications for modern human origins. *Comparative Biochemistry and Physiology - Part A: Molecular & Integrative Physiology, 136*(1), 71-84. doi: Doi: 10.1016/s1095-6433(02)00294-5

Boos, W. R. (2011). Climate: Cold winters from warm oceans. [10.1038/471584a]. *Nature, 471*(7340), 584-586.

Bougainville, L.-A. d. (1967). *A voyage round the world*. Amsterdam: N. Israel.

Bowler, J. M., Johnston, H., Olley, J. M., Prescott, J. R., Roberts, R. G., Shawcross, W., & Spooner, N. A. (2003). New ages for human occupation and climatic change at Lake Mungo, Australia. Nature 421:837-840. *Nature, 421*, 837-840.

Brace, C. L. (1990). Micronesians, Asians, Thais, and relations: a cranofacial and odontometric perspective. *Micronesica Supplement, 2*, 323-348.

Brace, C. L. (1998). Book Review: People of the Great Ocean: Aspects of Human Biology. *Asian Perspectives, 37*(1), 115-117.

Brace, C. L., Brace, M. L., & Leonard, W. R. (1989). Reflections on the face of Japan: A multivariate craniofacial and odontometric perspective. *American Journal of Physical Anthropology, 78*(1), 93-113. doi: 10.1002/ajpa.1330780110

Brace, C. L., & Nagai, M. (1982). Japanese tooth size: Past and present. *American Journal of Physical Anthropology, 59*(4), 399-411. doi: 10.1002/ajpa.1330590410

Brace, C. L., & Ryan, A. S. (1980). Sexual dimorphism and human tooth size differences. *Journal of Human Evolution, 9*(5), 417-435.

Bräuer, G., Yokoyama, Y., Falguères, C., & Mbua., E. (1997). Modern human origins backdated. *Nature, 336*, 337-338.

Brewis, A. A., Irwin, G., & Allen, J. (1995). Patterns of colonisation and the "thrifty" genotype in Pacific prehistory. *Asia Pacific Journal of Clinical Nutrition, 4*, 361-365.

Brown, G. M., & Page, J. (1952). The Effect of Chronic Exposure to Cold on Temperature and Blood Flow of the Hand. *Journal of Applied Physiology, 5*(5), 221-227.

Bruck, K. (1980). *Basic mechanisms in longtime thermal adaptations*. Paper presented at the Contributions to thermal physiology : Satellite Symposium of the 28th International Congress of Physiological Sciences, Pécs, Hungary.

Buck, P. H. (1922). Maori Somatology: Racial Averages. *Journal of the Polynesian Society, 31*(1,3,4), 37-44,145-153,159-170.

Buck, P. H. (1923). Maori Somatology: Racial Averages. *Journal of the Polynesian Society, 32*(1,4), 21-28, 189-199.

Buckley, H. R., Tayles, N. G., Spriggs, M., & Bedford, S. (2008). A Preliminary Report on Health and Disease in Early Lapita Skeletons, Vanuatu: Possible Biological Costs of Island Colonization. *The Journal of Island and Coastal Archaeology, 3*(1), 87 - 114.

Bustamante, C. D., & Henn, B. M. (2010). Human origins: Shadows of early migrations. [10.1038/4681044a]. *Nature, 468*(7327), 1044-1045.

Caldwell, S. H., Ikura, Y., Iezzoni, J. C., & Liu, Z. (2007). Has natural selection in human populations produced two types of metabolic syndrome (with and without fatty liver)? *Journal of Gastroenterology & Hepatology, 22*, S11-S19.

Cameron, N. (1984). *The Measurement of Human Growth*. London: Croom Held.

Campbell, N. A., & Reece, J. B. (2005). *Biology* (7th ed.). San Francisco: Pearson/Benjamin Cummings.

Capelli, C., Wilson, J. F., Richards, M., Stumpf, M. P. H., Gratrix, F., Oppenheimer, S., . . . Goldstein, D. B. (2001). A Predominantly Indigenous Paternal Heritage for the Austronesian-Speaking Peoples of Insular Southeast Asia and Oceania. *American Journal of Human Genetics, 68*(2), 432-443.

Cavalli-Sforza, L. L., & Feldman, M. W. (2003). The application of molecular genetic approaches to the study of human evolution. *Nat Genet, 33*, 266-275.

Celi, F. M. (2009). Brown Adipose Tissue -- When It Pays to Be Inefficient. *The New England Journal of Medicine, 360*(15), 1553.

Chakravarthy, M. V., & Booth, F. W. (2004). Eating, exercise, and "thrifty" genotypes: connecting the dots toward an evolutionary understanding of modern chronic diseases. *Journal of Applied Physiology, 96*(1), 3-10. doi: 10.1152/japplphysiol.00757.2003

Chang, J. G., Ko, Y. C., Lee, J. C. I., Chang, S. J., Liu, T. C., Shih, M. C., & Peng, C. T. (2002). Molecular analysis of mutations and polymorphisms of the Lewis secretor type α(1,2)-fucosyltransferase gene reveals that Taiwan aborigines are of Austronesian derivation. *Journal of Human Genetics, 47*(2), 60-65. doi: 10.1007/s100380200001

Chang, K.-C. (1959). Chinese Prehistory in Pacific Perspective: Some Hypotheses and Problems. *Harvard Journal of Asiatic Studies, 22*(ArticleType: research-article / Full publication date: Dec., 1959 / Copyright © 1959 Harvard-Yenching Institute), 100-149.

Chang, K.-C. (1964). Prehistoric and Early Historic Culture Horizons and Traditions in South China. *Current Anthropology, 5*(5), 359-375.

Chang, K.-C. (1969). *Fengpitou, Tapenkeng, and the prehistory of Taiwan*. New Haven,: Dept. of Anthropology, Yale University.

Chang, K.-C. (1995). Taiwan Strait Archaeology and Proto-Austronesian. In P. J.-K. Li, C.-H. Tsang, Y.-K. Huang, D.-A. Ho & C.-Y. Tseng (Eds.), *Austronesian Studies Relating To Taiwan* (pp. 161-183). Taipei: Instuitute of History and Philology, Academia Sinica.

Chapman, P. M., & Gill, G. W. (1998). Estimation of Stature for the Prehistoric/Protohistoric Rapanui. *Journal of the Polynesian Society, 107*(2), 187-194.

Chen, J. C. (2008). Sea Nomads in Prehistory on the South Coast of China. *Bulletin of the Indo-Pacific Prehistory Association*, 51-62.

Cheng-hwa, T. (2004). Recent discoveries at the Tapenkeng culture sites in Taiwan. In L. Sagart, R. Blench & A. Sanchez-Mazas (Eds.), *The peopling of East Asia : putting together archaeology, linguistics and genetics* (pp. 63-73). New York: RoutledgeCurzon.

Chiu, M., Austin, P. C., Manuel, D. G., Shah, B. R., & Tu, J. V. (2011). Deriving Ethnic-Specific BMI Cutoff Points for Assessing Diabetes Risk. *Diabetes Care, 34*(8), 1741-1748. doi: 10.2337/dc10-2300

Choo, V. (2002). WHO reassesses appropriate body-mass index for Asian populations. *Lancet, 360*(9328), 235.

Chow, R. A., Caeiro, J. L., Chen, S.-J., Garcia-Bertrand, R. L., & Herrera, R. J. (2005). Genetic characterization of four Austronesian-speaking populations. *Journal of Human Genetics, 50*(11), 550-559.

Churchill, S. E. (1998). Cold adaptation, heterochrony, and neandertals. *Evolutionary Anthropology: Issues, News, and Reviews, 7*(2), 46-60. doi: 10.1002/(sici)1520-6505(1998)7:2<46::aid-evan2>3.0.co;2-n

Ciochon, R. L., & Bettis III, E. A. (2009). Palaeoanthropology: Asian Homo erectus converges in time. *Nature, 458*(7235), 153-154.

Clark, J. T., & Kelly, K. M. (1993). Human Genetics, Paleoenvironments, and Malaria: Relationships and Implications for the Settlement of Oceania. *American Anthropologist, 95*(3), 612-630. doi: doi:10.1525/aa.1993.95.3.02a00040

Cleophas, T. J., Fennis, J. F., & van't Laar, A. (1982). Finger temperature after a finger-cooling test: influence of air temperature and smoking. *Journal of Applied Physiology, 52*(5), 1167-1171.

Cohen, J. (1988). *Statistical power analysis for the behavioral sciences* (2nd ed.). Hillsdale, N.J.: L. Erlbaum Associates.

Cole, T. J. (2003). The secular trend in human physical growth: a biological view. *Economics & Human Biology, 1*(2), 161-168. doi: Doi: 10.1016/s1570-677x(02)00033-3

Cook, J., & Beaglehole, J. C. (1988a). *The journals of Captain James Cook on his voyages of discovery* (Vol. 1). Millwood, N.Y.: Kraus Reprint.

Cook, J., & Beaglehole, J. C. (1988b). *The journals of Captain James Cook on his voyages of discovery* (Vol. 2). Millwood, N.Y.: Kraus Reprint.

Cooke, J. P., Creager, M. A., Osmundson, P. J., & Shepherd, J. T. (1990). Sex differences in control of cutaneous blood flow. *Circulation, 82*(5), 1607-1615.

Coon, C. S., Garn, S. M., & Birdsell, J. B. (1950). *Races; a study of the problems of race formation in man*. Springfield, Ill.,: C. C. Thomas.

Coop, G., Pickrell, J. K., Novembre, J., Kudaravalli, S., Jun, L., Absher, D., . . . Pritchard, J. K. (2009). The Role of Geography in Human Adaptation. [Article]. *PLoS Genetics, 5*(6), 1-16. doi: 10.1371/journal.pgen.1000500

Cox, M. P. (2005). Indonesian mitochondrial DNA and its opposition to a Pleistocene era origin of proto-Polynesians in island Southeast Asia. *Human Biology, 77*(2), 179(110).

Cox, M. P., Karafet, T. M., Lansing, J. S., Sudoyo, H., & Hammer, M. F. (2010). Autosomal and X-linked single nucleotide polymorphisms reveal a steep Asian–Melanesian ancestry cline in eastern Indonesia and a sex bias in admixture rates. *Proceedings of the Royal Society B: Biological Sciences, 277*(1687), 1589-1596. doi: 10.1098/rspb.2009.2041

Cox, M. P., Redd, A. J., Karafet, T. M., Ponder, C. A., Lansing, J. S., Sudoyo, H., & Hammer, M. F. (2007). A Polynesian motif on the Y chromosome: population structure in remote Oceania.(Report). *Human Biology, 79*(5), 525(511).

Crawford, M. H. (2007). Foundations of Anthropological Genetics. In M. H. Crawford (Ed.), *Anthropological genetics : theory, methods and applications* (pp. x, 476 p.). Cambridge ; New York: Cambridge University Press.

Crognier, E. (1981). Climate and anthropometric variations in Europe and the Mediterranean area. *Annals of Human Biology, 8*(2), 99-107. doi: doi:10.1080/03014468100004841

Cypess, A., Lehman, S., Williams, G., Tal, I., Rodman, D., Goldfine, A., . . . Kahn, C. (2009). Identification and Importance of Brown Adipose Tissue in Adult Humans. *The New England Journal of Medicine, 360*(15), 1509.

Daanen, H. A. M. (2001). Cold injury risk of marines [in Dutch]. *TNO Human Factors, Soesterberg, Report TM-A050.*

Daanen, H. A. M. (2003). Finger cold-induced vasodilation: a review. *European Journal of Applied Physiology, V89*(5), 411-426.

Daanen, H. A. M., & Ducharme, M. B. (2000). Axon reflexes in human cold exposed fingers *European Journal of Applied Physiology, 81*(3).

Daanen, H. A. M., Van de Linde, F. J. G., Romet, T. T., & Ducharme, M. B. (1997). The effect of body temperature on the hunting response of the middle finger skin temperature. *European Journal of Applied Physiology, 76*(6), 538-543.

Daanen, H. A. M., & Van Ruiten, H. J. A. (2000). Cold-Induced Peripheral Vasodilation at High Altitudes - A Field Study. *High Altitude Medicine & Biology, 1*(4), 323-329. doi: doi:10.1089/15270290050502390

Damon, A. (1977). *Human Biology and Ecology*. New York: W. W. Norton and Company.

Deacon, H. J. (1992). Southern Africa and Modern Human Origins. *Philosophical Transactions: Biological Sciences, 337*(1280), 177-183.

Delfin, F., Myles, S., Choi, Y., Hughes, D., Illek, R., van Oven, M., . . . Stoneking, M. (2012). Bridging Near and Remote Oceania: mtDNA and NRY Variation in the Solomon Islands. *Molecular Biology and Evolution, 29*(2), 545-564. doi: 10.1093/molbev/msr186

Derenko, M., Malyarchuk, B., Grzybowski, T., Denisova, G., Dambueva, I., Perkova, M., . . . Zakharov, I. (2007). Phylogeographic Analysis of Mitochondrial DNA in Northern Asian Populations. *The American Journal of Human Genetics, 81*(5), 1025-1041. doi: 10.1086/522933

Dettwyler, K. A. (1992). Nutritional status of adults in rural Mali. *American Journal of Physical Anthropology, 88*(3), 309-321.

Diamond, J. M. (1988). Express train to Polynesia. *Nature, 336*, 307-308.

Diamond, J. M. (2000). Linguistics: Taiwan's gift to the world. *Nature, 403*(6771), 709-710.

Diamond, J. M., & Bellwood, P. (2003). Farmers and Their Languages: The First Expansions. *Science, 300*(5619), 597-603. doi: 10.1126/science.1078208

Dubrova, Y. E., Kurbatova, O. L., Kholod, O. N., & Prokhorovskaya, V. D. (1995). Secular Growth Trend in Two Generations of the Russian Population. *Human Biology, 67*, 755.

Dunn, L. C., & Tozzer, A. M. (1928). *An anthropometric study of Hawaiians of pure and mixed blood*: Papers of the Peabody Museum, vol.11, no. 3. Cambridge, Mass.

Dyen, I. (1965). Formosan evidence for some new proto-Austronesian phonemes. *Lingua, 14*, 285-305. doi: Doi: 10.1016/0024-3841(65)90046-x

Eagan, C. J. (1963). Local vascular adaptations to cold in man. *Federation proceedings., 22*, 947-952.

Elsner, R. W., Nelms, J. D., & Irving, L. (1960). Circulation of heat to hands of Arctic Indian. *J Appl Physiol, 15*, 662-666.

Erickson, J. (1990). *Ice ages : past and future* (1st ed.). Blue Ridge Summit, PA: TAB Books.

Erskine, J. E. (1853). *Journal of a cruise among the islands of the western Pacific, including the Feejees and others inhabited by the Polynesian Negro races, in Her Majesty's ship Havannah*. London: J. Murray.

Etler, D. A. (1996). The Fossil Evidence for Human Evolution in Asia. *Annual Review of Anthropology, 25*, 275-301.

Eveleth, P. B., & Tanner, J. M. (1990). *Worldwide Variation in Human Growth* (2nd ed.). Cambridge: Cambridge University Press.

Fagan, B. M. (2009). *The complete Ice Age : how climate change shaped the world*. New York: Thames & Hudson.

Ferrell, R. E. (1966). The Formosan Tribes: a preliminary linguistic, archaeological and cultural synthesis. *Bulletin of the Institute of Ethnology, Academia Sinica, 21*, 97-130.

Field, A. P. (2009). *Discovering statistics using SPSS : (and sex, drugs and rock'n'roll)* (3rd ed.). London: SAGE.

Floud, R., Gregory, A., & Wachter, K. W. (1990). *Height, health and history : nutritional status in the United Kingdom, 1750-1980*. Cambridge: Cambridge University Press.

Fogel, R. W., & Grotte, N. (2011). An Overview Of The Changing Body: Health, Nutrition, And Human Development In The Western World Since 1700 *NBER Working Paper Series* (Vol. Working Paper 16938). Cambridge, MA: National Bureau Of Economic Research.

Foley, W. A. (1986). *The Papuan languages of New Guinea*. Cambridge Cambridgeshire ; New York: Cambridge University Press.

Folkow, B., Fox, R. H., Krog, J., Odelram, H., & Thorén, O. (1963). Studies on the Reactions of the Cutaneous Vessels to Cold Exposure. *Acta Physiologica Scandinavica, 58*(4), 342-354. doi: 10.1111/j.1748-1716.1963.tb02656.x

Forster, P. (2004). Ice Ages and the mitochondrial DNA chronology of human dispersals: a review. *Philosophical Transactions of the Royal Society B: Biological Sciences 359*(1442), 255-264.

Freedman, R. R., Sabharwal, S. C., Moten, M., & Migaly, P. (1992). Local temperature modulates alpha 1- and alpha 2-adrenergic vasoconstriction in men. *American Journal of Physiology - Heart and Circulatory Physiology, 263*(4), H1197-H1200.

Friedlaender, J. S. (1998). Book Review: People of the great ocean: Aspects of human biology of the early pacific. *American Journal of Physical Anthropology, 106*(4), 553-557.

Friedlaender, J. S., Friedlaender, F. o. R., Reed, F. A., Kidd, K. K., Kidd, J. R., Chambers, G. K., . . . Weber, J. L. (2008). The Genetic Structure of Pacific Islanders. *PLoS Genetics,* e19.

Friedlaender, J. S., Friedlaender, F. R., Hodgson, J. A., Stoltz, M., Koki, G., Horvat, G., . . . Merriwether, D. A. (2007). Melanesian mtDNA Complexity. [4/3/7]. *PLoS ONE, 2(2)*(February 28).

Friedlaender, J. S., Gentz, F., Green, K., & Merriwether, D. A. (2002). A cautionary tale on ancient migration detection: mitochondrial DNA variation in Santa Cruz Islands, Solomon Islands. *Human Biology, 74*(3), 453(419).

Frisancho, A. R. (1993). *Human adaptation and accommodation*. Ann Arbor: University of Michigan Press.

Froehlich, J. W. (1970). Migration and the plasticity of physique in the Japanese-Americans of Hawaii. *American Journal of Physical Anthropology, 32*(3), 429-442.

Galloway, T., Chateau-Degat, M.-L., Egeland, G. M., & Young, T. K. (2011). Does sitting height ratio affect estimates of obesity prevalence among Canadian Inuit? results from the 2007–2008 Inuit health survey. *American Journal of Human Biology, June 16 Epub ahead of print*. doi: 10.1002/ajhb.21194

Gardner, C. A., & Webb, R. C. (1986). Cold-induced vasodilatation in isolated, perfused rat tail artery. *American Journal of Physiology - Heart and Circulatory Physiology, 251*(1), H176-H181.

Gaydos, H. F., & Dusek, E. R. (1958). Effects of Localized Hand Cooling Versus Total Body Cooling on Manual Performance. *Journal of Applied Physiology, 12*(3), 377-380.

Geist, V. (1987). Bergmann's rule is invalid. *Canadian Journal of Zoology, 65*(4), 1035-1038.

Gesta, S., Tseng, Y., & Kahn, C. (2007). Developmental Origin of Fat: Tracking Obesity to Its Source. *Cell, 131*(2), 242-256.

Gilbert, M. T. P., Bandelt, H.-J., Hofreiter, M., & Barnes, I. (2005). Assessing ancient DNA studies. *Trends in Ecology & Evolution, 20*(10), 541-544. doi: DOI: 10.1016/j.tree.2005.07.005

Gilligan, I., & Bulbeck, D. (2007). Environment and morphology in Australian Aborigines: A re-analysis of the Birdsell database. *American Journal of Physical Anthropology, 134*(1), 75-91.

Gillman, L. N., Keeling, D. J., Ross, H. A., & Wright, S. D. (2009). Latitude, elevation and the tempo of molecular evolution in mammals. *Proceedings of the Royal Society B: Biological Sciences, 276*(1671), 3353-3359. doi: 10.1098/rspb.2009.0674

Glaser, E. M., Hall, M. S., & Whittow, G. C. (1959). Habituation to heating and cooling of the same hand. *Journal of Physiology, 146*, 152-164.

Glaser, E. M., & Whittow, G. C. (1957). Retention in a warm environment of adaptation to localized cooling. *Journal of Physiology, 136*, 98-111.

Goebel, T. (1999). Pleistocene human colonization of Siberia and peopling of the Americas: An ecological approach. *Evolutionary Anthropology: Issues, News, and Reviews, 8*(6), 208-227. doi: 10.1002/(sici)1520-6505(1999)8:6<208::aid-evan2>3.0.co;2-m

Goebel, T., Waters, M. R., & O'Rourke, D. H. (2008). The Late Pleistocene Dispersal of Modern Humans in the Americas. *Science, 319*(5869), 1497-1502. doi: 10.1126/science.1153569

Gonda, E. R. I., & Katayama, K. (2006). Big feet in Polynesia: a somatometric study of the Tongans. *Anthropological Science, 114*(2), 127-131.

Granberg, P. O. (1991). Alcohol and cold. *Arctic Medical Research, 50*(Suppl 6), 43-47.

Grant, R. T. (1930). Observations on direct communications between arteries and veins in the rabbit's ear. *Heart, 15*, 281.

Grant, R. T., & Bland, E. (1931). Observations on the arterio-venous anastomoses in human skin and bird's foot with special reference to the reaction to cold. *Heart, 15*, 385-411.

Gray, R. D., Drummond, A. J., & Greenhill, S. J. (2009). Language Phylogenies Reveal Expansion Pulses and Pauses in Pacific Settlement. *Science, 323*(5913), 479-483. doi: 10.1126/science.1166858

Gray, R. D., & Jordan, F. M. (2000). Language trees support the express-train sequence of Austronesian expansion. *Nature, 405*(6790), 1052-1055.

Green, R. (2003). *The Lapita horizon and traditions - Signature for one set of oceanic migrations.* Paper presented at the Pacific archaeology : assessments and prospects : proceedings of the international conference for the 50th anniversary of the first Lapita excavation, Noumea.

Greenhill, S. J., Drummond, A. J., & Gray, R. D. (2010). How Accurate and Robust Are the Phylogenetic Estimates of Austronesian Language Relationships? *PLoS ONE, 5*(3), e9573. doi: 10.1371/journal.pone.0009573

Greenhill, S. J., & Gray, R. D. (2005). Testing population dispersal hypotheses: Pacific settlement, phylogenetic trees and Austronesian languages.

Grun, R., Brink, J. S., Spooner, N. A., Taylor, L., Stringer, C. B., Franciscus, R. G., & Murray, A. S. (1996). Direct dating of Florisbad hominid. *Nature, 382*, 500-501.

Hage, P., & Marck, J. (2002). Proto-Micronesian Kin Terms, Descent Groups, and Interisland Voyaging. *Oceanic Linguistics, 41*(1), 159-170.

Hage, P., & Marck, J. (2003). Matrilineality and the Melanesian Origin of Polynesian Y Chromosomes. *Current Anthropology, 44*, S121-S127.

Hagelberg, E. (1997). Ancient and modern mitochondrial DNA sequences and the colonization of the pacific. *Electrophoresis, 18*(9), 1529-1533.

Hagelberg, E., & Clegg, J. B. (1993). Genetic Polymorphisms in Prehistoric Pacific Islanders Determined by Analysis of Ancient Bone DNA. *Proceedings of the Royal Society of London. Series B: Biological Sciences, 252*(1334), 163-170. doi: 10.1098/rspb.1993.0061

Hale, A. R., & Burch, G. E. (1960). The Arteriovenous Anastomoses and Blood Vessels of the Human Finger. In A. M. Harvey (Ed.), *Medicine: Analytical Reviews of General Medicine, Neurology, Psychiatry, Dermatology and Pediatrics* (Vol. XXXIX). Baltimore: The Williams and Wilkins Company.

Hall, R., Roy, D., & Boling, D. (2004). Pleistocene migration routes into the Americas: Human biological adaptations and environmental constraints. *Evolutionary Anthropology: Issues, News, and Reviews, 13*(4), 132-144. doi: 10.1002/evan.20013

Hall, R. L., & Hall, D. A. (1995). Geographic variation of Native people along the Pacific Coast. *Human Biology, 67*(3), 407.

Haman, F. (2006). Shivering in the cold: from mechanisms of fuel selection to survival. *Journal of Applied Physiology, 100*(5), 1702-1708. doi: 10.1152/japplphysiol.01088.2005

Hammer, M. F., Karafet, T., Rasanayagam, A., Wood, E. T., Altheide, T. K., Jenkins, T., . . . Zegura, S. L. (1998). Out of Africa and back again: nested cladistic analysis of human Y chromosome variation. *Mol Biol Evol, 15*(4), 427-441.

Hancock, A. M., Witonsky, D. B., Alkorta-Aranburu, G., Beall, C. M., Gebremedhin, A., Sukernik, R., . . . Di Rienzo, A. (2011). Adaptations to Climate-Mediated Selective Pressures in Humans. [Article]. *PLoS Genetics, 7*(4), 1-16. doi: 10.1371/journal.pgen.1001375

Hancock, A. M., Witonsky, D. B., Gordon, A. S., Eshel, G., Pritchard, J. K., Coop, G., & Di Rienzo, A. (2008). Adaptations to Climate in Candidate Genes for Common Metabolic Disorders. *PLoS Genet, 4*(2), e32.

Hanihara, K. (1986). The Origin of the Japanese in Relation to Other Ethnic Groups in East Asia. In R. J. Pearson, G. L. Barnes & K. L. Hutterer (Eds.), *Windows on the Japanese past : studies in archaeology and prehistory* (pp. 75-83.). Ann Arbor, MI: Center for Japanese Studies, University of Michigan.

Hanna, J. M., & Brown, D. E. (1983). Human Heat Tolerance: An Anthropological Perspective. *Annual Review of Anthropology, 12*, 259-284.

Harjo, T. C., Perez, A., Lopez, V., & Wong, N. D. (2011). Prevalence of Diabetes and Cardiovascular Risk Factors Among California Native American Adults Compared to Other Ethnicities: The 2005 California Health Interview Survey *Metabolic Syndrome and Related Disorders, 9*(1), 49-54. doi: doi:10.1089/met.2010.0043

Henry, H. M. (1992). How big were early hominids? *Evolutionary Anthropology: Issues, News, and Reviews, 1*(1), 15-20.

Hertzberg, M., Mickleson, K. N. P., Serjeantson, S. W., Prior, J. F., & Trent, R. J. (1989). An Asian-specific 9-bp deletion of mitochondrial DNA is frequently found in Polynesians. *American Journal of Human Genetics, 44*(4), 504-510.

Heus, R., Daanen, H. A. M., & Havenith, G. (1995). Physiological criteria for functioning of hands in the cold : A review. *Applied Ergonomics, 26*(1), 5-13.

Hiernaux, J. (1985). A comparison of the shoulder-hip-width sexual dimorphism in sub-Saharan Africa and Europe. In J. Ghesquiere, R. D. Martin & F. Newcombe (Eds.), *Human sexual dimorphism* (pp. viii, 375 p.). Philadelphia: Taylor & Francis.

Hiernaux, J., & Froment, A. (1976). The Correlations Between Anthropobiological And Climatic Variables In Sub-Saharan Africa: Revised Estimates. *Human Biology, 48*, 757.

Hiernaux, J., Rudan, P., & Brambati, A. (1975). Climate and the weight/height relationship in sub-Saharan Africa. *Annals of Human Biology, 2*, 3-11. doi: 10.1080/03014467500000511

Hill, A. V., Gentile, B., Bonnardot, J. M., Roux, J., Weatherall, D. J., & Clegg, J. B. (1987). Polynesian origins and affinities: globin gene variants in eastern Polynesia. *Am J Hum Genet., 40*(5), 453-463.

Hill, C., Soares, P., Mormina, M., Macaulay, V., Clarke, D., Blumbach, P. B., . . . Richards, M. (2007). A Mitochondrial Stratigraphy for Island Southeast Asia. *American Journal of Human Genetics, 80*(1), 29-43.

Holliday, T. W. (1997a). Body proportions in Late Pleistocene Europe and modern human origins. *Journal of Human Evolution, 32*, 423-447.

Holliday, T. W. (1997b). Postcranial evidence of cold adaptation in European Neandertals. *American Journal of Physical Anthropology, 104*(2), 245-258. doi: 10.1002/(sici)1096-8644(199710)104:2<245::aid-ajpa10>3.0.co;2-#

Holliday, T. W. (1999). Brachial and crural indices of European Late Upper Paleolithic and Mesolithic humans. *Journal of Human Evolution, 36*(5), 549-566.

Holliday, T. W., & Ruff, C. B. (2001). Relative variation in human proximal and distal limb segment lengths. *American Journal of Physical Anthropology, 116*(1), 26-33.

Hopkins, M. (1866). *Hawaii : the past, present, and future of its island-kingdom. An historical account of the Sandwich Islands (Polynesia)* (2d ed.). London: Longmans, Green.

Hornyak, M. E., Naver, H. K., Rydenhag, B., & Wallin, B. G. (1990). Sympathetic activity influences the vascular axon reflex in the skin. *Acta Physiologica Scandinavica, 139*(1-2), 77-84. doi: 10.1111/j.1748-1716.1990.tb08899.x

Houghton, P. (1978). Polynesian mandibles. *J Anat., 127(Pt 2)*, 251–260.

Houghton, P. (1980). *The First New Zealanders*. Auckland: Hodder & Stoughton.

Houghton, P. (1990). The adaptive significance of Polynesian body form. *Annals of Human Biology, 17*(1), 19-32.

Houghton, P. (1991a). The Early Human Biology of the Pacific: Some Considerations. *Journal of the Polynesian Society, 100*, 167-196.

Houghton, P. (1991b). Selective influences and morphological variation amongst PacificHomo sapiens. *Journal of Human Evolution, 21*(1), 49-59. doi: Doi: 10.1016/0047-2484(91)90035-t

Houghton, P. (1995). Polynesian body size: an adaptation to environmental temperature? *Asia Pacific Journal of Clinical Nutrition, 4*, 354-356.

Houghton, P. (1996). *People Of The Great Ocean: Aspects of Human Biology Of The Early Pacific*. Cambridge: Cambridge University Press.

Houghton, P., Leach, B. F., & Sutton, D. G. (1975). The estimation of stature of prehistoric Polynesians in New Zealand. [Stature]. *Journal of the Polynesian Society, 84*(1), 325-336.

Howells, W. W. (1970). Anthropometric Grouping of Pacific Peoples. *Archaeology & Physical Anthropology in Oceania, 5*, 192-217.

Howells, W. W. (1979). Physical Anthropology. In J. D. Jennings (Ed.), *The Prehistory of Polynesia* (pp. 271-285). Cambridge, Mass.: Harvard University Press.

Howells, W. W. (1986). Physical Anthropology of the Prehistoric Japanese. In R. J. Pearson, G. L. Barnes & K. L. Hutterer (Eds.), *Windows on the Japanese past : studies in archaeology and prehistory* (pp. 85-99.). Ann Arbor, MI: Center for Japanese Studies, University of Michigan.

Howells, W. W., & Moss, W. L. (1933). *Anthropometry and blood types in Fiji and the Solomon Islands*. New York: American Museum of Natural History.

Hubbe, M., Hanihara, T., & Harvati, K. (2009). Climate Signatures in the Morphological Differentiation of Worldwide Modern Human Populations. *The Anatomical Record: Advances in Integrative Anatomy and Evolutionary Biology, 292*(11), 1720-1733.

Hublin, J. J. (2009). The origin of Neandertals. *Proceedings of the National Academy of Sciences, 106*(38), 16022-16027. doi: 10.1073/pnas.0904119106

Hulse, F. S. (1960). Adaptation, Selection, and Plasticity in Ongoing Human Evolution. *Human Biology, 32*(1), 63-79.

Hulse, F. S. (1964). Exogamy and heterosis. *Yearbook of Physical Anthropology, 9*, 240-257.

Hunley, K., Dunn, M., Lindström, E., Reesink, G., Terrill, A., Healy, M. E., . . . Friedlaender, J. S. (2008). Genetic and Linguistic Coevolution in Northern Island Melanesia. *PLoS Genet, 4*(10), e1000239.

Hurles, M. E., Matisoo-Smith, E., Gray, R. D., & Penny, D. (2003). Untangling Oceanic settlement: the edge of the knowable. [4/3/7]. *Trends in Ecology & Evolution, 18*(10), 531-540.

Hurles, M. E., Nicholson, J., Bosch, E., Renfrew, C., Sykes, B. C., & Jobling, M. A. (2002). Y Chromosomal Evidence for the Origins of Oceanic-Speaking Peoples. *Genetics, 160*(1), 289-303.

Hurlich, M. G., & Steegmann, A. T. (1979). Hand Immersion in Cold Water at 5°C in Sub-Arctic Algonkian Indian Males from Two Villages: A European Admixture Effect? *Human Biology, 51*(3), 255-278.

Huss-Ashmore, R. (2000). Theory in Human Biology: Evolution, Ecology, Adaptability, and Variation. In B. B. Sara Stinson, Rebecca Huss-Ashmore, Dennis O'Rourke (Ed.), *Human Biology: An Evolutionary and Biocultural Perspective*. New York: Wiley-Liss.

Huston, M. A., & Wolverton, S. (2011). Regulation of animal size by eNPP, Bergmann's rule, and related phenomena. *Ecological Monographs, 81*(3), 349-405. doi: 10.1890/10-1523.1

Huttunen, P., Hirvonen, J., & Kinnula, V. (1981). The occurrence of brown adipose tissue in outdoor workers. *European Journal of Applied Physiology and Occupational Physiology, 46*(4), 339-345. doi: 10.1007/bf00422121

Iiampietro, P. F., Goldman, R. F., Buskirk, E. R., & Bass, D. E. (1959). Response of Negro and white males to cold. *Journal of Applied Physiology, 14*, 798-800.

International Diabetes Federation. (2010). Diabetes Prevalence - Country Rankings 2010 from http://www.allcountries.org/ranks/diabetes_prevalence_country_ranks.html

Irving, L. (1957). The Usefulness of Scholander's Views on Adaptive Insulation of Animals. *Evolution, 11*(2), 257-259.

Irwin, G. (1989). Against, across and down the wind: a case for the systematic exploration of the remote pacific islands. *Journal of the Polynesian Society, 98*(2), 167-206.

Irwin, G. (1992). *The Prehistoric Exploration and Colonisation of the Pacific*. Cambridge: Cambridge University Press.

Irwin, G. (1998). The Colonisation Of the Pacific Plate: Chronological, Navigational and Social Issues. *Journal of the Polynesian Society, 107*(2), 111-144.

Irwin, G. (2008). Pacific seascapes, canoe performance, and a review of Lapita voyaging with regard to theories of migration.(Report). *Asian Perspectives: the Journal of Archaeology for Asia and the Pacific, 47*(1), 12(16).

Irwin, G. (2010). Pacific Voyaging and Settlement: Issues of Biogeography and Archaeology, Canoe Performance and Computer Simulation. In A. Anderson, J. Barrett & K. Boyle (Eds.), *The Global Origins and Development of Seafaring* (pp. 131-141). Cambridge: McDonald Institute Monograqphs.

Irwin, G., Bickle, S., & Quirke, P. (1990). Voyaging by canoe and computer: experiments in the settlement of the Pacific Ocean *Antiquity, 64*(242), 34-50.

Jackson, D. A., & Somers, K. M. (1989). Are probability estimates from the permutation model of Mantel's test stable? *Canadian Journal of Zoology, 67*(3), 766-769. doi: 10.1139/z89-108

James, F. C. (1970). Geographic Size Variation in Birds and Its Relationship to Climate. *Ecology, 51*(3), 365-390.

James, W. P. T. (2008). The fundamental drivers of the obesity epidemic. *Obesity Reviews, 9*, 6-13. doi: 10.1111/j.1467-789X.2007.00432.x

Jantz, L. M., & Jantz, R. L. (1999). Secular change in long bone length and proportion in the United States, 1800–1970. *American Journal of Physical Anthropology, 110*(1), 57-67. doi: 10.1002/(sici)1096-8644(199909)110:1<57::aid-ajpa5>3.0.co;2-1

Jantz, R. L., Jantz, C. A., & Marr, P. (2007). Body proportions in recent Native Americans: do they really follow ecogeographic rules? *American Journal of Physical Anthropology, 132*(S44), 136. doi: 10.1002/ajpa.20577

Jin, L., & Su, B. (2000). Natives or immigrants: modern human origin in East Asia. *Nature Reviews Genetics, 1*(2), 126-133.

Jobe, J. B., Goldman, R. F., & Beetham, W. P. J. (1985). Comparison of the hunting reaction in normals and individuals with Raynaud's disease. *Aviation, Space and Environmental Medicine, 56*(6), 568-571.

Jobling, M., Hurles, M., & Tyler-Smith, C. (Eds.). (2004). *Human evolutionary genetics : origins, peoples & disease*. New York: Garland Science.

Johnston, F. E., Ensroth, A. E., Laughlin, W. S., & Harper, A. B. (1982). Physical growth of St. Lawrence Island Eskimos: Body size, proportion, and composition. *American Journal of Physical Anthropology, 58*(4), 397-401. doi: 10.1002/ajpa.1330580407

Johnston, F. E., & Schell, L. M. (1979). Anthropometric Variation of Native American Children and Adaults. In W. S. Laughlin & A. B. Harper (Eds.), *The First Americans: Origins, affinities and adaptations* (pp. 275-291). New York: Gustav Fischer.

Jones, D. (2011). The Matrilocal Tribe. *Human Nature, 22*(1), 177-200. doi: 10.1007/s12110-011-9108-6

Jordan, F. M., Gray, R. D., Greenhill, S. J., & Mace, R. (2009). Matrilocal residence is ancestral in Austronesian societies. *Proceedings of the Royal Society B: Biological Sciences, 276*(1664), 1957-1964. doi: 10.1098/rspb.2009.0088

Jorgensen, M. E., Glumer, C., Bjerregaard, P., Gyntelberg, F., Jorgensen, T., & Borch-Johnsen, K. (2003). Obesity and central fat pattern among Greenland Inuit and a general population of Denmark (Inter99): Relationship to metabolic risk factors. *International Journal of Obesity & Related Metabolic Disorders, 27*(12), 1507-1515.

Kaiser, H. (1970). A second generation little jiffy. *Psychometrika, 35*(4), 401-415. doi: 10.1007/bf02291817

Kaiser, H. (1974). An index of factorial simplicity. *Psychometrika, 39*(1), 31-36. doi: 10.1007/bf02291575

Kaplan, B. A. (1954). Environment and Human Plasticity. *American Anthropologist, 56*(5), 780-800.

Kaspi, Y., & Schneider, T. (2011). Winter cold of eastern continental boundaries induced by warm ocean waters. *Nature, 471*(7340), 621-624.

Katayama, K. (1990). A scenario on prehistoric mongoloid dispersals into the South Pacific, with special reference to hypothetic proto-oceanic connection. *Man and Culture in Oceania, 6*, 151-159.

Katayama, K. (1996). Polynesians the hypermorphic Asiatics - A scenario on prehistoric Mongoloid dispersals into Oceania. *Anthropological Science, 104*(1), 15-30.

Katzmarzyk, P. T., & Leonard, W. R. (1998). Climatic influences on human body size and proportions: Ecological adaptations and secular trends. *American Journal of Physical Anthropology, 106*(4), 483-503.

Kayser, M., Brauer, S., Cordaux, R., Casto, A., Lao, O., Zhivotovsky, L. A., . . . Stoneking, M. (2006). Melanesian and Asian Origins of Polynesians: mtDNA and Y Chromosome Gradients Across the Pacific. *Mol Biol Evol, 23*(11), 2234-2244. doi: 10.1093/molbev/msl093

Kayser, M., Brauer, S., Weiss, G., Underhill, P., Roewer, L., Schiefenhovel, W., & Stoneking, M. (2000). Melanesian origin of Polynesian Y chromosomes. *Current Biology, 10*(20), 1237-1246.

Kayser, M., Choi, Y., van Oven, M., Mona, S., Brauer, S., Trent, R. J., . . . Stoneking, M. (2008). The Impact of the Austronesian Expansion: Evidence from mtDNA and Y Chromosome Diversity in the Admiralty Islands of Melanesia. *Mol Biol Evol, 25*(7), 1362-1374. doi: 10.1093/molbev/msn078

Kayser, M., Lao, O., Saar, K., Brauer, S., Wang, X., Nurnberg, P., . . . Stoneking, M. (2008). Genome-wide Analysis Indicates More Asian than Melanesian Ancestry of Polynesians. *The American Journal of Human Genetics, 82*(1), 194-198.

Kazuro, H. (1986). The Origin of the Japanese in Relation to Other Ethnic Groups in East Asia. In R. J. Pearson, G. L. Barnes & K. L. Hutterer (Eds.), *Windows on the Japanese past : studies in archaeology and prehistory* (pp. 75-83.). Ann Arbor, MI: Center for Japanese Studies, University of Michigan.

Kean, M. R., & Houghton, P. (1990). Polynesian face and dentition: Functional perspective. *American Journal of Physical Anthropology, 82*(3), 361-369.

Keatinge, W. R. (1961). The effect of repeated daily exposure to cold and of improved physical fitness on the metabolic and vascular response to cold air. *Journal of Physiology, 157*, 209-220.

Keatinge, W. R. (1970). Direct effect of temperature on blood vessels: their role in vasodilation. In J. D. Hardy, A. P. Gagge & J. A. J. Stolwijk (Eds.), *Physiological and behavioral temperature regulation*. Springfield, Ill.,: Thomas.

Keatinge, W. R., & Harman, M. C. (1980). *Local mechanisms controlling blood vessels*. London ; New York: Academic Press.

Kelly, C., & Martin. (1966). *La Austrialia del espiritu santo : the journal of Fray Martin de Munilla and other documents relating to the voyage of Pedro Fernandez de Quiros to the South Sea [1605-1606] and the Franciscan Missionary Plan (1617-1627)*. Cambridge: Hakluyt Society at the University Press.

Khan, F., Spence, V. A., & Belch, J. J. (1992). Cutaneous vascular responses and thermoregulation in relation to age. *Clin. Sci., 82*(5), 521-528.

Kimura, R., Ohashi, J., Matsumura, Y., Nakazawa, M., Inaoka, T., Ohtsuka, R., . . . Tokunaga, K. (2008). Gene Flow and Natural Selection in Oceanic Human Populations Inferred from Genome-Wide SNP Typing. *Molecular Biology and Evolution, 25*(8), 1750-1761. doi: 10.1093/molbev/msn128

Kinnear, P. R., & Gray, C. D. (2009). *SPSS 16 made simple*. Hove England ; New York: Psychology Press.

Kirch, P. V. (1997). *The Lapita Peoples*. Oxford: Blackwell.

Kirch, P. V. (2000). *On the Road of the Winds*. Los Angeles: University of California.

Kirch, P. V. (2010). Peopling of the Pacific: A Holistic Anthropological Perspective. *Annual Review of Anthropology, 39*(1), 131-148. doi: doi:10.1146/annurev.anthro.012809.104936

Kirk, R. E. (1996). Practical Significance: A Concept Whose Time Has Come. *Educational and Psychological Measurement, 56*(5), 746-759. doi: 10.1177/0013164496056005002

Kivisild, T., Rootsi, S., Metspalu, M., Mastana, S., Kaldma, K., Parik, J., . . . Villems, R. (2003). The Genetic Heritage of the Earliest Settlers Persists Both in Indian Tribal and Caste Populations. *The American Journal of Human Genetics, 72*(2), 313-332. doi: Doi: 10.1086/346068

Knowler, W. C., Pettitt, D. J., Saad, M. F., & Bennett, P. H. (1990). Diabetes mellitus in the pima indians: Incidence, risk factors and pathogenesis. *Diabetes/Metabolism Reviews, 6*(1), 1-27. doi: 10.1002/dmr.5610060101

Kolman, C. J., Sambuughin, N., & Bermingham, E. (1996). Mitochondrial DNA Analysis of Mongolian Populations and Implications for the Origin of New World Founders. *Genetics, 142*(4), 1321-1334.

Kong, Q.-P., Sun, C., Wang, H.-W., Zhao, M., Wang, W.-Z., Zhong, L., . . . Zhang, Y.-P. (2011). Large-Scale mtDNA Screening Reveals a Surprising Matrilineal Complexity in East Asia and Its Implications to the Peopling of the Region. *Molecular Biology and Evolution, 28*(1), 513-522. doi: 10.1093/molbev/msq219

Kreh, A., Anton, F., Gilly, H., & Handwerker, H. O. (1984). Vascular reactions correlated with pain due to cold. *Experimental Neurology, 85*(3), 533-546. doi: Doi: 10.1016/0014-4886(84)90029-3

Krog, J., Folkow, B., Fox, R. H., & Andersen, K. L. (1960). Hand circulation in the cold of Lapps and North Norwegian fishermen. *J Appl Physiol, 15*, 654-658.

Lahr, M. M., & Foley, R. A. (1998). Towards a theory of modern human origins: Geography, demography, and diversity in recent human evolution. *American Journal of Physical Anthropology, 107*(S27), 137-176.

Lansing, J. S., Cox, M. P., de Vet, T. A., Downey, S. S., Hallmark, B., & Sudoyo, H. (2011). An ongoing Austronesian expansion in Island Southeast Asia. *Journal of Anthropological Archaeology, 30*(3), 262-272. doi: 10.1016/j.jaa.2011.06.004

Larson, G., Cucchi, T., Fujita, M., Matisoo-Smith, E., Robins, J., Anderson, A., . . . Dobney, K. (2007). Phylogeny and ancient DNA of Sus provides insights into neolithic expansion in Island Southeast Asia and Oceania. *Proceedings of the National Academy of Sciences, 104*(12), 4834-4839. doi: 10.1073/pnas.0607753104

Leach, W. N. (2006). *Alaskan Eskimo and Polynesian island population skeletal anatomy: the "Pacific paradox" revisited through surface area to body mass comparisons.* Master of Arts, University of Montana, Missoula.

LeBlanc, J. (1975). *Man in the cold*. Springfield, Ill.: Thomas.

LeBlanc, J., Hildes, J. A., & Heroux, O. (1960). Tolerance of Gaspe fishermen to cold water. *J Appl Physiol, 15*(6), 1031-1034.

Lee, M.-J., Popkin, B. M., & Kim, S. (2002). The unique aspects of the nutrition transition in South Korea: the retention of healthful elements in their traditional diet. *Public Health Nutrition, 5*(1A), 197-203.

Levi-Strauss, C. (1987). *Anthropology and myth : lectures, 1951-1982*. Oxford: Blackwell.

Lewis, T. (1930). Observations upon the reactions of the vessels of the human skin to cold. *Heart, 15*, 177-208.

Lin, M., Chu, C. C., Lee, H. L., Chang, S. L., Ohashi, J., Tokunaga, K., . . . Juji, T. (2000). Heterogeneity of Taiwan's indigenous population: possible relation to prehistoric Mongoloid dispersals. *Tissue Antigens, 55*(1), 1-9. doi: doi:10.1034/j.1399-0039.2000.550101.x

Little, M. A., Brooke, T. R., Mazess, R. B., & Baker, P. T. (1971). Population Differences and Developmental Changes in Extremity Temperature Responses to Cold Among Andean Indians. *Human Biology, 43*(1), 70-91.

Liu, Y.-P., Wu, G.-S., Yao, Y.-G., Miao, Y.-W., Luikart, G., Baig, M., . . . Zhang, Y.-P. (2006). Multiple maternal origins of chickens: Out of the Asian jungles. *Molecular Phylogenetics and Evolution, 38*(1), 12-19. doi: DOI: 10.1016/j.ympev.2005.09.014

Livingstone, S. D. (1976). Changes in cold-induced vasodilation during Arctic exercises. *J Appl Physiol, 40*(3), 455-457.

Livingstone, S. D., Romet, T., Keefe, A. A., & Nolan, R. W. (1996). Changes in cold tolerance due to a 14-day stay in the Canadian Arctic. *International Journal of Biometeorology, 39*(4), 182-186.

Livshits, G., Roset, A., Yakovenko, K., Trofimov, S., & Kobyliansky, E. (2002). Genetics of human body size and shape: body proportions and indices. [Article]. *Annals of Human Biology, 29*(3), 271-289. doi: 10.1080/03014460110085322

Lockhart, J. M., Kiess, H. O., & Clegg, T. J. (1975). Effect of rate and level of lowered finger surface temperature on manual performance. *Journal of Applied Psychology, 60*(1), 106-113.

Lorenz, J. G., & Smith, D. G. (1994). Distribution of the 9-bp mitochondrial DNA region V deletion among North American Indians. *Human Biology, v66*(n5), p777(712).

Lum, J. K., & Cann, R. L. (2000). mtDNA lineage analyses: Origins and migrations of Micronesians and Polynesians. *American Journal of Physical Anthropology, 113*(2), 151-168.

Lum, J. K., Jorde, L. B., & Schiefenhovel, W. (2002). Affinities among Melanesians, Micronesians, and Polynesians: a neutral, biparental genetic perspective.(Statistical Data Included). *Human Biology, 74*(3), 413(418).

Lum, J. K., McIntyre, J. K., Greger, D. L., Huffman, K. W., & Vilar, M. G. (2006). Recent Southeast Asian domestication and Lapita dispersal of sacred male pseudohermaphroditic "tuskers" and hairless pigs of Vanuatu. *Proceedings of the National Academy of Sciences, 103*(46), 17190-17195. doi: 10.1073/pnas.0608220103

Lund-Larsen, K., Wika, M., & Krog, J. (1970). Circulatory Responses of the Hand of Greenlanders to Local Cold Stimulation. *Arctic Anthropology, 7*(1), 21-25.

Maca-Meyer, N., Gonzalez, A., Larruga, J., Flores, C., & Cabrera, V. (2001). Major genomic mitochondrial lineages delineate early human expansions. *BMC Genetics, 2*(1), 13.

Macaulay, V., Hill, C., Achilli, A., Rengo, C., Clarke, D., Meehan, W., . . . Richards, M. (2005). Single, Rapid Coastal Settlement of Asia Revealed by Analysis of Complete Mitochondrial Genomes. *Science, 308*(5724), 1034-1036. doi: 10.1126/science.1109792

Mack, S. J., Bugawan, T. L., Moonsamy, P. V., Erlich, J. A., Trachtenberg, E. A., Paik, Y. K., . . . Erlich, H. A. (2000). Evolution of Pacific/Asian populations inferred from HLA class II allele frequency distributions. *Tissue Antigens, 55*(5), 383-400. doi: 10.1034/j.1399-0039.2000.550501.x

Mackworth, N. H. (1953). Finger Numbness in Very Cold Winds. *Journal of Applied Physiology, 5*(9), 533-543.

Madrigal, L., & Barbujani, G. (2007). Partitioning of Genetic Variation in Human Populations. In M. H. Crawford (Ed.), *Anthropological genetics: theory, methods and applications* (pp. 19-37.). Cambridge ; New York: Cambridge University Press.

Mantel, N. (1967). The Detection of Disease Clustering and a Generalized Regression Approach. *Cancer Research, 27*(2 Part 1), 209-220.

Maps of the World. from http://www.mapsofworld.com/

Mathew, L., Purkayastha, S. S., & Nayar, H. S. (1979). Variation in the susceptibility to cold injury in Indians. *International Journal of Biometeorology, 23*(3), 263-270.

Mathew, L., Purkayastha, S. S., Selvamurthy, W., & Malhotra, M. S. (1977). Cold induced vasodilation and peripheral blood flow under local cold stress in man at altitude. *Aviation, Space, and Environmental Medicine, 48*, 497-500.

Matisoo-Smith, E. (2009). The Commensal Model for Human Settlement of the Pacific 10 Years on—What Can We Say and Where to Now? *The Journal of Island and Coastal Archaeology, 4*(2), 151 - 163.

Matisoo-Smith, E., & Robins, J. H. (2004). Origins and dispersals of Pacific peoples: Evidence from mtDNA phylogenies of the Pacific rat. *PNAS, 101*(24), 9167-9172. doi: 10.1073/pnas.0403120101

Mayes, A. T. (2010). These bones are read: the science and politics of ancient Native America.(Essay). *The American Indian Quarterly, 34*(2), 131(126).

Mayr, E. (1942). *Systematics and the origin of species, from the viewpoint of a zoologist*. New York: Columbia University Press.

Mayr, E. (1956). Geographical Character Gradients and Climatic Adaptation. *Evolution, 10*(1), 105-108.

McBrearty, S., & Brooks, A. S. (2000). The revolution that wasn't: a new interpretation of the origin of modern human behavior. *Journal of Human Evolution, 39*(5), 453-563.

McDougall, I., Brown, F. H., & Fleagle, J. G. (2005). Stratigraphic placement and age of modern humans from Kibish, Ethiopia. *Nature, 433*(7027), 733-736.

McGarvey, S. T. (1994). The thrifty gene concept and adiposity studies in biological anthropology. *Journal of the Polynesian Society, 103*, 29-42.

McGarvey, S. T. (1995). Thrifty genotype concepts and health in modernising Samoans. *Asia Pacific Journal of Clinical Nutrition, 4*, 351-353.

McHenry, H. M. (1994). Behavioral ecological implications of early hominid body size. *Journal of Human Evolution, 27*(1-3), 77-87.

McHenry, H. M., & Berger, L. R. (1998). Body proportions in Australopithecus afarensis and A. africanus and the origin of the genus Homo. *Journal of Human Evolution, 35*(1), 1-22.

McHenry, H. M., & Coffing, K. (2000). Australopithecus to Homo: Transformations in Body and Mind. *Annual Review of Anthropology, 29*, 125-146.

McLenaghen, D. (2012). Did Ancient Drifters 'Discover' British Columbia, from http://radiofreethinker.com/tag/polynesians/

McNab, B. (1971). On the Ecological Significance of Bergmann's Rule. *Ecology, 52*(5), 845-854.

McNab, B. (2010). Geographic and temporal correlations of mammalian size reconsidered: a resource rule. *Oecologia, 164*(1), 13-23. doi: 10.1007/s00442-010-1621-5

Meacham, W. (1984). On the Improbability of Austronesian Origins in South China. *Asian Perspectives, 26*(1), 89.

Meacham, W. (1995). Austronesian Origins and the Peopling of Taiwan. In P. J.-K. Li, C.-H. Tsang, Y.-K. Huang, D.-A. Ho & C.-Y. Tseng (Eds.), *Austronesian Studies Relating To Taiwan* (pp. 227-253). Taipei: Instuitute of History and Philology, Academia Sinica.

Meehan, J. P. (1955a). Body Heat Production and Surface Temperatures in Response to a Cold Stimulus. *J Appl Physiol, 7*(5), 537-541.

Meehan, J. P. (1955b). Individual and racial variations in vascular response to cold stimulus. *Military Medicine, 116*, 330-334.

Meiri, S. (2011). Bergmann's Rule – what's in a name? *Global Ecology and Biogeography, 20*(1), 203-207. doi: 10.1111/j.1466-8238.2010.00577.x

Meiri, S., & Dayan, T. (2003). On the validity of Bergmann's rule. *Journal of Biogeography, 30*(3), 331-351. doi: 10.1046/j.1365-2699.2003.00837.x

Melton, T., Peterson, R., Redd, A. J., Saha, N., Sofro, A. S. M., Martinson, J., & Stoneking', M. (1995). Polynesian Genetic Affinities with Southeast Asian Populations as Identified by mtDNA Analysis. *American Journal of Human Genetics, 57*, 403-414.

Metspalu, M., Kivisild, T., Bandelt, H.-J., Richards, M., & Villems, R. (2006). The Pioneer Settlement of Modern Humans in Asia. In H.-J. Bandelt, V. Macaulay & M. Richards (Eds.), *Human mitochondrial DNA and the evolution of homo sapiens* (pp. 188-191.). Berlin ; New York: Springer.

Miller, L. K., & Irving, L. (1962). Local reactions to air cooling in an Eskimo population. *Journal of Applied Physiology, 17*(3), 449-455.

Mirabal, S., Herrera, K. J., Gayden, T., Regueiro, M., Underhill, P. A., Garcia-Bertrand, R. L., & Herrera, R. J. (2012). Increased Y-chromosome resolution of haplogroup O suggests genetic ties between the Ami aborigines of Taiwan and the Polynesian Islands of Samoa and Tonga. *Gene, 492*(2), 339-348. doi: 10.1016/j.gene.2011.10.042

Molnar, S. (2002). *Human Variation: Races, Types and Ethnic Groups*. Upper Saddle River, New Jersey: Prentice Hall.

Moodley, Y., Linz, B., Yamaoka, Y., Windsor, H. M., Breurec, S., Wu, J.-Y., . . . Achtman, M. (2009). The Peopling of the Pacific from a Bacterial Perspective. *Science, 323*(5913), 527-530. doi: 10.1126/science.1166083

Moran, E. (2008). *Human Adaptability: An introduction to ecological anthropology*. Boulder, Colorado: Westview Press.

Myles, S., Hradetzky, E., Engelken, J., Lao, O., Nurnberg, P., Trent, R. J., . . . Stoneking, M. (2007). Identification of a candidate genetic variant for the high prevalence of type II diabetes in Polynesians. *Eur J Hum Genet, 15*(5), 584-589.

Myles, S., Lea, R., Ohashi, J., Chambers, G., Weiss, J., Hardouin, E., . . . Stoneking, M. (2011). Testing the thrifty gene hypothesis: the Gly482Ser variant in PPARGC1A is associated with BMI in Tongans. *BMC Medical Genetics, 12*(1), 10.

National Heart and Lung Institute. (2012) Retrieved 3 April, 2012, from http://www.nhlbisupport.com/bmi/

Neel, J. V. (1962). Diabetes mellitus: a 'thrifty' genotype rendered detrimental by 'progress'. *American Journal of Human Genetics, 14*(4), 353-362.

Nei, M., & Roychoudhury, A. K. (1993). Evolutionary relationships of human populations on a global scale. *Molecular Biology and Evolution, 10*(5), 927-943.

Nelms, J. D., & Soper, D. J. G. (1962). Cold vasodilation and cold acclimatization in the hands of British fish filleters. *J Appl Physiol, 17*(3), 444-448.

Nelson, T. L., Vogler, G. P., Pedersen, N. L., Hong, Y., & Miles, T. P. (2003). Genetic and environmental influences on body fat distribution, fasting insulin levels and CVD: are the influences shared? . *Twin Research and Human Genetics 3*(1), 43-50.

Newman, M. T. (1953). The Application of Ecological Rules to the Racial Anthropology of the Aboriginal New World. *American Anthropologist, 55*(3), 311-327.

Newman, M. T. (1956). Adaptation of Man to Cold Climates. *Evolution, 10*(1), 101-105.

Newman, M. T. (1960). Adaptations in the Physique of American Aborigines to Nutritional Factors. *Human Biology, 32*, 288.

Newman, M. T. (1967). A comparison of Negro and White responses in a 5ºC water bath (Abst). *American Journal of Physical Anthropology, 27*, 249.

Newman, R. W. (1969). Cold acclimation in Negro Americans. *J Appl Physiol, 27*(3), 316-319.

Newman, R. W. (1970). Why Man is such a Sweaty and Thirsty Naked Animal: A Speculative Review. *Human Biology, 42*, 12.

Newman, R. W., & Munro, E. H. (1955). The relation of climate and body size in U. S. males. *American Journal of Physical Anthropology, 13*(1), 1-17.

Norgan, N. G. (1998). Body-proportion differences. In S. J. Ulijaszek, F. E. Johnston & M. A. Preece (Eds.), *Cambridge Encyclopedia of Human Growth and Development*. Cambridge: Cambridge University Press.

Normile, D. (2009). SNP Study Supports Southern Migration Route to Asia. *Science, 326*(5959), 1470. doi: 10.1126/science.326.5959.1470

O'Brien, C. (2005). Reproducibility of the cold-induced vasodilation response in the human finger. *J Appl Physiol, 98*(4), 1334-1340. doi: 10.1152/japplphysiol.00859.2004

Ohashi, J., Naka, I., Tokunaga, K., Inaoka, T., Ataka, Y., Nakazawa, M., . . . Ohtsuka, R. (2006). Brief communication: Mitochondrial DNA variation suggests extensive gene flow from Polynesian ancestors to indigenous Melanesians in the northwestern Bismarck Archipelago. *American Journal of Physical Anthropology, 130*(4), 551-556.

Oliver, D. L. (1974). *Ancient Tahitian society*. Honolulu: University Press of Hawaii.

Ollivier, I., & Spencer, J. (1985). *Extracts from journals relating to the visit to New Zealand in May-July 1772 of the French ships Mascarin and Marquis de Castries under the command of M.-J. Marion du Fresne*. Wellington, N.Z.: Alexander Turnbull Library Endowment Trust : Indosuez New Zealand Ltd.

Omoto, K. (1971-72). Polymorphisms and Genetic affinities of the Ainu of Hokkaido. *Human biology in Oceania, 1*, 278-288.

Oota, H., Settheetham-Ishida, W., Tiwawech, D., Ishida, T., & Stoneking, M. (2001). Human mtDNA and Y-chromosome variation is correlated with matrilocal versus patrilocal residence. *Nat Genet, 29*(1), 20-21.

Oppenheimer, S. (2009). The great arc of dispersal of modern humans: Africa to Australia. *Quaternary International, 202*(1-2), 2-13.

Oppenheimer, S. (2012). Out-of-Africa, the peopling of continents and islands: tracing uniparental gene trees across the map. *Philosophical Transactions of the Royal Society B: Biological Sciences, 367*(1590), 770-784. doi: 10.1098/rstb.2011.0306

Oppenheimer, S., & Richards, M. (2001). Polynesian origins: Slow boat to Melanesia? *Nature, 410*(6825), 166-167.

Oppenheimer, S., & Richards, M. (2002). Polynesians: Devolved Taiwanese Rice Farmers or Wallace an Maritime Traders with Fishing, Foraging and Horticultural Skills? In P. S. Bellwood & C. Renfrew (Eds.), *Examining the farming/language dispersal hypothesis* (pp. 287-297). Cambridge, UK: McDonald Institute for Archaeological Research.

Orr, K. D., & Fainer, D. C. (1952). Cold Injuries In Korea During Winter Of 1950-51. *Medicine, 31*(2), 177-220.

Pallant, J. (2011). *SPSS survival manual : a step by step guide to data analysis using SPSS* (4th ed.). Crows Nest, N.S.W.: Allen & Unwin.

Pawley, A. (2002). The Austronesian Dispersal: Languages, Technologies, and People. In P. S. Bellwood & C. Renfrew (Eds.), *Examining the farming/language dispersal hypothesis* (pp. 251-274). Cambridge, UK: McDonald Institute for Archaeological Research.

Pawley, A., & Pawley, M. (1994). Early Austronesian terms for canoe parts and seafaring. In A. Pawley & M. Ross (Eds.), *Austronesian terminologies : continuity and change* (pp. 329-361.). Canberra, ACT: Australian National University.

Pawley, A., & Ross, M. (1993). Austronesian Historical Linguistics and Culture History. *Annual Review of Anthropology, 22*(1), 425-459. doi: doi:10.1146/annurev.an.22.100193.002233

Pawson, I. G. (1986). The Morphological Characteristics of Samoan Adults. In P. T. Baker, J. M. Hanna & T. S. Baker (Eds.), *The Changing Samoans : behavior and health in transition* (pp. xii, 482 p.). New York: Oxford University Press.

Pierson, M. J., Martinez-Arias, R., Holland, B. R., Gemmell, N. J., Hurles, M. E., & Penny, D. (2006). Deciphering Past Human Population Movements in Oceania: Provably Optimal Trees of 127 mtDNA Genomes. *Mol Biol Evol, 23*(10), 1966-1975. doi: 10.1093/molbev/msl063

Pietrusewsky, M. (1996). The physical anthropology of Polynesia: A review of some cranial and skeletal studies. In R. C. Green & J. M. Davidson (Eds.), *Oceanic culture history: essays in honour of Roger Green* (pp. 343-353). Dunedin, N.Z.: New Zealand Journal of Archaeology.

Pietrusewsky, M. (2006). The initial settlement of remote Oceania: the evidence from physical anthropology. In T. Simanjuntak, I. H. E. Pojoh & M. Hisyam (Eds.), *Austronesian Diaspora and the Ethnogenesis of People in Indonesian Archipelago. Proceedings of the International Symposium.* (pp. 320-347). Jakarta, Indonesia: Indonesian Institute of Sciences, LIPI Press.

Pigafetta, A., & Skelton, R. A. (1994). *Magellan's voyage : a narrative account of the first circumnavigation*. New York: Dover Publications.

Pollock, N. J. (1995). Cultural elaborations of obesity - fattening practices in Pacific societies. *Asia Pacific Journal of Clinical Nutrition, 4,* 357-360.

Pope, K. O., & Terrell, J. E. (2008). Environmental setting of human migrations in the circum-Pacific region. *Journal of Biogeography, 35*(1), 1-21. doi: 10.1111/j.1365-2699.2007.01797.x

Porter, A. M. W. (1999). Modern human, early modern human and Neanderthal limb proportions. *International Journal of Osteoarchaeology, 9*(1), 54-67.

Purkayastha, S. S., Selvamurthy, W., & Ilavazhagan, G. (1992). Peripheral Vascular Response to Local Cold Stress of Tropical Men during Sojourn in the Arctic Cold Region. *Japanese Journal of Physiology, 42,* 877-889.

Queirós, P. F. d., Markham, C. R., Soulsby, B. H., Belmonte y Bermúdez, L. d., Gonzalez de Leza, G., Torquemada, J. d., . . . Arias, J. L. (1904). *The voyages of Pedro Fernandez de Quiros, 1595 to 1606*. London: Printed for the Hakluyt Society.

Razafindrazaka, H., Ricaut, F.-X., Cox, M. P., Mormina, M., Dugoujon, J.-M., Randriamarolaza, L. P., . . . Crubezy, E. (2009). Complete mitochondrial DNA sequences provide new insights into the Polynesian motif and the peopling of Madagascar. *Eur J Hum Genet.*

Reading, J. E., Roberts, D. E., & Prusaczyk, W. K. (1997). Gender differences in finger temperatures during cold air exercises *NHRC Publication 97-37*. San Diego: Naval Health Research Centre Publication 97-37.

Redd, A. J., Takezaki, N., Sherry, S. T., McGarvey, S. T., Sofro, A. S., & Stoneking, M. (1995). Evolutionary history of the COII/tRNALys intergenic 9 base pair deletion in human mitochondrial DNAs from the Pacific. *Mol Biol Evol, 12*(4), 604-615.

Regueiro, M., Mirabal, S., Lacau, H., Caeiro, J., Garcia-Bertrand, R., & Herrera, R. (2008). Austronesian genetic signature in East African Madagascar and Polynesia. *Journal of Human Genetics, 53*(2), 106-120. doi: 10.1007/s10038-007-0224-4

Reich, D., Green, R. E., Kircher, M., Krause, J., Patterson, N., Durand, E. Y., . . . Paabo, S. (2010). Genetic history of an archaic hominin group from Denisova Cave in Siberia. *Nature, 468*(7327), 1053-1060.

Reich, D., Patterson, N., Kircher, M., Delfin, F., Nandineni, Madhusudan R., Pugach, I., . . . Stoneking, M. (2011). Denisova Admixture and the First Modern Human Dispersals into Southeast Asia and Oceania. *The American Journal of Human Genetics, 89*(4), 516-528. doi: 10.1016/j.ajhg.2011.09.005

Rennie, D. W., & Adams, T. (1957). Comparative Thermoregulatory Responses of Negroes and White Persons to Acute Cold Stress. *J Appl Physiol, 11*(2), 201-204.

Rensch, B. (1938). Some problems of geographical variation and species formation. *Proceedings of the Linnean Society, London, 150*, 275-285.

Richards, M., Bandelt, H.-J., Kivisild, T., & Oppenheimer, S. (2006). A model for the dispersal of modern humans out of Africa. In H.-J. Bandelt, V. Macaulay & M. Richards (Eds.), *Human mitochondrial DNA and the evolution of Homo sapiens*. Berlin: Springer.

Richards, M., Oppenheimer, S., & Sykes, B. (1998). mtDNA suggests Polynesian origins in Eastern Indonesia. *Am J Hum Genet., 63*(4), 1234-1236.

Roberts, D. F. (1953). Body weight, race and climate. *American Journal of Physical Anthropology, 11*(4), 533-558.

Roberts, D. F. (1978). *Climate and Human Variability* (2nd ed.). Menlo Park: Cummings Publishing Company, Inc.

Roberts, D. F. (1981). Selection and Body Size. In N. Kretchmer & D. N. Walcher (Eds.), *Food, nutrition, and evolution : food as an environmental factor in the genesis of human variability* (pp. 121-132). New York: Masson Pub. USA.

Roberts, D. F., & Kahlon, D. P. S. (1976). Environmental correlations of skin colour. *Annals of Human Biology, 3*, 11-22.

Roddie, I. C. (2011). *Circulation to Skin and Adipose Tissue*: John Wiley & Sons, Inc.

Roggeveen, J., & Sharp, A. (1970). *The journal of Jacob Roggeveen*. Oxford,: Clarendon P.

Rolett, B. V., Jiao, T., & Lin, G. (2002). Early seafaring in the Taiwan Strait and the search for Austronesian origins. *Journal of Early Modern History, 4*(1), 307-319.

Rolett, B. V., Wei-chun, C., & Sinton, J. M. (2000). Taiwan, Neolithic seafaring and Austronesian origins. *Antiquity, 74*, 54-61.

Ruff, C. B. (1991). Climate and body shape in hominid evolution. *Journal of Human Evolution, 21*(2), 81-105.

Ruff, C. B. (1993). Climatic adaptation and hominid evolution: The thermoregulatory imperative. *Evolutionary Anthropology, 2*, 53-60.

Ruff, C. B. (1994). Morphological adaptation to climate in modern and fossil hominids. *American Journal of Physical Anthropology, 37*(S19), 65-107.

Ruff, C. B. (2002). Variation in Human Body Size and Shape. *Annual Review of Anthropology, 31*(1), 211-232. doi: doi:10.1146/annurev.anthro.31.040402.085407

Ruff, C. B., & Walker, A. (1993). Body size and body shape. In A. Walker & R. E. Leakey (Eds.), *The Nariokotome Homo erectus skeleton* (pp. 234-265). Cambridge, Mass.: Harvard University Press.

Rush, E. C., Freitas, I., & Plank, L. D. (2009). Body size, body composition and fat distribution: comparative analysis of European, Maori, Pacific Island and Asian Indian adults. *British Journal of Nutrition, 102*, 632-641.

Sanchez-Mazas, A., Di, D., & Riccio, M. (2011). A Genetic Focus on the Peopling History of East Asia: Critical Views. *Rice, 4*(3), 159-169. doi: 10.1007/s12284-011-9066-y

Sawada, S.-I. (1996). Cold-Induced Vasodilation of Finger Skin Blood Vessels in Older Men Observed by Using a Modified Local Cold Tolerance Test. *Industrial Health, 34,* 51-56.

Scheinfeldt, L., Friedlaender, F., Friedlaender, J., Latham, K., Koki, G., Karafet, T., . . . Lorenz, J. (2006). Unexpected NRY Chromosome Variation in Northern Island Melanesia. *Mol Biol Evol, 23*(8), 1628-1641. doi: 10.1093/molbev/msl028

Schell, L. M. (1995). Human biological adaptability with special emphasis on plasticity: history development and problems for the future. In C. G. N. Mascie-Taylor & B. Bogin (Eds.), *Human variability and plasticity* (pp. 213-237). Cambridge Cambridge University Press.

Schmidt-Nielsen, K. (1983). *Animal physiology : adaptation and environment* (3rd ed.). Cambridge [Cambridgeshire] ; New York: Cambridge University Press.

Scholander, P. F. (1955). Evolution of Climatic Adaptation in Homeotherms. *Evolution, 9*(1), 15-26.

Scholander, P. F. (1956). Climatic Rules. *Evolution, 10*(3), 339-340.

Schuman, L. M. (1953). Epidemiology of frostbite, Korea, 1951-1952 *Cold Injury - Korea, 1951-1952* (Vol. Report 113, pp. 205-568): U.S. Army Medical Research Laboratory, Fort Knox, Ky.

Schurr, T. G., & Wallace, D. C. (2002). Mitochondrial DNA diversity in Southeast Asian populations. *Human Biology, 74*(3), 431(422).

Seager, R., Battisti, D. S., Yin, J., Gordon, N., Naik, N., Clement, A. C., & Cane, M. A. (2002). Is the Gulf Stream responsible for Europe's mild winters? *Quarterly Journal of the Royal Meteorological Society, 128*(586), 2563-2586. doi: 10.1256/qj.01.128

Sendowski, I., Savourey, G., Besnard, Y., & Bittel, J. (1997). Cold induced vasodilatation and cardiovascular responses in humans during cold water immersion of various upper limb areas. *European Journal of Applied Physiology and Occupational Physiology, 75*(6), 471-477.

Serjeantson, S. W., & Hill, A. V. S. (1989). The Colonization of the Pacific: the genetic evidence. In A. V. S. Hill & S. W. Serjeantson (Eds.), *The Colonization of the Pacific : a genetic trail* (pp. ix, 298 p.). Oxford & New York: Clarendon Press,Oxford University Press.

Sewerin, B., Cuza, F. J., Szmulewicz, M. N., Rowold, D. J., Bertrand-Garcia, R. L., & Herrera, R. J. (2002). On the genetic uniqueness of the Ami aborigines of Formosa. *American Journal of Physical Anthropology, 119*(3), 240-248.

Shapiro, H. L., Beaglehole, E., & Beaglehole, P. (1942). *The anthropometry of Pukapuka*. New York: The American Museum of Natural History.

Shapiro, H. L., & Buck, P. H. (1936). *The physical characters of the Cook Islanders*. Honolulu, Hawaii: The Museum.

Shapiro, H. L., Handy, E. S. C., & Handy, W. (1930). *The physical characters of the Society Islanders*. Honolulu, Hawaiik: Bernice P. Bishop Museum.

Sharp, A. (1968). *The voyages of Abel Janszoon Tasman*. London,: Clarendon P.

Shea, J. J. (2003). Neandertals, competition, and the origin of modern human behavior in the Levant. *Evolutionary Anthropology: Issues, News, and Reviews, 12*(4), 173-187.

Shen, G., Gao, X., Gao, B., & Granger, D. E. (2009). Age of Zhoukoudian Homo erectus determined with 26Al/10Be burial dating. *Nature, 458*(7235), 198-200.

Shephard, R. J. (1991). *Body composition in biological anthropology*. Cambridge [England] ; New York: Cambridge University Press.

Sheppard, P. J. (2009). Lapita Colonization across the Near/Remote Oceania Boundary. *Current Anthropology, 52*(6), 799-840.

Shi, H., & Su, B. (2009). Origin of modern humans in East Asia: clues from the Y chromosome. *Frontiers of Biology in China, 4*(3), 241-247. doi: 10.1007/s11515-009-0010-0

Shichirō, M. (1976). The Malayo-Polynesian Component in the Japanese Language. *Journal of Japanese Studies, 2*(2), 413-436.

Silventoinen, K., Sammalisto, S., Perola, M., Boomsma, D., Cornes, B., Davis, C., . . . Kaprio, J. (2003). Heritability of Adult Body Height: A Comparative Study of Twin Cohorts in Eight Countries. *Twin Research and Human Genetics, 6*(5), 399-408.

So, J. K. (1975). Genetic, acclimatizational and anthropometric factors in hand cooling among North and South Chinese. *American Journal of Physical Anthropology, 43*(1), 31-38.

Soares, P., Rito, T., Trejaut, J., Mormina, M., Hill, C., Tinkler-Hundal, E., . . . Richards, M. B. (2011). Ancient Voyaging and Polynesian Origins. *American Journal of Human Genetics, 88*(2), 239-247.

Solheim, W. G. (1984). The Nusantao Hypothesis: The Origin and Spread of Austronesian Speakers. *Asian Perspectives, 26*(1), 77.

Solheim, W. G. (2000). Taiwan, Coastal South China And Northern Viet Nam And The Nusantao Maritime Trading Network. *Journal of East Asian Archaeology, 2*(1/2), 273-284.

Spriggs, M. (1995). The Lapita Culture And Austronesian Prehistory In Oceania. In P. S. Bellwood, J. J. Fox & D. T. Tryon (Eds.), *The Austronesians : historical and comparative perspectives* (pp. 112-133). Canberra: Australian National University.

Staron, R. S., Hikida, R. S., Hagerman, F. C., Dudley, G. A., & Murray, T. F. (1984). Human skeletal muscle fiber type adaptability to various workloads. *Journal of Histochemistry & Cytochemistry, 32*(2), 146-152. doi: 10.1177/32.2.6229571

Steegmann, A. T. (1975). Human Adaptation to Cold. In A. Damon (Ed.), *Physiological Anthropology*. New York: Oxford University Press.

Steegmann, A. T. (1977). Finger temperatures during work in natural cold: the Northern Ojibwa. *Human Biology, 49*, 349.

Steudel, K., Porter, W. P., & Sher, D. (1994). The biophysics of Bergmann's rule: a comparison of the effects of pelage and body size variation on metabolic rate *Canadian Journal of Zoology, 72*(1), 70-77.

Stini, W. A. (1969). Nutritional stress and growth: Sex difference in adaptive response. *American Journal of Physical Anthropology, 31*(3), 417-426.

Stinson, S. (2000). Growth Variation: Biological and Cultural Factors. In B. B. Sara Stinson, Rebecca Huss-Ashmore, Dennis O'Rourke (Ed.), *Human Biology: An Evolutionary and Biocultural Perspective*. New York: Wiley-Liss.

Stringer, C. B. (1984). Human evolution and biological adaptation in the Pleistocene. In R. Foley (Ed.), *Hominid evolution and community ecology*. London: Academic Press.

Stringer, C. B. (1989). Documenting the origin of modern humans. In E. Trinkaus (Ed.), *The Emergence of modern humans : biocultural adaptations in the later Pleistocene* (pp. 67-96). New York: Cambridge University Press.

Stringer, C. B. (2000). Palaeoanthropology: Coasting out of Africa. *Nature, 405*, 24-27.

Stringer, C. B. (2002). Modern human origins: progress and prospects. *Philosophical Transactions of the Royal Society of London. Series B: Biological Sciences, 357*(1420), 563-579. doi: 10.1098/rstb.2001.1057

Sullivan, L. R. (1921). *A contribution to Samoan somatology, based on the field studies of E. W. Gifford and W. C. McKern*. Honolulu: Bishop museum press.

Sullivan, L. R. (1927). Observations on Hawaiian somatology. Prepared by Clark Wissler. *Bernice, P. Bishop Museum. Memoirs ; (v. 9, no. 4: 269-342), Honolulu*.

Sullivan, L. R., Gifford, E. W., & McKern, W. C. (1922). *A contribution to Tongan somatology*. Honolulu, Hawaii: Bishop Museum Press.

Sullivan, L. R., & Handy, E. S. C. (1923). *Marquesan somatology with comparative notes on Samoa and Tonga : based on the field studies of E. S. Craighill Handy and Willowdean C. Handy*. Honolulu: Bishop Museum Press.

Tabachnick, B. G., & Fidell, L. S. (2007). *Using multivariate statistics* (5th ed.). Boston: Pearson/Allyn & Bacon.

Tabbada, K. A., Trejaut, J., Loo, J.-H., Chen, Y.-M., Lin, M., Mirazón-Lahr, M., . . . De Ungria, M. C. A. (2010). Philippine Mitochondrial DNA Diversity: A Populated Viaduct between Taiwan and Indonesia? *Molecular Biology and Evolution, 27*(1), 21-31. doi: 10.1093/molbev/msp215

Takahashi, E. (1986). Secular Trend of Female Body Shape in Japan. *Human Biology, 58*, 293.

Tanaka, M. (1971a). Experimental Studies on Human Reaction to Cold. *Bull. Tokyo Med. Dent. University, 18*, 169-177.

Tanaka, M. (1971b). Experimental studies on human reaction to cold. Differences in the vascular hunting reaction to cold according to sex, season, and environmental temperature *The bulletin of Tokyo Medical and Dental University, 18*, 269-280.

Tanaka, M., Cabrera, V. M., Gonzalez, A. M., Larruga, J. M., Takeyasu, T., Fuku, N., . . . Shimodaira, H. (2004). Mitochondrial Genome Variation in Eastern Asia and the Peopling of Japan. *Genome Res., 14*(10a), 1832-1850. doi: 10.1101/gr.2286304

Terrell, J. E., Kelly, K. M., Rainbird, P., Bellwood, P., Bradshaw, J., Burley, D. V., . . . Richards, M. (2001). Foregone Conclusions?: In Search of "Papuans" and "Austronesians"(1). *Current Anthropology, 42*(1), 97.

Terrell, J. E., & Welsch, R. L. (1997). Lapita and the temporal geography of prehistory *Antiquity, 71*(273), 548-572.

Terwilliger, J. D., & Lee, J. H. (2007). Natural Experiments in Human Gene Mapping: The Intersection of Anthropological Genetics and Genetic Epidemiology. In M. H. Crawford (Ed.), *Anthropological genetics: theory, methods and applications*. Cambridge ; New York: Cambridge University Press.

Thomson, A. S. (1854). Contribution to the Natural History of the New Zealand Race of Men; Being Observations on Their Stature, Weight, Size of Chest, and Physical Strength. *Journal of the Statistical Society of London, 17*(1), 27-33.

Thomson, A. S. (1859). *The Story of New Zealand*. London: Murray.

Tiemei, C., & Yinyun, Z. (1991). Palaeolithic Chronology and Possible Coexistence of Homo erectus and Homo sapiens in China. *World Archaeology, 23*(2), 147-154.

Tilkens, M. J., Wall-Scheffler, C., Weaver, T. D., & Steudel-Numbers, K. (2007). The effects of body proportions on thermoregulation: an experimental assessment of Allen's rule. *Journal of Human Evolution, 53*(3), 286-291.

Trejaut, J. A., Kivisild, T., Loo, J. H., Lee, C. L., He, C. L., Hsu, C. J., . . . Lin, M. (2005). Traces of Archaic Mitochondrial Lineages Persist in Austronesian-Speaking Formosan Populations. *PLoS Biology, 3*(8), 1-11.

Trejaut, J. A., Yen, J. C., Loo, J. H., & Lin, M. (2011). Modern human migrations in insular Asia according to mitochondrial DNA and non-recombining Y chromosome. *ISBT Science Series, 6*(2), 361-365. doi: 10.1111/j.1751-2824.2011.01516.x

Trinkaus, E. (1981). Neandertal limb proportions and cold adaptation. In C. B. Stringer (Ed.), *Aspects of Human Evolution* (pp. 187-224). London: Taylor & Harris.

Trinkaus, E. (1989). *The Emergence of modern humans : biocultural adaptations in the later Pleistocene*. Cambridge ; New York: Cambridge University Press.

Trinkaus, E. (2005). Early Modern Humans. *Annual Review of Anthropology, 34*(1), 207-230. doi: doi:10.1146/annurev.anthro.34.030905.154913

Tsukahara, T., Hombhanje, F., Lum, J., Hwaihwanje, I., Masta, A., Kaneko, A., & Kobayakawa, T. (2006). Austronesian origin of the 27-bp deletion of the erythrocyte band 3 gene in East Sepik, Papua New Guinea inferred from mtDNA analysis. *Journal of Human Genetics, 51*(3), 244-248.

Underhill, P. A., & Kivisild, T. (2007). Use of Y chromosome and mitochondrial DNA population structure in tracing human migrations. *Annual Review of Genetics, 41,* 539(526).

Underhill, P. A., Passarino, G., Lin, A. A., Marzuki, S., Oefner, P. J., Cavalli-Sforza, L. L., & Chambers, G. K. (2001). Maori origins, Y-chromosome haplotypes and implications for human history in the Pacific. *Human Mutation, 17*(4), 271-280.

Underhill, P. A., Shen, P., Lin, A. A., Jin, L., Passarino, G., Yang, W. H., . . . Oefner, P. J. (2000). Y chromosome sequence variation and the history of human populations. *Nature Genetics, 26*(3), 358-361.

van Dijk, N. (1991). The Hansel and Gretel Syndrome: A Critique of Houghton's Cold Adaptation Hypothesis and an Alternative Model. *New Zealand Journal of Archaeology, 13,* 65-89.

Van Marken Lichtenbelt, W., Vanhommerig, J., Smulders, N., Drossaerts, J., Kemerink, G., Bouvy, N., . . . Teule, G. (2009). Cold-Activated Brown Adipose Tissue in Healthy Men. *The New England Journal of Medicine, 360*(15), 1500.

Vanggaard, L. (1975). Physiological reactions to wet cold. *Aviation, Space, and Environmental Medicine, 46*(1), 33-36.

Vlastovsky, V. G. (1966). The Secular Trend in the Growth and Development of Children and Young Persons in the Soviet Union. *Human Biology, 38,* 219.

Wade, A. J., Marbut, M. M., & Round, J. M. (1990). Muscle fibre type and the aetiology of obesity. *Lancet, 335,* 805-808.

Wallace, D. C., & Torroni, A. (2009). American Indian Prehistory as Written in the Mitochondrial DNA: A Review. *Human Biology, 81*(5-6), 509-521. doi: 10.3378/027.081.0602

Warren, M. W. (1998). Prenatal long bone growth and proportionality in fetal abortus and stillborns (Abstract). *American Journal of Physical Anthropology, 26* (Suppl.), 226.

Weaver, T. D. (2009). The meaning of Neandertal skeletal morphology. *Proceedings of the National Academy of Sciences, 106*(38), 16028-16033. doi: 10.1073/pnas.0903864106

Weaver, T. D., & Steudel-Numbers, K. (2005). Does Climate or Mobility Explain the Differences in Body Proportions Between Neandertals and Their Upper Paleolithic Successors? *Evolutionary Anthropology: Issues, News, and Reviews, 14*(6), 218-223. doi: 10.1002/evan.20069

Webster, A. P. (1952). Caloric Requirement of Man in Cold Climates: Theoretical Considerations. *J Appl Physiol, 5*(3), 134-142.

Werner, J. (1987). Thermoregulation mechanisms: adaptations to thermal loads. In S. Samueloff & M. K. Yousef (Eds.), *Adaptive physiology to stressful environments* (pp. 17-25). Boca Raton, Fla.: CRC Press.

Weyer, E. M. (1969). *The Eskimos; their environment and folkways*. Hamden, Conn.: Archon Books.

White, J. P., Allen, J., & Specht, J. (1988). Peopling of the Pacific. *Australian Natural History, 22,* 410-416.

Whitlock, M., & Schluter, D. (2009). *The analysis of biological data*. Greenwood Village, Colo.: Roberts and Co. Publishers.

Whyte, A. L. H., Marshall, S. J., & Chambers, G. K. (2005). Human evolution in Polynesia. *Human Biology, 77*(2), 157(121).

Wilber, C. G. (1957). Physiological Regulations and the Origin of Human Types. *Human Biology, 29,* 329.

Williams, D. (2008). Power Play. *Time, New Zealand Edition*(8 September), 40-43.

Wilmshurst, J. M., Hunt, T. L., Lipo, C. P., & Anderson, A. J. (2011). High-precision radiocarbon dating shows recent and rapid initial human colonization of East

Polynesia. *Proceedings of the National Academy of Sciences, 108*(5), 1815-1820. doi: 10.1073/pnas.1015876108

Wilson, O., & Goldman, R. F. (1970). Role of air temperature and wind in the time necessary for a finger to freeze. *Journal of Applied Physiology, 29*(5), 658-664.

World Health Organisation. (2000). Obesity: preventing and managing the global epidemic, Report of a WHO Expert Committee, WHO Technical Report Series 894. Geneva: World Health Organization.

World Health Organization. (2011). Global Health Observatory, from http://www.who.int/gho/ncd/risk_factors/overweight/en/

World Meteorological Organization. (2011). World Weather Information Service, from http://www.worldweather.org/

Wu, Y. (2006). Overweight and obesity in China. *BMJ, 333*(7564), 362-363. doi: 10.1136/bmj.333.7564.362

Xu, S., Pugach, I., Stoneking, M., Kayser, M., Jin, L., & Consortium, T. H. P.-A. S. (2012). Genetic dating indicates that the Asian–Papuan admixture through Eastern Indonesia corresponds to the Austronesian expansion. *Proceedings of the National Academy of Sciences, 109*(12), 4574-4579. doi: 10.1073/pnas.1118892109

Yanagihara, R., Nerurkar, V. R., Scheirich, I., Agostini, H. T., Mgone, C. S., Cui, X. H., . . . Stoner, G. L. (2002). JC virus genotypes in the Western Pacific suggest Asian mainland relationships and virus association with early population movements. *Human Biology, 74*(3), 473-488.

Yoshimura, H., & Iida, T. (1950). Studies on the reactivity of skin vessels to extreme cold. Part 1. A point test on the resistance against frostbite *Japanese Journal of Physiology, 1*, 147-159.

Yoshimura, H., & Iida, T. (1952). Studies on the reactivity of skin vessels to extreme cold, Part II. Factors governing the individual difference of the reactivity, or the resistance against frostbite. *Japanese Journal of Physiology, 2*, 177-185.

Young, T. K. (2007). Are the circumpolar inuit becoming obese? *American Journal of Human Biology, 19*(2), 181-189.

Young, T. K., Schraer, C. D., Shubnikoff, E. V., Szathmary, E. k. J. E., & Nikitin, Y. P. (1992). Prevalence of Diagnosed Diabetes in Circumpolar Indigenous Populations. *International Journal of Epidemiology, 21*(4), 730-736. doi: 10.1093/ije/21.4.730

Zhong, H., Shi, H., Qi, X.-B., Duan, Z.-Y., Tan, P.-P., Jin, L., . . . Ma, R. Z. (2011). Extended Y Chromosome Investigation Suggests Postglacial Migrations of Modern Humans into East Asia via the Northern Route. *Molecular Biology and Evolution, 28*(1), 717-727. doi: 10.1093/molbev/msq247

Zhu, R. X., Potts, R., Xie, F., Hoffman, K. A., Deng, C. L., Shi, C. D., . . . Wu, N. Q. (2004). New evidence on the earliest human presence at high northern latitudes in northeast Asia. *Nature, 431*(7008), 559-562.

Zimmet, P., Dowse, G., & Finch, C. (1990). The epidemiology and natural history of NIDDM - lessons from the South Pacific. *Diabetes Metabolism Reviews, 6*, 91-124.

Appendices

Appendix A. Interview Sheet and Data Form

Interview Sheet and Data Recording Form

1. Identity Number ________________ Test Number_______________
2. Location _________________________
3. Date _________________________
4. Birth date _________________________ Age _____________
5. Place of Birth _________________________
6. Gender _________________________
7. History of occupations

____

____

8. Countries resided in for more than a 12 month period during lifetime

____

____

9. Ancestry of Father's Mother

Ancestry___________________________ Birthplace_________________________________

10. Ancestry of Father's Father

Ancestry___________________________ Birthplace_________________________________

11. Ancestry of Mother's Mother

Ancestry___________________________ Birthplace_________________________________

12. Ancestry of Mother's Father

Ancestry___________________________ Birthplace_________________________________

13. Ancestry of Mother Birthplace___________________________________
14. Ancestry of Father Birthplace___________________________________

15. Participant Ancestry_____________________ Group___________________

17. Any history of medical conditions: ie. vascular, respiratory, heart , diabetes, circulation

____

18. Are you on any medications

____

19. Estimated fitness level

____

20. Smoking history ____

____

21. Last time of caffeine consumption ____

22. Last time of alcohol consumption ____

23. Weight __________________________

24. Height __________________________ BMI_______________

25. Sitting height Chair__________Head__________ Trunk Height_______

26. Bi-acromial breadth __________________________ S/H Ratio_______

27. Bi-illiac breadth __________________________

28. Wrist breadth (left) __________________________

29. Finger Breadth __________________________

30. Mid Bicep circumference (left) __________________________

31. Skinfold (left) Biceps (F)______________ Triceps (B) ____________

Waist_________________

32. Blood pressure (left) ________________________________

33. Pulse ________________________________

34. Body Temperature (left ear) ______________

35. Air Temp & Weather __________________________

Appendix B. Anthropometric Measurements Statistical Tables.

Table 69. Pulse, body temperature and blood pressure of participants by EG1.

EG1		Pulse BPM	Body Temp ºC	BP systolic mmHg	BP diastolic mmHg
Other European	N	46	44	46	46
	Mean	69.96	36.348	126.63	80.41
	Std. Deviation	11.664	.4038	12.466	11.521
	Std. Error of Mean	1.720	.0609	1.838	1.699
	Minimum	37	35.5	81	61
	Maximum	92	37.2	157	130
North European	N	12	12	12	12
	Mean	70.33	36.233	122.83	78.50
	Std. Deviation	14.718	.4376	8.526	7.441
	Std. Error of Mean	4.249	.1263	2.461	2.148
	Minimum	38	35.8	107	68
	Maximum	87	37.0	133	97
Korean	N	24	23	24	24
	Mean	75.00	36.417	111.96	75.42
	Std. Deviation	11.736	.3172	15.264	8.500
	Std. Error of Mean	2.396	.0661	3.116	1.735
	Minimum	56	35.6	81	62
	Maximum	95	36.9	148	95
Chinese	N	25	25	25	25
	Mean	73.80	36.456	114.00	73.76
	Std. Deviation	13.191	.6178	15.286	14.638
	Std. Error of Mean	2.638	.1236	3.057	2.928
	Minimum	56	35.6	86	53
	Maximum	100	38.4	147	130
Indian	N	51	51	51	51
	Mean	78.00	36.218	115.08	75.59
	Std. Deviation	14.667	.4014	14.623	8.814
	Std. Error of Mean	2.054	.0562	2.048	1.234
	Minimum	52	35.5	78	56
	Maximum	111	37.5	152	95
African	N	21	20	21	21
	Mean	74.14	36.350	119.19	73.95
	Std. Deviation	16.608	.4007	11.129	11.859
	Std. Error of Mean	3.624	.0896	2.429	2.588
	Minimum	47	35.7	99	57
	Maximum	99	36.9	148	110
Polynesian	N	50	50	50	50
	Mean	75.32	36.634	122.32	79.68
	Std. Deviation	13.222	.4434	12.934	11.089
	Std. Error of Mean	1.870	.0627	1.829	1.568
	Minimum	35	35.5	97	59
	Maximum	105	37.4	153	106
Melanesian	N	25	25	25	25
	Mean	73.68	36.536	124.32	84.64
	Std. Deviation	12.325	.2343	19.784	13.943
	Std. Error of Mean	2.465	.0469	3.957	2.789
	Minimum	47	35.9	101	69
	Maximum	99	36.9	186	132
Other	N	21	21	21	21
	Mean	79.76	36.548	122.14	77.10

	Std. Deviation	11.432	.3281	13.150	10.319
	Std. Error of Mean	2.495	.0716	2.870	2.252
	Minimum	60	36.0	97	60
	Maximum	97	37.1	153	109
Total	N	275	271	275	275
	Mean	74.64	36.420	119.99	77.90
	Std. Deviation	13.424	.4326	14.752	11.412
	Std. Error of Mean	.810	.0263	.890	.688
	Minimum	35	35.5	78	53
	Maximum	111	38.4	186	132

Table 70. Weight, mid biceps diameter and BMI means for males by EG1.

EG1 Male		Weight kg	Mid Biceps diam mm	BMI
Other European	N	31	31	31
	Mean	76.784	297.71	23.839
	Std. Deviation	7.7777	29.962	2.0095
	Std. Error of Mean	1.3969	5.381	.3609
	Minimum	61.5	242	19.6
	Maximum	90.0	380	26.9
North European	N	7	7	7
	Mean	78.786	298.00	24.400
	Std. Deviation	6.3630	14.640	2.0271
	Std. Error of Mean	2.4050	5.533	.7662
	Minimum	74.0	283	22.7
	Maximum	92.5	318	28.7
Korean	N	11	11	11
	Mean	72.900	293.45	23.763
	Std. Deviation	13.0008	36.291	3.8622
	Std. Error of Mean	3.9199	10.942	1.1645
	Minimum	54.0	234	18.3
	Maximum	95.5	345	32.0
Chinese	N	13	13	13
	Mean	73.731	286.38	24.205
	Std. Deviation	11.7567	25.085	3.3385
	Std. Error of Mean	3.2607	6.957	.9259
	Minimum	56.0	253	18.8
	Maximum	91.3	323	30.4
Indian	N	31	31	31
	Mean	75.074	296.58	24.992
	Std. Deviation	13.0394	35.989	3.6909
	Std. Error of Mean	2.3420	6.464	.6629
	Minimum	47.0	217	17.5
	Maximum	112.5	359	33.3
African	N	14	14	14
	Mean	70.393	283.36	23.501
	Std. Deviation	9.8908	22.249	3.0099
	Std. Error of Mean	2.6434	5.946	.8044
	Minimum	54.6	248	19.1
	Maximum	92.2	315	28.1
Polynesian	N	19	19	19
	Mean	101.737	355.05	32.141
	Std. Deviation	17.9640	29.313	5.3592
	Std. Error of Mean	4.1212	6.725	1.2295
	Minimum	72.7	318	23.7
	Maximum	140.0	423	42.4
Melanesian	N	7	7	7
	Mean	90.229	328.00	30.343
	Std. Deviation	12.7919	40.849	6.5962
	Std. Error of Mean	4.8349	15.440	2.4931
	Minimum	72.0	293	18.5
	Maximum	107.0	401	38.4
Other	N	8	8	8
	Mean	65.325	278.62	22.070

	Std. Deviation	11.0745	37.557	2.3488
	Std. Error of Mean	3.9154	13.279	.8304
	Minimum	47.3	223	19.0
	Maximum	80.6	336	25.7
Total	N	141	141	141
	Mean	78.668	302.82	25.456
	Std. Deviation	15.5956	38.032	4.6909
	Std. Error of Mean	1.3134	3.203	.3950
	Minimum	47.0	217	17.5
	Maximum	140.0	423	42.4

Table 71. Weight, mid biceps diameter and BMI means for females by EG1.

EG1 Female		Weight kg	Mid Biceps diam mm	BMI
Other European	N	21	21	21
	Mean	65.719	277.95	22.815
	Std. Deviation	17.6791	43.444	5.1349
	Std. Error of Mean	3.8579	9.480	1.1205
	Minimum	47.3	224	18.6
	Maximum	135.0	430	42.6
North European	N	6	6	6
	Mean	63.983	277.83	22.418
	Std. Deviation	9.0134	30.420	2.2071
	Std. Error of Mean	3.6797	12.419	.9010
	Minimum	54.5	233	20.0
	Maximum	77.0	315	25.3
Korean	N	13	13	13
	Mean	51.454	247.31	20.280
	Std. Deviation	6.8045	19.981	2.1283
	Std. Error of Mean	1.8872	5.542	.5903
	Minimum	42.0	212	17.6
	Maximum	67.5	280	23.9
Chinese	N	14	14	14
	Mean	52.379	244.57	20.630
	Std. Deviation	6.9634	21.678	2.0577
	Std. Error of Mean	1.8611	5.794	.5500
	Minimum	41.0	201	17.3
	Maximum	61.0	285	24.2
Indian	N	20	20	20
	Mean	55.880	262.05	22.679
	Std. Deviation	10.1363	35.790	4.6174
	Std. Error of Mean	2.2665	8.003	1.0325
	Minimum	41.7	200	16.7
	Maximum	79.5	340	34.1
African	N	7	7	7
	Mean	59.700	264.57	22.294
	Std. Deviation	3.0687	23.909	1.8651
	Std. Error of Mean	1.1598	9.037	.7049
	Minimum	55.4	246	20.3
	Maximum	64.7	315	26.3
Polynesian	N	31	31	31
	Mean	87.774	321.90	31.348
	Std. Deviation	21.4937	45.573	7.7682
	Std. Error of Mean	3.8604	8.185	1.3952
	Minimum	57.0	263	21.4
	Maximum	139.0	416	50.9
Melanesian	N	18	18	18
	Mean	77.211	300.78	31.061
	Std. Deviation	12.2956	39.137	5.0183
	Std. Error of Mean	2.8981	9.225	1.1828
	Minimum	57.6	238	23.9
	Maximum	101.0	378	40.6
Other	N	14	14	14
	Mean	64.143	273.36	24.876

	Std. Deviation	20.4358	47.308	7.2711
	Std. Error of Mean	5.4617	12.644	1.9433
	Minimum	42.0	223	18.8
	Maximum	119.3	395	44.3
Total	N	144	144	144
	Mean	67.434	280.94	25.381
	Std. Deviation	19.8108	45.869	6.8750
	Std. Error of Mean	1.6509	3.822	.5729
	Minimum	41.0	200	16.7
	Maximum	139.0	430	50.9

Table 72. Biceps, triceps, waist skinfold and total skinfold means for males by EG1.

EG1 Male		Biceps Skinfold mm	Triceps Skinfold mm	Waist Skinfold mm	Total Skinfold mm
Other European	N	31	31	31	31
	Mean	6.16	8.52	12.84	27.52
	Std. Deviation	2.818	3.345	6.061	11.009
	Std. Error of Mean	.506	.601	1.089	1.977
	Minimum	3	4	5	14
	Maximum	16	16	30	54
North European	N	7	7	7	7
	Mean	6.43	10.86	19.14	36.43
	Std. Deviation	1.902	3.024	7.151	10.097
	Std. Error of Mean	.719	1.143	2.703	3.816
	Minimum	4	6	11	21
	Maximum	9	15	31	54
Korean	N	11	11	11	11
	Mean	5.82	9.36	17.91	33.09
	Std. Deviation	2.442	2.873	8.746	13.003
	Std. Error of Mean	.736	.866	2.637	3.921
	Minimum	3	5	7	15
	Maximum	10	15	35	53
Chinese	N	13	13	13	13
	Mean	5.69	9.31	18.15	33.15
	Std. Deviation	2.323	3.146	8.009	11.423
	Std. Error of Mean	.644	.873	2.221	3.168
	Minimum	2	4	5	11
	Maximum	9	14	37	53
Indian	N	31	31	31	31
	Mean	6.81	12.16	21.74	40.71
	Std. Deviation	2.688	5.067	7.326	13.702
	Std. Error of Mean	.483	.910	1.316	2.461
	Minimum	4	5	9	20
	Maximum	15	24	36	66
African	N	14	14	14	14
	Mean	5.93	9.79	14.50	30.21
	Std. Deviation	1.817	4.458	8.103	13.435
	Std. Error of Mean	.486	1.191	2.166	3.591
	Minimum	4	5	5	15
	Maximum	10	17	33	55
Polynesian	N	19	19	19	19
	Mean	10.16	13.42	25.63	49.21
	Std. Deviation	4.586	4.799	8.642	16.099
	Std. Error of Mean	1.052	1.101	1.983	3.693
	Minimum	5	7	8	20
	Maximum	22	22	40	78
Melanesian	N	7	7	7	7
	Mean	4.86	7.57	26.43	38.86
	Std. Deviation	2.116	3.409	10.876	15.302
	Std. Error of Mean	.800	1.288	4.111	5.784
	Minimum	3	4	14	22
	Maximum	8	14	46	68
Other	N	8	8	8	8

	Mean	6.88	10.25	15.13	32.25
	Std. Deviation	1.959	2.915	5.463	9.910
	Std. Error of Mean	.693	1.031	1.931	3.504
	Minimum	4	6	9	19
	Maximum	10	14	25	48
Total	N	141	141	141	141
	Mean	6.74	10.41	18.69	35.84
	Std. Deviation	3.125	4.338	8.748	14.469
	Std. Error of Mean	.263	.365	.737	1.219
	Minimum	2	4	5	11
	Maximum	22	24	46	78

Table 73. Biceps, triceps, waist skinfold and total skinfold means for females by EG1.

EG1 Male		Biceps Skinfold mm	Triceps Skinfold mm	Waist Skinfold mm	Total Skinfold mm
Other European	N	21	21	21	21
	Mean	10.19	15.43	15.10	40.71
	Std. Deviation	4.167	4.770	5.966	13.380
	Std. Error of Mean	.909	1.041	1.302	2.920
	Minimum	3	9	7	22
	Maximum	20	29	35	84
North European	N	6	6	6	6
	Mean	8.83	14.83	17.67	41.33
	Std. Deviation	4.215	3.869	4.761	12.437
	Std. Error of Mean	1.721	1.579	1.944	5.077
	Minimum	4	10	13	28
	Maximum	16	20	25	61
Korean	N	13	13	13	13
	Mean	7.85	14.31	15.54	37.69
	Std. Deviation	2.853	2.594	4.539	7.016
	Std. Error of Mean	.791	.720	1.259	1.946
	Minimum	4	9	9	25
	Maximum	15	18	26	51
Chinese	N	14	14	14	14
	Mean	8.00	14.71	15.57	38.29
	Std. Deviation	2.961	4.514	5.958	11.585
	Std. Error of Mean	.791	1.206	1.592	3.096
	Minimum	4	8	6	18
	Maximum	14	25	27	63
Indian	N	20	20	20	20
	Mean	11.05	16.85	20.85	48.75
	Std. Deviation	4.019	5.585	7.936	15.967
	Std. Error of Mean	.899	1.249	1.774	3.570
	Minimum	4	8	11	26
	Maximum	20	28	37	82
African	N	7	7	7	7
	Mean	10.00	18.29	19.86	48.14
	Std. Deviation	2.828	5.024	1.215	6.388
	Std. Error of Mean	1.069	1.899	.459	2.415
	Minimum	7	10	18	40
	Maximum	14	25	21	60
Polynesian	N	31	31	31	31
	Mean	14.90	20.84	28.77	64.52
	Std. Deviation	6.258	6.283	8.913	19.635
	Std. Error of Mean	1.124	1.128	1.601	3.527
	Minimum	5	11	16	33
	Maximum	30	34	49	106
Melanesian	N	18	18	18	18
	Mean	9.78	16.39	28.28	54.44
	Std. Deviation	5.755	5.521	7.775	16.762
	Std. Error of Mean	1.357	1.301	1.833	3.951
	Minimum	4	10	16	36
	Maximum	25	28	47	100
Other	N	14	14	14	14

	Mean	9.29	14.86	20.00	44.14
	Std. Deviation	3.688	4.928	7.390	14.357
	Std. Error of Mean	.986	1.317	1.975	3.837
	Minimum	6	10	10	29
	Maximum	16	25	33	71
Total	N	144	144	144	144
	Mean	10.69	16.80	21.39	48.88
	Std. Deviation	5.120	5.559	8.885	17.580
	Std. Error of Mean	.427	.463	.740	1.465
	Minimum	3	8	6	18
	Maximum	30	34	49	106

Table 74. Height, biiliac, biacromial, and SHR means for males by EG1.

EG1 Male		Height mm	Biacromial mm	Biiliac mm	SHR
Other European	N	31	31	31	31
	Mean	1793.90	410.97	294.87	.5208
	Std. Deviation	49.135	18.220	12.748	.01102
	Std. Error of Mean	8.825	3.272	2.290	.00198
	Minimum	1703	361	273	.49
	Maximum	1904	441	316	.54
North European	N	7	7	7	7
	Mean	1797.57	409.29	296.71	.5201
	Std. Deviation	38.630	18.246	11.686	.01099
	Std. Error of Mean	14.601	6.896	4.417	.00415
	Minimum	1732	372	279	.51
	Maximum	1844	428	318	.54
Korean	N	11	11	11	11
	Mean	1749.91	420.64	289.64	.5394
	Std. Deviation	49.172	17.253	16.842	.01312
	Std. Error of Mean	14.826	5.202	5.078	.00396
	Minimum	1674	396	264	.52
	Maximum	1833	448	321	.57
Chinese	N	13	13	13	13
	Mean	1744.15	406.69	287.46	.5356
	Std. Deviation	67.278	17.675	14.892	.01249
	Std. Error of Mean	18.660	4.902	4.130	.00347
	Minimum	1662	375	269	.51
	Maximum	1882	428	318	.56
Indian	N	31	31	31	31
	Mean	1731.68	409.55	282.61	.5122
	Std. Deviation	70.161	14.647	19.361	.01057
	Std. Error of Mean	12.601	2.631	3.477	.00190
	Minimum	1586	383	249	.49
	Maximum	1840	445	326	.53
African	N	14	14	14	14
	Mean	1732.29	406.36	271.07	.5087
	Std. Deviation	93.029	17.504	17.256	.01549
	Std. Error of Mean	24.863	4.678	4.612	.00414
	Minimum	1595	379	247	.49
	Maximum	1851	436	299	.53
Polynesian	N	19	19	19	19
	Mean	1779.74	434.79	320.32	.5243
	Std. Deviation	76.809	14.597	26.514	.01359
	Std. Error of Mean	17.621	3.349	6.083	.00312
	Minimum	1665	409	263	.50
	Maximum	1990	462	386	.55
Melanesian	N	7	7	7	7
	Mean	1688.57	414.14	300.43	.5224
	Std. Deviation	67.047	18.951	18.928	.01962
	Std. Error of Mean	25.341	7.163	7.154	.00742
	Minimum	1603	380	272	.50
	Maximum	1796	438	329	.55
Other	N	8	8	8	8
	Mean	1714.63	397.25	281.88	.5284

	Std. Deviation	74.241	19.470	12.484	.01714
	Std. Error of Mean	26.248	6.884	4.414	.00606
	Minimum	1566	368	256	.50
	Maximum	1795	434	294	.56
Total	N	141	141	141	141
	Mean	1754.63	413.06	291.78	.5215
	Std. Deviation	72.351	19.110	22.096	.01553
	Std. Error of Mean	6.093	1.609	1.861	.00131
	Minimum	1566	361	247	.49
	Maximum	1990	462	386	.57

Table 75. Height, biiliac, biacromial, and SHR means for females by EG1.

EG1 Male		Height mm	Biacromial mm	Biiliac mm	SHR
Other European	N	21	21	21	21
	Mean	1692.81	369.95	285.14	.5270
	Std. Deviation	69.656	19.663	17.124	.01284
	Std. Error of Mean	15.200	4.291	3.737	.00280
	Minimum	1587	326	250	.50
	Maximum	1858	408	325	.55
North European	N	6	6	6	6
	Mean	1686.50	356.67	274.67	.5237
	Std. Deviation	44.194	26.500	23.244	.00850
	Std. Error of Mean	18.042	10.819	9.489	.00347
	Minimum	1630	322	237	.51
	Maximum	1745	386	305	.53
Korean	N	13	13	13	13
	Mean	1591.23	357.69	272.85	.5415
	Std. Deviation	51.144	14.562	12.368	.01233
	Std. Error of Mean	14.185	4.039	3.430	.00342
	Minimum	1504	326	251	.52
	Maximum	1700	378	291	.56
Chinese	N	14	14	14	14
	Mean	1591.00	366.64	269.71	.5414
	Std. Deviation	50.745	17.064	16.146	.01483
	Std. Error of Mean	13.562	4.560	4.315	.00396
	Minimum	1522	329	243	.51
	Maximum	1680	389	300	.57
Indian	N	20	20	20	20
	Mean	1573.60	353.95	273.90	.5189
	Std. Deviation	69.005	15.551	10.711	.01519
	Std. Error of Mean	15.430	3.477	2.395	.00340
	Minimum	1473	324	255	.49
	Maximum	1714	381	289	.54
African	N	7	7	7	7
	Mean	1638.43	365.00	269.29	.5246
	Std. Deviation	47.261	11.633	16.570	.01817
	Std. Error of Mean	17.863	4.397	6.263	.00687
	Minimum	1570	348	238	.51
	Maximum	1685	381	286	.55
Polynesian	N	31	31	31	31
	Mean	1674.10	397.74	311.39	.5337
	Std. Deviation	47.462	16.988	19.172	.01323
	Std. Error of Mean	8.524	3.051	3.443	.00238
	Minimum	1601	361	273	.51
	Maximum	1796	432	345	.56
Melanesian	N	18	18	18	18
	Mean	1577.33	374.22	301.17	.5227
	Std. Deviation	40.782	14.862	17.158	.01543
	Std. Error of Mean	9.612	3.503	4.044	.00364
	Minimum	1501	348	274	.50
	Maximum	1659	402	336	.56
Other	N	14	14	14	14
	Mean	1602.43	376.86	283.86	.5310

	Std. Deviation	75.104	24.538	27.369	.01378
	Std. Error of Mean	20.072	6.558	7.315	.00368
	Minimum	1412	338	246	.51
	Maximum	1696	411	341	.56
Total	N	144	144	144	144
	Mean	1627.03	372.69	287.29	.5296
	Std. Deviation	73.439	22.983	23.499	.01553
	Std. Error of Mean	6.120	1.915	1.958	.00129
	Minimum	1412	322	237	.49
	Maximum	1858	432	345	.57

Table 76. Wrist and finger width and trunk height means for males by EG1.

EG1 Male		Wrist Width mm	Finger Width mm	Trunk Height mm
Other European	N	31	22	31
	Mean	57.479	15.297	934.23
	Std. Deviation	2.7571	1.1356	32.573
	Std. Error of Mean	.4952	.2421	5.850
	Minimum	52.0	13.7	846
	Maximum	62.5	18.4	984
North European	N	7	3	7
	Mean	57.190	15.247	935.29
	Std. Deviation	2.6762	1.6093	33.420
	Std. Error of Mean	1.0115	.9291	12.632
	Minimum	53.0	13.8	901
	Maximum	61.9	17.0	998
Korean	N	11	11	11
	Mean	57.232	14.315	943.64
	Std. Deviation	3.0087	1.1330	29.978
	Std. Error of Mean	.9072	.3416	9.039
	Minimum	53.0	12.5	902
	Maximum	62.4	16.1	989
Chinese	N	13	11	13
	Mean	54.494	13.654	933.69
	Std. Deviation	3.1196	.7147	25.610
	Std. Error of Mean	.8652	.2155	7.103
	Minimum	50.7	12.5	892
	Maximum	62.9	14.7	987
Indian	N	31	30	31
	Mean	54.275	13.899	884.10
	Std. Deviation	2.7784	.6830	37.624
	Std. Error of Mean	.4990	.1247	6.757
	Minimum	48.6	12.9	803
	Maximum	59.7	15.3	972
African	N	14	14	14
	Mean	56.384	14.215	880.29
	Std. Deviation	2.2455	.6440	31.067
	Std. Error of Mean	.6001	.1721	8.303
	Minimum	51.8	13.3	824
	Maximum	60.0	15.5	921
Polynesian	N	19	19	19
	Mean	61.285	15.260	932.79
	Std. Deviation	2.8217	1.0913	37.871
	Std. Error of Mean	.6473	.2504	8.688
	Minimum	57.4	13.0	883
	Maximum	68.9	17.3	1035
Melanesian	N	7	7	7
	Mean	58.620	15.726	881.57
	Std. Deviation	2.2290	.9728	28.629
	Std. Error of Mean	.8425	.3677	10.821
	Minimum	55.6	13.9	819
	Maximum	61.5	16.8	904
Other	N	8	6	8
	Mean	54.481	14.083	905.00

	Std. Deviation	2.9442	.9014	32.693
	Std. Error of Mean	1.0409	.3680	11.559
	Minimum	49.0	13.2	849
	Maximum	57.8	15.7	949
Total	N	141	123	141
	Mean	56.756	14.557	914.12
	Std. Deviation	3.5295	1.1391	41.190
	Std. Error of Mean	.2972	.1027	3.469
	Minimum	48.6	12.5	803
	Maximum	68.9	18.4	1035

Table 77, Wrist and finger width and trunk height means for females by EG1.

EG1 Female		Wrist Width mm	Finger Width mm	Trunk Height mm
Other European	N	21	14	21
	Mean	51.024	12.919	891.90
	Std. Deviation	2.9194	.7139	35.554
	Std. Error of Mean	.6371	.1908	7.759
	Minimum	47.0	11.4	841
	Maximum	57.0	14.1	966
North European	N	6	4	6
	Mean	50.682	12.522	883.33
	Std. Deviation	2.2059	.6985	14.390
	Std. Error of Mean	.9005	.3492	5.875
	Minimum	48.4	11.8	862
	Maximum	54.3	13.5	898
Korean	N	13	13	13
	Mean	47.950	12.215	861.31
	Std. Deviation	3.3284	.8347	31.920
	Std. Error of Mean	.9231	.2315	8.853
	Minimum	42.0	11.0	805
	Maximum	54.5	13.9	930
Chinese	N	14	14	14
	Mean	47.644	11.977	861.57
	Std. Deviation	3.3061	1.0630	36.735
	Std. Error of Mean	.8836	.2841	9.818
	Minimum	42.4	10.3	798
	Maximum	53.5	13.4	948
Indian	N	20	19	20
	Mean	46.744	12.209	816.25
	Std. Deviation	3.0303	.6212	36.430
	Std. Error of Mean	.6776	.1425	8.146
	Minimum	38.3	11.1	755
	Maximum	52.0	13.4	890
African	N	7	7	7
	Mean	49.427	12.761	859.29
	Std. Deviation	2.3434	.6395	27.342
	Std. Error of Mean	.8857	.2417	10.334
	Minimum	46.2	11.7	839
	Maximum	53.0	13.7	916
Polynesian	N	31	31	31
	Mean	54.962	13.832	893.32
	Std. Deviation	3.3407	.9478	28.959
	Std. Error of Mean	.6000	.1702	5.201
	Minimum	47.5	11.8	819
	Maximum	62.0	16.5	946
Melanesian	N	18	18	18
	Mean	50.955	13.353	824.78
	Std. Deviation	2.2476	.9378	34.926
	Std. Error of Mean	.5298	.2210	8.232
	Minimum	45.7	11.8	770
	Maximum	55.4	15.2	885
Other	N	14	12	14
	Mean	50.027	12.528	850.29

	Std. Deviation	2.5552	.6971	33.493
	Std. Error of Mean	.6829	.2012	8.951
	Minimum	44.0	11.3	772
	Maximum	53.6	13.8	904
Total	N	144	132	144
	Mean	50.474	12.865	861.61
	Std. Deviation	4.0119	1.0620	43.206
	Std. Error of Mean	.3343	.0924	3.601
	Minimum	38.3	10.3	755
	Maximum	62.0	16.5	966

Appendix C. CIVD Response Statistical Tables

Table 78. CIVD temperature response statistics by EG1.

EG1		T_{av} ºC	Amplitude ºC	T_{min} ºC	T_{max} ºC	$T_{pretest}$ ºC	T_{30}
Other European	N	47	47	47	47	47	47
	Mean	7.6409	3.2314	5.7290	8.9071	27.7997	7.8538
	Std. Deviation	.81612	1.20223	.56274	1.29963	3.61772	1.05687
	Std. Error of Mean	.11904	.17536	.08208	.18957	.52770	.15416
	Minimum	5.78	.54	5.04	6.06	22.68	5.69
	Maximum	9.07	5.55	7.36	11.46	36.09	10.04
North European	N	13	13	13	13	13	13
	Mean	8.1799	3.6165	5.9532	9.5696	28.0505	8.2990
	Std. Deviation	.65179	1.32003	.71888	.83252	3.85796	.91822
	Std. Error of Mean	.18077	.36611	.19938	.23090	1.07001	.25467
	Minimum	7.27	1.65	5.20	8.57	21.83	6.43
	Maximum	9.43	5.61	7.39	11.10	33.56	9.93
Korean	N	24	24	24	24	24	24
	Mean	8.7572	3.4120	6.6048	10.0169	31.5491	8.4931
	Std. Deviation	.77542	.80878	.68785	1.16939	2.64013	.80141
	Std. Error of Mean	.15828	.16509	.14041	.23870	.53892	.16359
	Minimum	7.27	2.04	5.57	7.88	26.49	7.22
	Maximum	10.49	5.52	7.98	12.80	35.42	10.77
Chinese	N	26	26	26	26	26	26
	Mean	8.1645	3.0854	6.2187	9.3041	29.8922	8.0383
	Std. Deviation	.94555	1.15441	.87013	1.39867	3.21274	.91733
	Std. Error of Mean	.18544	.22640	.17065	.27430	.63007	.17990
	Minimum	6.51	1.12	5.15	7.36	23.60	5.99
	Maximum	10.37	5.91	8.75	12.77	35.24	10.22
Indian	N	51	51	51	51	51	51
	Mean	7.8440	3.2805	5.9352	9.1163	29.0149	7.6705
	Std. Deviation	1.02476	1.53482	.56126	1.61052	3.92756	1.03853
	Std. Error of Mean	.14350	.21492	.07859	.22552	.54997	.14542
	Minimum	6.00	.79	5.16	6.25	22.19	5.58
	Maximum	10.41	7.00	7.48	12.59	35.18	10.34
African	N	20	20	20	20	20	20
	Mean	7.1343	2.8236	5.5799	8.4035	27.3283	7.5936
	Std. Deviation	.78494	1.38110	.38640	1.45055	3.55373	1.09925
	Std. Error of Mean	.17552	.30882	.08640	.32435	.79464	.24580
	Minimum	5.77	.23	5.18	5.58	22.88	5.46
	Maximum	8.66	4.82	6.85	10.60	32.64	9.52
Polynesian	N	49	49	49	49	49	49
	Mean	8.9358	3.8808	6.6417	10.5239	32.3758	8.5527
	Std. Deviation	.83316	1.60201	.58148	1.78561	2.07940	.83590
	Std. Error of Mean	.11902	.22886	.08307	.25509	.29706	.11941
	Minimum	7.19	1.63	5.56	7.57	25.77	6.95
	Maximum	10.58	8.95	8.42	15.67	35.54	10.42
Melanesian	N	23	23	23	23	23	23
	Mean	8.0324	3.2717	5.9820	9.2276	28.5507	7.8039
	Std. Deviation	.92008	1.10225	.64518	1.34832	2.92481	.87790
	Std. Error of Mean	.19185	.22983	.13453	.28114	.60986	.18305
	Minimum	6.34	1.68	5.15	7.09	22.04	6.31
	Maximum	9.73	6.03	7.80	12.24	33.72	10.31
Other	N	21	21	21	21	21	21
	Mean	8.2438	3.4888	6.1452	9.6340	29.1679	8.2522

	Std. Deviation	.91903	1.36978	.83886	1.61317	3.47312	.94865
	Std. Error of Mean	.20055	.29891	.18305	.35202	.75790	.20701
	Minimum	6.90	1.09	5.33	7.66	23.65	5.63
	Maximum	10.80	7.05	8.65	13.80	34.62	10.08
Total	N	274	274	274	274	274	274
	Mean	8.1254	3.3703	6.1067	9.4473	29.5166	8.0467
	Std. Deviation	1.01638	1.35434	.72472	1.58907	3.65636	1.00577
	Std. Error of Mean	.06140	.08182	.04378	.09600	.22089	.06076
	Minimum	5.77	.23	5.04	5.58	21.83	5.46
	Maximum	10.80	8.95	8.75	15.67	36.09	10.77

Table 79. CIVD time response and T_{index} statistics by EG1.

EG1		Onset time min	Peak time min	Time to max min	T_{index}
Other European	N	47	47	47	47
	Mean	5.3904	7.9660	13.6468	5.94
	Std. Deviation	2.32670	5.86938	7.02927	1.131
	Std. Error of Mean	.33938	.85614	1.02533	.165
	Minimum	2.50	1.55	5.00	3
	Maximum	13.35	24.30	29.40	8
North European	N	13	13	13	13
	Mean	4.8846	7.4846	12.5846	6.31
	Std. Deviation	2.17547	3.95497	4.61395	1.032
	Std. Error of Mean	.60337	1.09691	1.27968	.286
	Minimum	2.15	2.05	4.20	5
	Maximum	11.20	16.25	20.40	8
Korean	N	24	24	24	24
	Mean	3.8750	8.1479	12.2229	6.75
	Std. Deviation	2.03358	6.06032	6.77412	1.073
	Std. Error of Mean	.41510	1.23706	1.38276	.219
	Minimum	2.25	1.35	4.00	5
	Maximum	12.30	21.50	25.45	9
Chinese	N	26	26	26	26
	Mean	4.1269	6.9423	11.2231	6.15
	Std. Deviation	1.26461	5.96788	6.95497	1.008
	Std. Error of Mean	.24801	1.17040	1.36398	.198
	Minimum	2.35	1.40	4.45	4
	Maximum	7.40	23.25	29.15	8
Indian	N	51	51	51	51
	Mean	5.1913	9.2069	14.2765	5.76
	Std. Deviation	2.02515	5.83750	6.36723	1.226
	Std. Error of Mean	.28358	.81741	.89159	.172
	Minimum	3.10	1.50	5.00	3
	Maximum	13.50	23.30	29.50	8
African	N	20	20	20	20
	Mean	8.4525	10.8275	19.0400	5.05
	Std. Deviation	4.15387	4.53433	6.67130	1.146
	Std. Error of Mean	.92883	1.01391	1.49175	.256
	Minimum	3.50	3.15	7.40	3
	Maximum	17.50	18.50	29.55	7
Polynesian	N	49	49	49	49
	Mean	3.9765	8.4673	12.6235	6.96
	Std. Deviation	.88389	5.77441	6.12182	1.020
	Std. Error of Mean	.12627	.82492	.87455	.146
	Minimum	2.40	2.05	5.00	5
	Maximum	7.25	22.35	26.30	9
Melanesian	N	23	23	23	23
	Mean	5.1413	11.1304	16.5326	6.17
	Std. Deviation	1.45857	5.31586	6.33387	1.029
	Std. Error of Mean	.30413	1.10843	1.32070	.215
	Minimum	2.55	2.50	5.45	3
	Maximum	8.00	21.50	29.50	8
Other	N	21	21	21	21
	Mean	4.3810	9.7881	14.3595	6.29

	Std. Deviation	1.23050	5.55511	6.03646	.902
	Std. Error of Mean	.26852	1.21222	1.31726	.197
	Minimum	2.40	2.30	5.25	5
	Maximum	7.20	24.10	30.00	8
Total	N	274	274	274	274
	Mean	4.9491	8.7967	13.8664	6.18
	Std. Deviation	2.30091	5.68977	6.66695	1.193
	Std. Error of Mean	.13900	.34373	.40277	.072
	Minimum	2.15	1.35	4.00	3
	Maximum	17.50	24.30	30.00	9

Table 80. CIVD response means by EG1 and gender.

EG1	Gender	Tav ºC	Amplitude ºC	T_{min} ºC	T_{max} ºC	$T_{pretest}$ ºC	T_{30} ºC
Other European	Male	7.5950	3.0661	5.8233	8.7880	28.3163	7.7239
	Female	7.6977	3.4361	5.6123	9.0545	27.1600	8.0147
	Total	7.6409	3.2314	5.7290	8.9071	27.7997	7.8538
North European	Male	8.2993	3.5709	6.0360	9.6069	27.9566	8.4861
	Female	8.0407	3.6697	5.8565	9.5262	28.1600	8.0807
	Total	8.1799	3.6165	5.9532	9.5696	28.0505	8.2990
Korean	Male	8.8610	3.1764	6.8805	10.0569	31.9551	8.6729
	Female	8.6693	3.6114	6.3716	9.9831	31.2055	8.3409
	Total	8.7572	3.4120	6.6048	10.0169	31.5491	8.4931
Chinese	Male	8.4877	3.0814	6.5654	9.6468	30.8165	8.1651
	Female	7.8874	3.0888	5.9215	9.0103	29.0999	7.9297
	Total	8.1645	3.0854	6.2187	9.3041	29.8922	8.0383
Indian	Male	8.0138	3.2871	6.0867	9.2103	30.5444	7.8612
	Female	7.5807	3.2704	5.7003	8.9706	26.6443	7.3749
	Total	7.8440	3.2805	5.9352	9.1163	29.0149	7.6705
African	Male	7.1471	2.6324	5.5644	8.1968	27.2079	7.7235
	Female	7.1106	3.1787	5.6086	8.7873	27.5517	7.3523
	Total	7.1343	2.8236	5.5799	8.4035	27.3283	7.5936
Polynesian	Male	8.6519	3.3467	6.6022	9.9490	32.3730	8.3271
	Female	9.1156	4.2190	6.6667	10.8880	32.3775	8.6957
	Total	8.9358	3.8808	6.6417	10.5239	32.3758	8.5527
Melanesian	Male	8.0770	3.2991	6.0299	9.2387	28.3629	7.6127
	Female	8.0129	3.2597	5.9611	9.2227	28.6329	7.8876
	Total	8.0324	3.2717	5.9820	9.2276	28.5507	7.8039
Other	Male	7.9018	3.2531	5.9784	9.2315	27.7019	8.0945
	Female	8.4543	3.6338	6.2479	9.8817	30.0700	8.3492
	Total	8.2438	3.4888	6.1452	9.6340	29.1679	8.2522
Total	Male	8.0625	3.1751	6.1540	9.2668	29.7690	8.0147
	Female	8.1856	3.5571	6.0614	9.6201	29.2750	8.0773
	Total	8.1254	3.3703	6.1067	9.4473	29.5166	8.0467

Appendix D. Participant Birthplaces

Table 81. List of participant birthplaces

Country	N
New Zealand	77
India	46
Korea	24
China	20
Solomon Islands	12
Samoa	10
PNG	10
UK	9
Nigeria	9
South Africa	7
Germany	6
Malaysia	6
Ethiopia	6
Canada	5
Fiji	5
Vanuatu	3
USA	2
Zimbabwe	2
Spain	2
Philippines	2
Ghana	2
Australia	1
Kenya	1
Tanzania	1
Argentina	1
Czech Republic	1
Slovakia	1
Vietnam	1
Chile	1
France	1
Belarus	1
Indonesia	1
Gambia	1
Poland	1
Netherlands	1
Japan	1
Niue	1
Eritrea	1
Sudan	1
Tonga	1
Tokelau	1
Total	285