Limb proportions in South Africans: secular changes, population differences and implications for stature estimation

Submitted by:
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DECLARATION

I, Jolandie Myburgh, declare that this dissertation is my own work. It is being submitted for the degree of PhD in Anatomy at the University of Pretoria. It has not been submitted before for any other degree or examination at this or any other Institution.

Sign: ________________________

This ______ Day of ___________________, 2015

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ABSTRACT

In order to provide accurate methods for stature estimations, ancestry differences and secular changes in stature and limb proportions need to be noted. Stature and limb proportion changes in human population groups are influenced by various genetic and environmental factors. The purpose of this study was to evaluate ancestry differences and secular changes in stature and limb proportions of South African population groups and to assess how these variables differ between individuals from southern and northern hemispheres. The sample comprised of osteometric and anthropometric data from modern black and white South Africans (17 and 68 years), North American and white European (Dutch and Swiss) populations. The sample was divided into birth cohorts of 5 years or 10 years to observe secular trends. Ancestry differences and secular trends in stature and limb proportions between South African population groups were compared. Also, differences and secular trends in stature and limb proportions were compared between white North American and European groups to determine whether differences exist between the southern and northern hemisphere groups. Additionally, the differences in stature between black and white South African and North American groups were compared. It was found that white South Africans were significantly taller than their black South African counterparts. Significant positive secular trends in stature were observed in black South African males while non-significant increases were observed in white South African males and white and black South African females. The secular trends in European samples are significantly greater than those observed in white South African males. Black South African groups had greater limb and distal limb lengths than white South African groups. Proximal limb ratios increased while the distal limb ratios decreased which suggests that regression formulae to estimate stature need to be regularly updated. The upper limb ratio and arm ratios were significantly higher in white South African groups compared to white North American groups. Secular changes are constantly taking place due to a combination of various factors such as climate, nutrition. Overall, secular changes in limb proportions indicate a trend where South African groups are becoming more similar to each other.

Keywords: Stature, limb proportions, ancestry differences, secular trends, osteometric, anthropometric, stature estimation

Chapter 1: Introduction

Human variation has extensively been studied around the world. Since the early to mid-19th century, researchers have used anthropometry or, the science of measurements of the human body for this purpose (Malinowski and Wolanski, 1988). Initially, most anthropologists believed that stature and limb proportions could be used to separate individuals into distinct biological groups (Bogin, 1999). However, further research indicated that anthropometric differences and changes appear to be related to heredity and environmental influences rather than being an indication of separate biological groups.

Numerous researchers (e.g., Scammon and Calkins, 1929; Schreider, 1950; Roberts, 1978; Eveleth and Tanner, 1990; Ruff, 1994, 2002; Bogin, 1999; Holliday and Falsetti, 1999) have observed that the size and shape of the human body vary considerably across the world. Also, the human body shape is not fixed and changes are continually taking place. This ability of organisms to change its phenotype in response to environmental factors is known as plasticity. Like most mammals, humans undergo certain changes in body shape and size in order to adapt to the environment. Therefore, the variations observed in human stature and limb proportions in the present day are the result of millions of years of evolutionary adaptation to the environment (Eveleth and Tanner, 1976; Ruff, 1994, 2000).

Researchers have suggested a variety of factors, such as adaptation to climate, which may have influenced the evolution of the current human body shapes. As outlined by Allen's rule, in colder climates, shorter appendages (limbs) with increased mass-to-surface ratios are adaptive because they are more effective at preventing heat loss. Conversely, greater appendages, with increased surface area relative to mass, are more adaptive in warmer climates because they promote heat loss (Allen, 1877). Therefore, individuals will exhibit body shapes that are more similar to the continent from which their ancestors derived (Holliday and Falsetti, 1999). For example, individuals of European descent tend to have shorter appendages than individuals of African descent due to their adaptation to colder climates. However, other factors, such as nutrition and health status, may also play a role in determining the shape of the body (Ruff, 1994, 2002; Bogin, 1999).

Changes in the stature and limb proportions of human population groups have been well documented over the past two centuries (e.g., Eveleth and Tanner, 1976; Bogin, 1999; Meadows and Jantz, 1995). The changes in the human body that affect the mean shape or size of individuals in a population over time are referred to as a secular trend. A positive secular trend is a change that results in an increase in the dimensions of the body, while a negative secular trend involves the decrease of the specific structure (Tobias, 1975; Kieser, 1990; Henneberg, 1992). Secular changes in body size and height have been extensively studied and may be associated with changes in the relationships of different parts of the body and research suggests that various parts of the body may respond differently and at different rates. For example, greater lower limb is associated with improved living conditions (i.e. better nutrition and access to health care) while trunk length is negatively associated with illness (Burchard, 1926; Sheldon *et al.*, 1940; Dupertuis, 1951; Meadow and Jantz, 1995; Wadsworth *et al.,* 2002). By studying secular trends in stature and limb proportions to overall stature, the effect of not only genetics and climate, but the influence of socio-economic status (SES) (education, occupation, nutrition and health) in human populations can be assessed (Eveleth and Tanner, 1979).

Differences and secular changes in stature and limb proportions are important in forensic anthropology. Forensic anthropologists deal with the task of analysing human remains and producing accurate biological profiles to aid in the identification of unknown individuals. A well-defined relationship exists between the height of an individual and long bone length, which allows stature estimates to be made (Arbenz, 1983; Himes, 1989; Villanueva-Canadas and Castilla-Gonzalo, 1991; Meadows and Jantz, 1995, 1999). There have been numerous studies on the use of long bones to estimate stature in South Africa (e.g., Lundy, 1983; Lundy and Feldesman, 1987; Dayal *et al.*, 2008; Bidmos, 2008) and elsewhere (e.g., Duyar and Penil, 2003; Hanser *et al.*, 2005; Adams and Herrmann, 2009). However, for the most accurate stature estimations to be made, the variation in limb proportions of individuals between and within populations needs to be understood.

Various researchers (e.g., Eveleth and Tanner, 1976; Meadows and Jantz, 1995; Bogin, 1999; Cole, 2003; Federico, 2003; Komlos and Baur, 2004; Komlos and Lauderdale, 2007; Komlos, 2009; Steckel, 2009; Bogin and Varela-Silva, 2010; Staub *et al.*, 2011) have reported that a general positive secular trend exists for stature and lower limb lengths in developed countries around the world. However, poor nutrition may influence growth during childhood resulting in a lack of positive secular trends (Bogin, 1999). Shorter statures and shorter lower limb lengths have been observed in population groups of lower SES (Garn *et al.*, 1975; Bogin and MacVean, 1978, 1981, 1984; Fulwood *et al.*, 1981; Malina *et al.*, 1983; Tobias, 1985). In South Africa, negative, null and positive secular trends have been reported. Negative secular trends were observed in the stature and proximal lower limb s of black South African groups from the early 20th century (Klark, 1954; Tobias and Netscher, 1976, 1977; Price *et al.*, 1987) while a positive secular trend was observed in the statures of

Khoesan individuals (Tobias, 1990). Henneberg and van der Berg (1990) observed small increases in the statures of black and white South African males. However, these secular increases are distinctly lower than those reported in Europe, indicating influences that are specific to South Africa (Henneberg and van der Berg, 1990; Louw and Henneberg, 1997). Although a lack of significant secular trends in stature have been previously observed, there is a gap in the literature available on the possible differences in the limb proportions between groups (Smith *et al.*, 1967a,b; Tobias 1975; Smith and Steyn, 2007). Furthermore, research on limb proportions in modern human populations is often limited to human growth studies of mostly sub-adult individuals (Krogman, 1970; Hamill *et al.*, 1973; Eveleth and Tanner, 1976; Kondo and Eto, 1975; Eveleth and Tanner, 1976; Wolanski, 1979, 1995; Fulwood *et al.*, 1981; Bolzan *et al.*, 1993; Hauspie *et al.*, 1996). Therefore, research on limb proportions in adults may provide information on the final proportions obtained after completion of growth.

Studies of secular trends are faced with numerous difficulties, the most important of these is the difficulty in obtaining suitable and consistent data. Anthropometric data and osteometric data have been used to study secular changes in human shape and size. However, both these methods have drawbacks. Although osteometric data provides information on past populations, skeletal collections often have a shortage of complete remains, a lack of accurate living stature data, and/or a lack of enough individuals within each demographic age group. Furthermore, the collection of osteometric data from fleshed remains can be problematic as it involves dissection of soft tissue. Most studies on growth and secular changes have used anthropometric data (Eveleth and Tanner, 1979; Bogin, 1999). Anthropometric measurements can aid in the evaluation of human growth and development and the secular trends in modern human populations (Adams and Herrman, 2009). However, most studies are limited to sub-adults or military conscripts. By making use of anthropometric data, in combination with osteometric data, a better understanding of past and present populations can be achieved.

Studies on growth and development have played an important part of anthropology since the founding of the discipline (Bogin, 1999). Although secular changes in human shape and size is often used to evaluate human migration and the effect of environment (e.g., nutrition and socio-economic standing) on growth the changes in relationships through time also have vast implications for ergonomics, the clothing industry and medicine. Knowledge of secular changes in stature and limb proportions is necessary to insure optimum workplace design for increased productivity and safety (Gielo-Perczak, 2010). Furthermore, this knowledge is also important in medicine where arm span is used to estimate stature in patients that are unable to stand. This may result in inaccurate stature estimations which will have an impact on the dosages of medicines as well as the results of specific tests (Miller *et al.*, 2005). Lastly, in forensic anthropology, it is required to make a positive identification from skeletal remains which are either incomplete or has no DNA available. Not considering secular changes that occur in stature and limb proportions could result in inaccurate stature estimations if outdated regression formulae are used.

Therefore, the aim of this study was to evaluate ancestry differences and secular changes in the stature and limb proportions of South African populations groups and to assess how these variables differ between individuals in the southern and northern hemispheres. The objectives of this study are therefore three-fold:

1. To study the differences in stature and limb proportions as well as the differences in the limb proportions relative to overall height in two adult South African populations (individuals of African descent as representatives of people who had a long history and development in warmer regions of the world and individuals of European descent who represent a group who had a long history of development in the colder regions of the world, but who had migrated to a warmer region).
2. To assess the changes in the proportional relationships over the past century by evaluating data of individuals born after 1900, using cohorts of 10 years. This also provided valuable information on secular trends (how these proportions are changing) and may predict to some extent where it will be going in the future.
3. To compare the limb proportions and dimensions of southern hemisphere groups (individuals of European and African descent in South Africa) to northern hemisphere groups from North America (individuals of European and African decent) and Europe. This will shed light on differences and the direction of any secular trends with regard to individuals of African and European descent in South Africa.

Chapter 2: Literature Review

This literature review outlines the fundamentals of studies on stature, limb proportions and secular trends across the world. This review will also provide detail on the various factors that influence secular change and the effect these changes have on stature estimations in a forensic context.

2.1 Allometry and limb proportions

The term allometry (Greek *allos* meaning "other" and *metron* which is "measure") was first coined in 1936 by Julian Huxley and Georges Teissier (Huxley, 1932; Gayon, 2000) to refer to studies involving relative growth. Allometry is the study of size-correlated variations seen in biological specimens (Huxley, 1932). This implies that the size or growth of one part of the body, in relation to the whole of the body, may differ between individuals or populations. Allometry can be isometric where one part of the body remains unchanged while the whole changes or it can be positive or negative where one part of the body changes (increases/decreases) in relation to change in the whole body. For example, the lower limb bones to stature ratio is positively allometric if the lower limb bones increase proportionally to the increase in stature (Jantz and Jantz, 1999).

Allometry plays an important role in understanding and explaining human evolutionary biology and the changes in limb proportions (Gould, 1966). Human proportions have been a subject of interest for many centuries as can be seen in the work of Roman architect, Marcus Vitruvius Pollio (15 BC). In his works, *The Books on Architecture,* he discussed the "perfect harmony" between the different parts of the human body. The most famous example of early perceptions of human limb proportions is reflected in the well-known sketch by Leonardo da Vinci of the Vitruvian Man based on the descriptions of the ideal human proportions by Marcus Vitruvius Pollio (Naini *et al.*, 2006; Ashrafian, 2011). The sketch, seen in Figure 2.1, implied that the stature of man is the same as the span of his outstretched arms and emphasizes the ratio between the different parts of the body and the whole (Gielo-Perczak, 2010). However, this generalization does not take human variation into account, and with continuing changes that are occurring in the stature and limb proportions of modern human populations this generalization may be far off the mark.

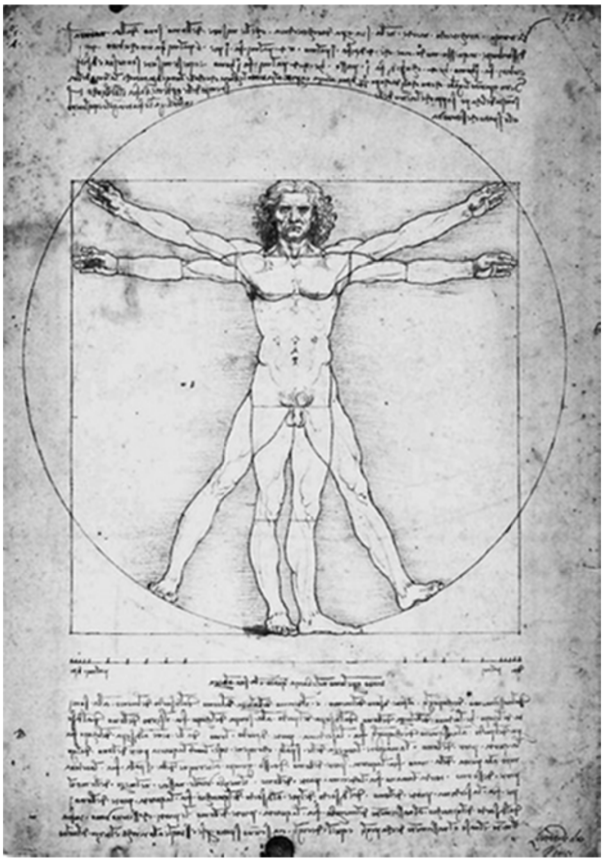


Figure 2.1 Vitruvian Man by Leonardo da Vinci, circa 1487. Gallerie dell'Accademia, Venice.

2.1.1 Development of limb proportions

Like most mammals, humans follow a cephalocaudal gradient of growth and development. Differences in body proportions are brought about by the differential growth of the various segments of the body and these differences can be seen as early as birth and change throughout development (Scammon and Calkins, 1929; Bogin and Varela-Silva, 2010). During human development, the metabolic demands for the growth of the brain are extremely high with 87% of the resting metabolic rate (RMR) being used for the growth of the brain whereas the RMR for adults are only 20-25% (Bogin and Varela-Silva, 2010). This may explain the delay in fetal and infant lower limb growth to allow for the rapid growth and development of the brain (Bogin and Varela-Silva, 2010). A classic example of this principle is demonstrated in the sketch by Stratz (1909) which portrays the approximate changes in body proportions during prenatal and postnatal growth (Figure 2.2)

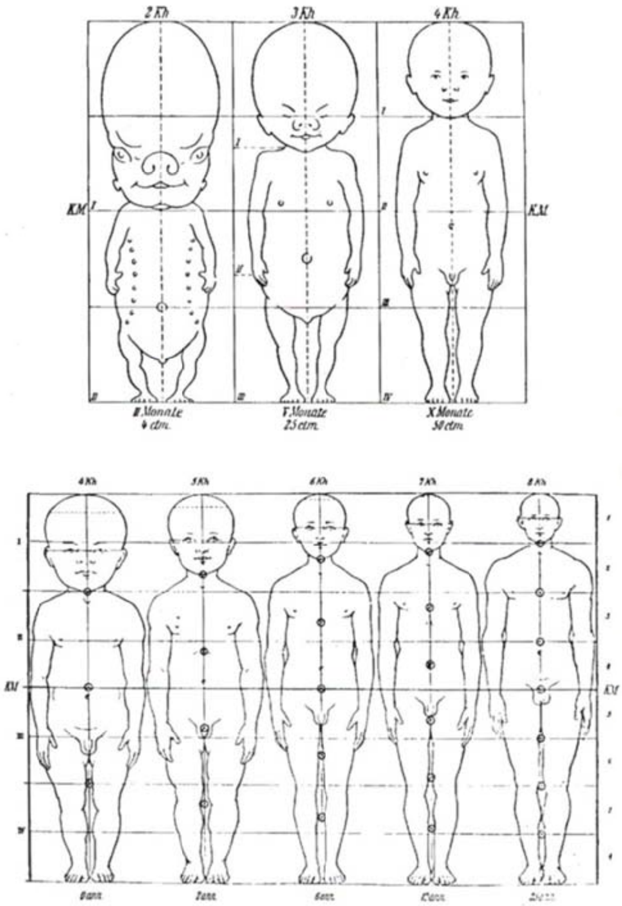


Figure 2.2 Differences in the body proportions during prenatal and postnatal growth (from Stratz, 1909).

At birth, the head length of an infant makes up approximately a quarter of the total body length. This ratio changes during life so that by adulthood the head length is only one-eighth of the total body length (Bogin and Rios, 2003). This change in body shape, known as ontogenic development, is the same in all human population groups. Proportional changes occur in the length of the limbs during development with the upper limbs and lower limbs becoming greater compared to the total body length (Scammon, 1930). This trade-off between the growth of the brain versus the growth and development of the other body segments is a common characteristic of the human species (Bailey *et al*., 2007; Bogin and Varela-Silva, 2007). The lower limbs specifically grow at a much faster rate than the other post-cranial segments which allows for efficient bipedal locomotion (Bogin and Rios, 2003).

The exact mechanism of controlling the differential growth in the body segments are not well known but genetic, hormonal and nutrient supply factors are likely to be involved.

Chondrocytes in the proliferative and hypertrophic zones of the growth plate are responsible for the growth of a bone in length (Ballock and O'Keefe, 2003; Rauch, 2005; Mackie *et al.*, 2011). The length of these proliferative columns in the growth plate directly correlates with the length of the limbs (Tanner, 1994; Rauch, 2005; Bogin and Varela-Silva, 2010). Thus, greater columns will be found in the lower limb than the upper limbs of species with long lower limbs and short upper limbs. Furthermore, a few specific genes responsible for human body proportions have been identified. Livshits *et al.* (2002) estimated that genetic effects may account for 40-75% of the inter-individual variation in body proportions. The expression of HOX genes (responsible for controlling growth in the antero-posterior axis), homeobox sequences, short stature homeobox-containing genes (SHOX) and growth factors (Mark et. al., 1997; Blum et. al., 2007; Reno et. al. 2008), change the sensitivity to promoting and inhibiting factors in the growth plates during development which results in different limb proportions (Kajantie, 2003; Serrat *et al.*, 2007). Also, the specific pattern of the fetal circulation to allow brain-lower limb growth trade-off (Boros *et al.*, 1975) may influence the body proportions in humans.

2.2 Evolutionary changes in limb proportions

One of the features used to distinguish human from non-human primates is the length of the limbs relative to stature (Bogin and Varela-Silva, 2010). The differential growth of different segments of the body results in mammalian limb proportions with limbs becoming greater relative to stature during growth (Schammon and Calkins, 1929; Scammon, 1930). Earlier hominid species (Australopithecines, early *Homo* and Neanderthals) had relative lower limbs that were, on average, shorter than that of modern humans (Holliday, 1997; Ruff, 1995, 2002). However, the relative lower limbs of later hominids from Africa were greater than many modern human populations (Ruff and Walker, 1993). This clearly indicates the evolutionary trend towards greater lower limbs in humans.

In relation to stature, modern humans have proportionately shorter upper limbs than lower limbs. The intermembral index and humerofemoral index show that, compared to non-human apes, humans have lower limb bone lengths which are approximately 34% greater relative to the upper limb bone lengths (Bogin and Varela-Silva, 2010). The differences in the limb proportions between modern humans, hominids and non-human primates (e.g. chimpanzees) are illustrated in Figure 2.3.

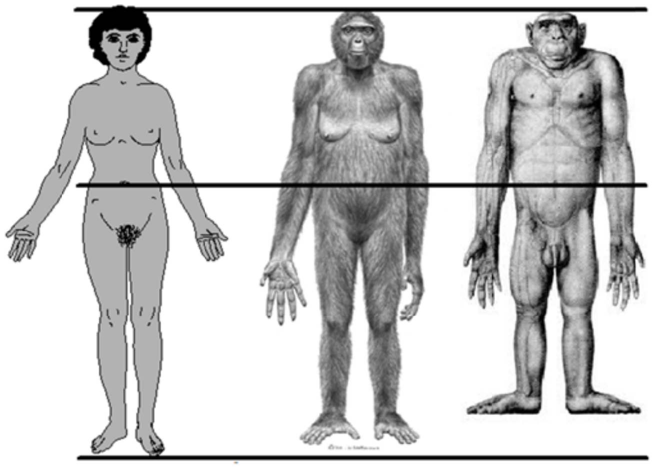


Figure 2.3 The approximate body proportions of humans (*Homo sapiens*), hominids (*Ardipithecus ramidus*) and chimpanzees (*Pan troglodytes*) (from Bogin and Varela-Silva, 2010).

Although non-human primates are capable of bipedal locomotion, they will only use bipedal locomotion over short distances. Hominid bipedalism is habitual and obligate, meaning that they use bipedalism as the standard and most efficient mode of locomotion and are committed to bipedalism, respectively (Jurmain *et al.*, 2000). In order to facilitate this mode of locomotion, hominids had to undergo several anatomical changes including proportional changes of various body segments. Furthermore, species-specific changes in limb proportions are not only important for efficient bipedal locomotion but may also have played a role in thermoregulation (Mayr, 1956; Ruff, 1991, 1993; Tilkens *et al.*, 2007; Bogin and Varela-Silva, 2010).

2.2.1 Limb proportions in bipedal locomotion

Many researchers see the elongation of the lower limbs as a key marker in the evolution of bipedalism (McHenry, 1978; Johanson *et al.*, 1982; Jungers, 1982; Wolpoff, 1983; Hartwig-Scherer and Martin, 1991; McHenry and Berger, 1998; Asfaw *et al.*, 1999; Richmond *et al.*, 2002; Ruff, 2003). Modern humans across the world exhibit a wide diversity in shape and size, most of which can be related to environmental adaptation (Schammon and Calkins, 1929; Scammon 1930; Meadows and Jantz, 1996; Holliday and Falseletti, 1999). The modern human form is the result of more than 2 million years of evolution of which the most notable change was the change from quadripedal to bipedal locomotion. Throughout the process of hominid evolution, changes in limb proportions relative to each other and the trunk occurred. Many early hominid taxa (for example the Australopithecines) had body proportions that are significantly different than that of modern human populations, with larger and greater upper limbs relative to the lower limbs (Ruff, 2002; Bogin and Varela-Silva, 2010). This may have been due to the retention of arboreal capabilities and locomotive patterns which changed in the later *Homo* lineages that were adapted to a fully terrestrial lifestyle (Ruff, 2002).

According to Bogin and Varela-Silva (2010), in order to achieve a biomechanical efficient striding gait, the lower limb has to be approximately half of the total stature. The ability for sagittal balance and greater lower limbs were important during early evolution as this allowed man to run faster and over greater distances than any other ape (Coon, 1955).

2.2.2 Limb proportions in thermoregulation

According to Allen's rule (1877), a homoeothermic species of geographically dispersed organisms at higher latitudes will have shorter extremities than their conspecifics at lower latitudes. This rule is often linked to Bergmann's rule (1847), which states that in a 'polytypic warm-blooded species", the body size increases with a decrease in the environmental temperature. The Bergmann and Allen rules are often used to explain that organisms in cold climates are adapted to reduce heat loss by minimizing the surface area:volume ratio. The opposite is true for organisms in hot climates (Holliday, 1996). Allen's rule offers an explanation for why humans (as well as other mammals) from warmer, tropical environments are, on average, taller with greater limbs than those from colder climates (Eveleth and Tanner, 1976). As early as 1950, Schreider demonstrated the association that exists between human shape and geography (Katzmarzyk and Leonard, 1998). The Bergmann and Allen rules were further substantiated by the works of Roberts (1953, 1973) which demonstrated a significant negative correlation between body size and mean annual temperatures such that individuals in tropical regions often have greater relative lower limb s than individuals in colder climates (Roberts, 1978; Katzmarzyk and Leonard, 1998; Holliday and Falsetti, 1999). Similarly, Eveleth and Tanner (1976) observed that the relative sitting height index, which is an indirect indicator of lower limb, also differs significantly between population groups. Europeans, Native Americans and Asians exhibit greater sitting height index values than sub-Saharan Africans and Australian aborigines, who are found in warmer areas, indicating that the population groups in colder climates have greater trunk heights and therefore shorter lower limbs relative to stature (Eveleth and Tanner, 1976; Holliday and Falsetti, 1999).

The Regional Continuity model for the development of modern humans (Wolpoff *et al.*, 1984; Wolpoff, 1989, 1992; Frayer *et al.*, 1993) supports the changes in limb proportions in hominids. This model proposes that modern humans gradually evolved from a single diverse ancestor in Africa. As our ancestors moved out of Africa, the limb proportions of hominids were greatly influenced by the climate. The early hominids moved into colder climates which increased the previously limited cold stresses which could have acted as a new selective force for changes in limb proportions (Holliday, 1996). Therefore, body proportions adapted for cold occurred outside of Africa. For example, Neanderthals in Europe had relatively short distal limb segments which may be attributed to long-term climatic selection whereas *Homo ergaster/erectus* in East Africa had relatively greater distal limb segments (Trinkaus, 1981, 1983, 1991; Franciscus, 1989; Ruff and Walker, 1993; Ruff, 1994; Holliday, 1995, 1997). Measurements from other fossil remains from the Early Upper Paleolithic period indicate that European humans had limb proportions similar to modern African populations while Late Upper Paleolithic and Mesolithic humans had limb proportions more similar to modern European populations, also indicating that changes in limb proportions may be due to adaptation to colder climates (Holliday, 1996). However, the changes seen in limb proportions (within a limb, between upper and lower limbs and between overall limb length and stature) may not be as simplistic due to continuous interaction between the genetic make-up of an individual and the environment as well as other factors such as nutrition, socioeconomic status and migration (Taylor *et al.*, 1974; Eveleth and Tanner, 1976; Heglund *et al.*, 1982; Jantz and Jantz, 1999; Bogin *et al.*, 2002; Malina *et al.*, 2004).

2.3 Modern studies on limb proportions

Many anthropometric studies have been conducted on the changes and differences in both sub-adult and adult limb proportions. Anthropometry (Greek anthropos, meaning "man" and *metron* which is "measure") is the scientific measurement of human body parts (Bogin, 1999; Meister, 1999). It is a popular and useful tool to understand the variation seen in limb proportions in living populations. The advantage of using living human specimens as opposed to skeletal remains is that it allows for large sample sizes, data from both sexes are available, human growth can be monitored using longitudinal studies over long periods of time and the differences in growth and dimensions between population groups can be compared (Eveleth and Tanner, 1976; Bogin 1999; Jantz and Jantz, 1999). These types of studies are important for observing secular changes in growth between population groups in order to understand the influences, whether evolutionary or social, that may still be playing a role. Anthropometric data have long been used as a means of observing the standard of living and health status of a population (Fogel *et al.*, 1983; Steckel, 1995).

Another method of studying stature and limb proportions in human populations is by making use of osteometric data. Measurements of the long bones and the total skeletal height can also give an indication of the trends that are occurring in the specific population group. The advantage of using osteometric measurements is that data are available of individuals that have long since been deceased. This offers a large time depth for researchers to compare data from historical populations with current population groups.

The average stature of a population group has a direct relationship with the living conditions and the per capita income of the individuals. For example, decreased stature is an indicator of the inequality in nutritional deprivation as a result of a lower income (Steckel, 1995). However, it is important to note that there are many other factors that can influence the stature of a population group.

The size and shape of human bodies vary considerably among population groups across the world (Eveleth and Tanner, 1976; Bogin 1999; Ruff, 2002). Furthermore, the human body shape is not fixed and it appears that changes in limb proportions are continually taking place. This phenomenon is known as plasticity which is the ability of an organism to change its phenotype in response to various environmental factors (Bogin and Rios, 2003). These changes, which may or may not be permanent during an organism's lifespan, can be morphological, physiological, behavioural or phenological (Price *et al.*, 2003). Plasticity is often used in developmental studies to indicate that human growth is not fixed during development but is constantly changing in response to environmental stresses. After cessation of growth the bones are less plastic and are said to become "fixed" (Bogin 1999; Bogin and Varela-Silva, 2010). It is for this reason that the body proportions and stature can be used as an indicator of the quality of the environment during the growth of an individual.

Researchers have suggested a variety of factors that may influence the change or evolution of limb proportions and stature in humans, including functional morphology (Jungers, 1984, 1985; Runestad and Ruff, 1995; Runestad, 1997; Porter, 1999), limb proportions related to climatic factors (Coon, 1962; Roberts 1978; Ruff, 1994; Holliday, 1997a,b), nutritional and stress factors (Jantz and Jantz, 1999; Bogin *et al.*, 2002; Malina *et al.*, 2004), as well as genetic factors (Eveleth and Tanner, 1976). These factors all need to be taken into account when explanations are sought as to differences in proportions and statures of people living in the same region.

2.3.1 The effect of genetics and climate on stature and limb proportions

Global growth studies by Eveleth and Tanner (1976) showed that marked higher relative sitting heights and therefore shorter limb proportions, exist in Europeans, Native Americans and Asians compared to the lower values seen in Australian aborigines and sub-Saharan Africans.

Although limb proportions are largely controlled by genetics, phenotypic plasticity may result in retention of differential limb proportions between ancestral groups regardless of the common climate and "interbreeding" (Hamill *et al.*, 1973; Martorell, *et al.*, 1988). Holliday and Falsetti (1999; 927) explain this by stating that "members of each group tend to exhibit body shapes more similar to those of the populations on the continent from which most of their ancestors derive (i.e., either Africa or Europe)". The final size or stature is the result of continuous interaction between the genetic make-up of an individual and the environment. According to Katzmarzyk and Leonard (1998), body shape and limb proportions are influenced by climate in three different ways:

1) Temperature acts as a direct selective pressure in order to favour the genetic adaptations which will result in the most efficient regulation of temperature. This implies that body shape and limb proportions are morphological characteristics which have a high degree of heritability.

2) The body shape best suited to the climate in the areas where development and growth takes place will be obtained due to the interaction between the temperature stresses and plasticity. This path implies that there is little genetic heritability; however the offspring will resemble their parents if both grew up in similar climates.

3) Climate influences body morphology by indirectly influencing nutrition and the availability of food in the area during development (Katzmarzyk and Leonard, 1998; Bogin and Rios, 2003).

Genetic selection and developmental plasticity also forms part of Ruff's model where not only climate but nutrition, health status as well as physical activity play a role in determining the shape of the body (Ruff, 1994, 2002). The influence of genetic selection may, however, be greater than expected. Many researchers have indicated that the genome-environment interaction has an effect on stature and the limb proportions during growth. Making use of anthropometric data (First National Health and Nutrition Examination Survey or NHANES I from the United States), Fulwood *et al.* (1981) observed that by controlling other factors, such as income, education, urban and rural residence and age, no significant difference in the average stature were observed between black (African-Americans) and white (European-Americans) individuals. Although the stature remained similar between different groups living in the same climate, the limb proportions did differ. Krogman (1970) observed that, for similar statures, the limb proportions differed between black and white groups with black individuals having shorter trunks and greater limbs than white individuals. This is especially true for the measurements of the leg and the forearm (Krogman, 1970). Similar results were observed by Hamill *et al*. (1973) and Trotter and Gleser (1952). Hamill and colleagues made use of the NHANES III data and found that black individuals had greater limbs which were probably due to their sub-Sahara African genomic origin (Hamill *et al.*, 1973; Bogin and Varela-Silva, 2010). Trotter and Gleser (1952) made use of North American black and white military personnel data and osteometric data from white males and females from the Terry collection to estimate stature from long bone measurements. The authors observed that black individuals had significantly greater limb lengths to stature than white individuals. This indicated that a difference in limb proportions does exist between black and white groups (i.e. individuals from a colder European descent versus individuals from a hotter African decent) and may indicate the effect of Allen's rule on limb lengths even after the individuals have been removed from these settings and support the genetic influence of modern limb proportions.

Differences in limb proportion can even be observed during fetal development. Schultz (1926) observed a difference of 1% in the relative lower limb between black and white foetuses at 40 weeks of gestation. However, it should be noted that genotypic contributions to differences in limb proportions might be relatively small. The estimated variance in stature caused by genetic influence is estimated to be around 0.04-0.06. Bogin and colleagues (2001) found that the contribution of geographic origin to variance in the sitting height ratio between groups was only 0.04 which falls into the genomic estimate of variance (Marks, 1995; Bogin *et al.*, 2001). The exact degree of influence of genetics and climate on differences in limb proportions is not entirely clear but it can be agreed that even when individuals of African and European descent share a common environment, extreme phenotypic plasticity remains small and body features are largely controlled by genetic factors (Schultz, 1923; Hamill *et al.*, 1973; Martorell *et al.*, 1988; Holliday and Falsetti, 1999). Thus, the individual will show limb proportions that are more similar to the population groups on the continent from which the individual's ancestors derive (Holliday and Falsetti, 1999). Styne and McHenry (1993) found that this phenomenon is not limited to modern populations but can be observed in prehistory and the last 2000 years. They found adult height for individuals during this period to be similar to the stature of modern human populations living in the same region (Styne and McHenry, 1993). Therefore, the ranges of normal body size seen in modern populations are reflected by the body shape and size over the past 1.8 million years (Bogin, 1999).

The same rules most probably apply to the proportions of the limbs in South Africa. Classically, the South African population is primarily defined into 4 groups: white, black, coloured and Asian. Black South Africans represent 80.2% of the current population, while white and coloured (also called "Cape Coloured") South Africans each only make up 8.4 and 8.8% of the population, respectively. Asians and groups classified as "other" represent another 2.5% of the population (Statistics South Africa, 2014). White, black and coloured South Africans have distinctly different ancestral influences. White South Africans are largely descended from colonial immigrants such as Dutch, French and German and other European groups (Steyn and Iscan, 1998; L'Abbe *et al.*, 2011). Genetic evidence also indicates low frequencies of alleles typically found in Khoesan and Bantu-speaking individuals (Greef, 2007). The black South African population mainly arose from Bantu-speaking individuals from the Nigerian/Cameroon highlands with gene flow evident from Khoesan groups (Herbert, 1990; Stynder, 2009). The coloured South African population is highly admixed with high levels of Khoesan, Bantu-speaking, Indian and European ancestries as well as smaller contributions from East Asian ancestry (Malay) (Patterson *et al.*, 2010).

Stature data on South African populations indicate that blacks and coloureds are generally shorter than white South Africans (Doornbos and Jonxis, 1968; Leary, 1968; Smith *et al.*, 1968; Steyn and Smith, 1997), however, no information regarding their relative limb proportions are available. A possible explanation for the shorter stature seen in Cape "coloured" individuals is that their gene pool includes genes from shorter stature population groups such as Khoesan, Malay and Indian (Schoeman, 2007). White South Africans may be taller than the black and coloured groups due to the strong influence from their taller Dutch ancestors. However, it is not known how these genetic sources contribute to the limb proportions, as no data are currently available.

2.3.2 The effect of nutrition on stature and limb proportions

In order to maintain normal growth, the human body requires an adequate supply of nutrients. Nutritional stress is not only limited to the amount of food available during growth but also the caloric density which is the average calories per weight (Eveleth and Tanner, 1976).

Numerous studies (e.g. Eveleth and Tanner, 1976; Fogel *et al*., 1983; Gunnell *et al*., 1998; Frisancho *et al*., 2001; Malina *et al*., 2004; Li *et al*., 2007; Dasgupta *et al*., 2008; Dixon *et al*., 2008; Floyd, 2008; Kim *et al*., 2008; Whitley et. al., 2008) have been done in order to establish the effect of nutrition on the growth of the human skeletal system. In 1951, Leitch proposed the use of lower limb/stature ratio to access early life nutrition history and health of individuals (Bogin and Varela-Silva, 2010). According to the reserve capacity hypothesis, growth and development of the somatic and cognitive system usually overreaches the minimum capacity that is necessary to sustain life and results in reserve capacity which can then be used for greater growth and health (Bogin, 1999). Leitch (1951, p145) states that "it would be expected on general principles that children continuously underfed would grow into underdeveloped adults" which will influence the length of the trunk as well as the lower limbs. Therefore, underfed children will not reach the full genetic potential for limb length. Bogin (1999) further states that the relative lower limb/stature ratio may be an indicator of the overall reserve capacity. Therefore, lower limb and body proportion ratios of adults are powerful indicators of the quality of the environment during growth (Bogin, 1999).

Generally, greater lower limbs are observed in groups with better nutrition. However, it should be noted that the influence of nutrition is more pronounced on body size than body shape. Limb proportional changes are more resistant to nutritional stress and more dependent on genetic variation. Eveleth and Tanner (1976) state, for example, that the limb proportions in a malnourished child of European descent will not take on the limb proportions seen in Asiatic population groups.

Vitamin D deficiency in the diet may also lead to decreased statures. Vitamin D is derived from sunlight but is also added to food supplements in areas that receive limited UV radiation such as Europe and plays an important part in the development of the skeletal system (Holick, 2003). Kremer and colleagues (2009) observed a positive correlation between the amount of circulating vitamin D and stature. Therefore, the quality of the food and supplements taken to prevent certain diseases, such as rickets which is caused by vitamin D deficiency, also has an important influence on stature and limb proportions.

Historical studies (Gould, 1869; Davenport and Love, 1921; Eveleth and Tanner, 1976; Sokoloff and Villaflor, 1982; Fogel, 1986; Sandberg and Steckel 1987; Brinkman *et al*., 1988; Komlos, 1989; Floud *et al*., 1990; Weir, 1993) on the secular changes in stature further indicate that there are changes in the average heights of population groups with changes in nutrition and health (Fogel *et al*., 1983; Steckel, 1995). However, these changes are complicated and are probably better explained when taking the socio-economic status into account.

2.3.3 The effect of socio-economic status on stature and limb proportions

Socio-economic status (SES) is a measure of education, occupation and social prestige which influences the growth and development of an individual (Bogin, 1999). Research on the effects of socio-economic status is extremely complicated, as SES reflects various factors that influence growth and development to different degrees.

Many studies observed shorter statures in population groups of lower SES (Garn *et al*., 1975; Bogin and MacVean, 1978, 1981 and 1984; Fulwood *et al*., 1981; Malina *et al*., 1983). However, the effect of SES seems to influence growth and development indirectly while the various factors that determine the SES have a direct influence. For example; a low SES does not directly result in poor growth and development, rather the poor living conditions and nutrition associated with a low SES causes low growth rates. Differences in stature were observed between individuals born and living in different regions. On average, individuals living in developing countries had greater differences in stature between low SES and higher SES (Bailey, 1970; Rea, 1971; Bogin and MacVean, 1978, 1981 and 1984). Similar differences in stature were observed in industrial developed countries such as America, Western Europe, Australia and Japan (Goldstein 1971; Davie *et al*., 1972; Miller *et al*., 1972; Cook *et al*., 1973; Fulwood *et al*., 1981; Malina *et al*., 1983). However, it would appear that these differences are also due to differences in SES between rural and urbanized environments (Eveleth and Tanner, 1976; Bogin 1999). Individuals living in urbanized areas tend to have better access to food, health care and social services than individuals in rural areas (Bogin, 1999). Mascie-Taylor and Boldsen (1985) found that individuals living in rural areas in Great Britain are shorter than those living in urbanized areas due to higher occupational stress of the fathers in the rural regions. In this instance, SES had a greater influence on growth than climate, diet and genetic variation. Similar results are seen in individuals who are migrants to urbanized areas. Panek and Piasecki (1971) observed that individuals who moved to urban areas were taller than individuals who remained in rural areas.

According to Bielicki and Welon (1982) and Matsumoto (1982), SES influences growth of a group due to differences in the diet and the availability of food; health care; levels of physical labour, family size, industrialization, national income level, urban population rate and the ratio of food to total living costs (known as Engel's coefficient).

Figure 2.4 summarizes the effect of SES on stature of a population. Stature is influenced by proximate determinants such as diet, disease, hard labour during development and genetics which ultimately place stress on the body during development and growth. In turn, these factors are influenced by socio-economic determinants such as income, access to health care and inequality. All these factors that have an effect on the stature of the individual can lead to functional consequences such as increased or decreased mortality and morbidity (Steckel, 1908).

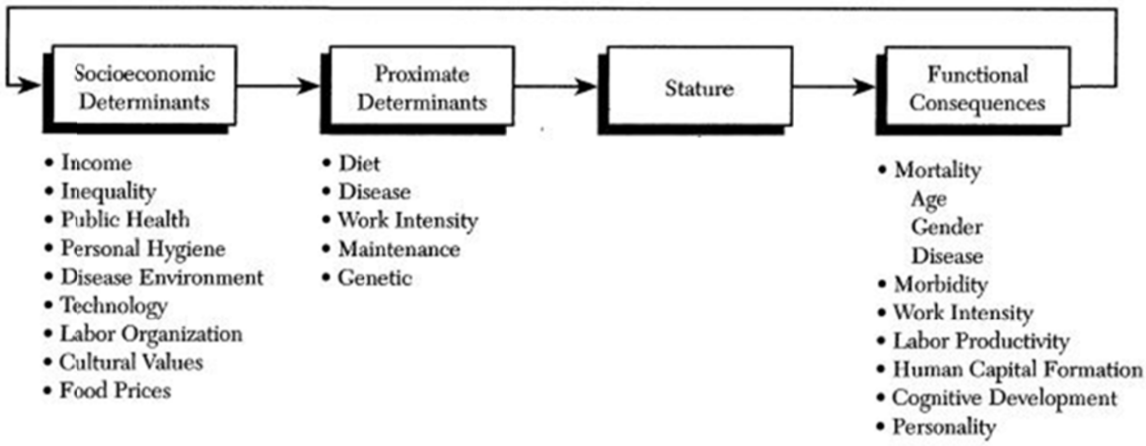


Figure 2.4 Relationships involving stature (adapted from Steckel, 1908).

According to Tobias (1985), the absence of a secular trend is most striking in developing countries while positive secular trends are often observed in developed countries which indicate the influence of SES on secular changes. The direction of secular change is often ascribed to "haves" and "have nots" with the "haves" exhibiting positive secular changes and the "have nots" negative or no secular changes. However, several exceptions were observed. Individuals in many industrialized countries with a high SES have reached their genetic plateau where no secular changes is currently taking place while low SES countries with hunter-gatherer groups (e.g. Khoesan and the aboriginal Australians) have shown positive secular trends. Tobias (1985) therefore suggested a fourfold subdivision classification of "have-most", have-ample", "have-little" and "have-least" groups. The secular changes recorded and the SES of the population group is summarized in Figure 2.5.

Category	Socio-economic status	Secular trend pattern	Interpretation
Have-most	Affluent stratum of industrialized communities	Positive until recently, followed by a plateau or absent secular trend	Have reached the upper phenotypic limit set by their genetic potential
Have-ample	Less affluent socio-economic classes of industrialized communities	Absent secular trend up to 19th century, followed by positive secular trend.	Moving from middle to upper reaches of genetically determined growth rate and body size range
Have-little	Most non-industrialized communities, with a predominantly pastoral or agricultural subsistence base	Absent or negative secular trend since early 20th century	Moving from middle to lower reaches of genetically determined range of growth rates and body sizes
Have-least	Many surviving hunting and gathering communities	Positive secular trend since late 19th or early 20th century	Rising from lowest reaches of genetic potential towards the middle of the range of growth rates and body sizes prescribed by the genome

Figure 2.5 Secular trend patterns in four subdivisions of the world's human population (from Tobias, 1985).

Not much research has focused on the effect of SES on the growth and development of limb proportions. However, research on secular trends observed greater long bone lengths which may be due to improvements in living conditions.

2.4 Secular changes in stature and limb proportions

Processes of micro-evolution (changes of allele frequencies over time) are constantly taking place in the human species through reproduction (Henneberg and van der Berg, 1990; Rühli and Henneberg, 2013). These changes are necessary for adaptation of the human species to its environment. The change in certain aspects of the human body is known as secular trends. Secular trends differ from micro-evolution in that they involve the change in phenotypic expression without any changes in allele frequencies (Rühli and Henneberg, 2013). The word "secular" comes from the Latin word "saecularis" which means age, a generation, a century or a very long time and therefore indicates something that is occurring gradually but persistently (Tobias, 1985). Secular changes in body size and proportions are seen as the increase or decrease of certain dimensions over time or from one generation to the next. These changes imply that the tissues, for example bone and muscle, may respond differently to the factors that influence secular changes (Himes, 1979). Therefore, changes in stature over time may take place at a different rate than changes in weight. Most research on secular trends focus on stature, weight (Body Mass Index or BMI), rate of maturation (skeletal, dental and pubertal development) and proportional differences such as sitting height and lower limb. Secular changes can either be positive, unchanged (null or isometric) or negative. Positive secular trends imply that there is an increase over time in the measurement being observed while negative secular trends indicate that the body size and shape are decreasing from one generation to the next. If no change is observed, it is said that the secular trend is absent or null (isometric) (Bogin, 1999).

The direction and rate of secular trends is subject to change and may also be more pronounced in specific population groups (Tobias and Netscher, 1977; Wolanski, 1978; Roche, 1979; Tobias, 1985; Price *et al.*, 1987; Henneberg and van der Berg, 1990). Secular trends occur due to natural selection in response to variations in living conditions. Many authors commonly accept that the direction and tempo of secular trends are a reflection of changes in the socioeconomic situation in a country (Henneberg and van der Berg, 1990; Tobias, 1990; Louw and Henneberg, 1997; Bogin, 1999; Staub *et al.*, 2011; Rühli and Henneberg, 2013). Therefore, the direction and rate of secular trends of population groups should correspond with the standard of living (e.g. GDP per capita, real wages, access to healthcare and other SES variables) within the country (Henneberg and van der Berg, 1990; Bogin, 1999; Staub *et al.*, 2011). For example, in countries with high standards of living, marked positive secular trends are expected. It is also important to observe secular trends within a nation's subpopulations. According to Henneberg and van der Berg (1990), in order to observe whether differences in the secular change in subpopulations are occurring, the direction and magnitude of the changes should 1) be similar for all populations groups under comparable SES or 2) differ between groups with dissimilar SES.

Many researchers have also noted that sex differences exist in the magnitude of secular trends. In general, male growth is more sensitive to environmental stresses than female growth (Greulich, 1951; Tanner, 1962; Stini, 1972, 1979; Tobias, 1972; Wolanski and Kasprzak, 1976; Stinson, 1985). In population groups with high levels of environmental stress male growth is more retarded that that of females. Thus, males exhibit more plasticity while females exhibit canalization; a lesser tendency to deviate from normal growth (Tanner, 1962; Kuh *et al.*, 1991). Tobias (1962, 1972, 1975b) suggested that although male growth is more sensitive to stresses during adverse conditions, males also respond more quickly to improved environmental conditions.

Although many researchers have noted that in certain populations males have a larger rate of secular trend (e.g. Shapiro, 1939; Acheson and Fowler, 1964; Froelich, 1970; Bielicki and Charzewski, 1977), the sex difference in secular trends in stature is complicated. A number of possible explanations exist for the differences between male and female rates in secular trends from biased sample sizes to different cultural practises. Studies making use of individuals younger than 20 years of age tended to overestimate the rate of secular increase in males since they reach their final adult stature later than females (Stinson, 1985). Cultural practises also have an effect on the rates of secular change between males and females as the "discriminatory" sex may be exposed to greater nutritional stresses (Froelich, 1970; Stinson, 1985). Therefore, all possible effects need to be taken into account when interpreting sex differences in secular trends.

2.4.1 Worldwide secular changes in stature and limb proportions

Most studies (e.g., Eveleth and Tanner, 1976; Meadows and Jantz, 1995; Bogin, 1999; Cole, 2003; Federico, 2003; Komlos and Baur, 2004; Komlos and Lauderdale, 2007; Komlos, 2009; Steckel 2009; Bogin and Varela-Silva, 2010; Staub *et al.*, 2011) on secular trends in stature and limb proportions across the globe have shown that there is a general trend towards an increase in stature. This can mostly be ascribed to increases in the lower limb length, especially the distal lower limbs (Eveleth and Tanner, 1976; Meadows and Jantz, 1995). For example, based on Dutch male conscript data, the mean height has increased from 165 cm in 1860 to 181 cm in 1990 with height averages of 184 cm for males and 171 cm for females in 1997 based on cohort-studies (Cole, 2000, 2003). The positive secular trend observed in the Dutch conscripts continued into the 20th century and was even greater after the Second World War (WWII) (Cole, 2003). The magnitude of these secular changes in adult height in various European countries can be seen in Figure 2.6.

However, this trend has only been taking place since the mid-19th century. During the 18th century, the mean average heights in many countries decreased due to poor harvests and high grain prices which resulted in poor nutrition during growth (Komlos, 1985; Floud *et al.*, 1990). Therefore, the increase in the 19th century is possibly a "correction" of the decreased statures observed in the 18th century.

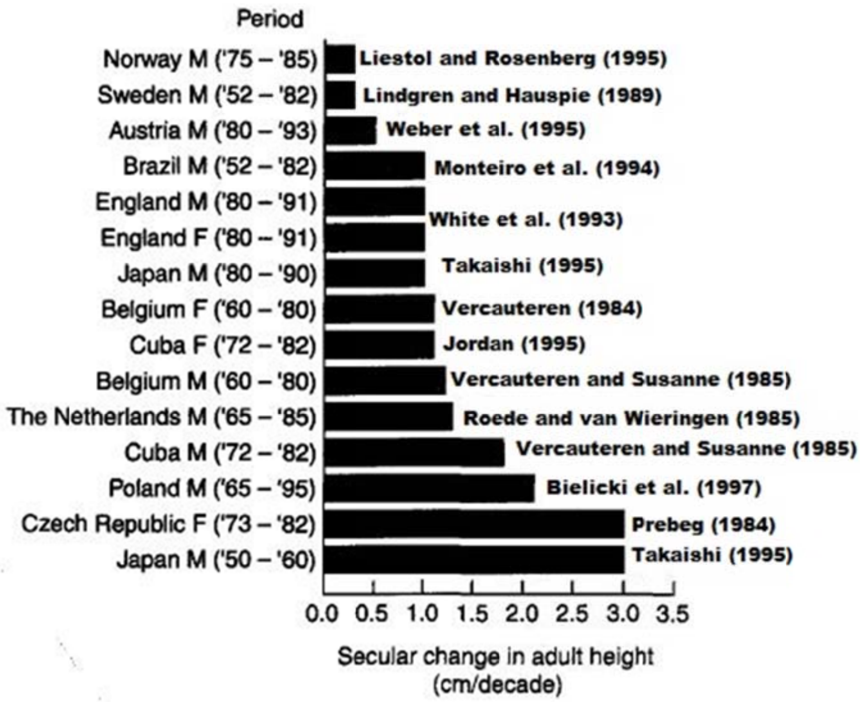


Figure 2.6 Secular trends in adult height in various countries (from Hauspie *et al*., 1997).

Bogin and Keep (1998) reviewed anthropometric data of 322 adult males and 219 adult females from Latin America and found that no secular trend occurred in stature between 1873 and 1989. However, the mean stature did decrease between 1898 and 1939 with 4.5 cm for males and 3.0 cm for females. The mean stature then increased again from 1940 to 1989 with 5.0 cm for males and 4.0 cm for females. The authors explain that the negative secular trend is probably due to socio-economic factors such as poor health and nutrition during this period. The positive secular trend observed from 1940 may have been caused by world-wide economic recovery after WWII (Bogin and Keep, 1998; Bogin, 1999).

Hauspie and colleagues (1996, 1997) have reviewed anthropometric data from children of various countries across the world (Europe and North America as well as Japan, Taiwan, Cuba, Brazil) as well as living adult stature of Eastern European countries. They observed that, since World War II, a positive secular trend was still visible in most Western and industrialized countries (Hauspie *et al*., 1997; Bogin, 1999; Cole, 2003). The secular increase of adult stature ranged between 3 mm/decade in Northern Europe (Sweden and Norway) to 30 mm/decade in parts of Southern and Eastern Europe. Countries with smaller rates of secular change, such as the Scandinavian countries and the Netherlands, appeared to be reaching a plateau of genetic potential for stature. Similar results were observed in the mean height of Japanese adult men between 1950 and 1995. The rate of increase during this period slowed down from approximately 4 cm during the first decade to approximately 1 cm during the last decade. Less well-off countries with larger rates of secular trend may increase in height for some decades (Hauspie *et al*., 1997; Cole, 2003). Several other researchers have observed this slowdown in the height trend in Europe (Schmidt *et al*., 1995; Larnkjaer *et al*., 2006; Staub *et al*., 2011) and North America (Komlos and Baur, 2004; Komlos and Lauderdale, 2007) which indicates that even with increased average income in a country, the population groups can only increase in height until the full genetic potential is reached. Another factor that may possibly be responsible for the genetic endpoint being reached is the absence of vitamin D deficiencies in Europe which may cause height differences in individuals (Kremer *et al*., 2009). However, not enough data are currently available to determine whether the absence of secular trends are short term due to stabilization in the economy of the countries or whether the trends in stature will change in the future due to possible changes in factors such as social inequality or inadequate health care and nutrition (Staub *et al*., 2011).

Family studies on secular trends in stature indicate that secular trends are taking place around the world. Numerous researchers (Boyne and Leitch, 1954; Hulse, 1957; Boyne, 1960; Tanner, 1962) observed that children in Western Europe are taller than their parents. Acheson and Fowler (1964) studied 152 families in Wales and London. The Welsh sample comprised of parents who were employed as miners as well as individuals from professional or commercial occupations. The London sample comprised of the children of fathers who were all professionals. The living environment of the children in the London and Welsh coalminers groups enjoyed a higher standard of living than their parents while the living standard between the first and second generation of Welsh professionals remained relatively the same. The researchers found that the predicted adult height of the children would be taller than the measured height of the adults from the London sample and the Welsh coalminers while the Welsh professional group remained unchanged. This clearly indicates the effect of improved environmental factors on positive secular changes. Similar results were obtained by various researchers in Norway (Brundtland *et al*., 1980), Sweden (Ljung *et al*., 1974), Japan (Gruelich, 1976), Belgium and North America (Meredith, 1976; Bakwin and McLaughlin, 1964). The results of these studies can be seen in Figure 2.7.

Group	Sex	cm/ decade	Age	Years	Source
Japan	M	1.13	20	1900 vs. 1970	Greulich (1976)
	F	1.23	20	1900 vs. 1970	
Norway	M	1.16	18	1920 vs. 1975	Brundtland et al. (1980)
	F	1.11	18	1920 vs. 1975	
Sweden	M	1.61	18	1883 vs. 1938–1939	Ljung et al. (1974)
	F	0.98	18	1883 vs. 1938–1939	
Belgium	M	0.49	20–25	1823–1825 vs. 1960	Meredith (1976)
	F	0.27	20–25	1823–1825 vs. 1960	
U.S. (blacks)	M	0.57	20–25	1863–1864 vs. 1957–1958	Meredith (1976)
	F	0.82	17–18	1896–1898 vs. 1963	
U.S. (whites)	M	0.31	20–25	1863–1864 vs. 1957–1958	Meredith (1976)
	F	0.62	17–18	1896–1898 vs. 1963	
U.S. (Harvard and Wellesley Students)	M	0.98	16–19	1930s vs. 1958–1959	Bakwin and McLaughlin (1964)
	F	0.22	—	1930s vs. 1958–1959	

Figure 2.7 Secular trends in height in late adolescence and young adulthood (from Stinson, 1985).

The heights in North America currently lags behind those observed in Northern Europe (Cole, 2004). Kuczmarski *et al*. (2000) observed that the average height of North American males (177 cm) and females (163 cm) are 7 cm or 4% less than that for the Netherlands. However, a positive secular trend is still visible in North America. Meadows and Jantz (1995) observed that proportional secular changes exist in the long bones of adult black and white North American males from the mid 1800's to 1970. They observed that over time the lower limbs became greater with an increase in stature (positive allometry) while the upper limb bones did not change much (isometric). This may also explain secular trends seen in modern human populations where there is a decrease in stresses, such as starvation and unsanitary living conditions, resulting in greater growth of the limbs over the decades. Therefore, the general trend in stature and limb proportions seems to favour an overall increase in stature with associated increases in the lower limbs while the upper limb stays stable. For this reason it is important to note variations that lead to null or negative secular changes.

Numerous studies in countries with low SES such as India (Vogel, 1971), Peru (Frisancho *et al*., 1975), Guatemala (Bogin and MacVean, 1984), Mexico (Malina *et al*., 1980, 1983), Malawi, Kenya, Uganda, Angola, South Africa and South West Africa/Namibia (Kark, 1954; Shaper and Saxton, 1969; Shaper *et al*., 1969; Burgess and Wheeler, 1970; Tobias, 1975a, 1975b, 1986) have recorded evidence of negative secular trends. Third world countries often exhibit negative or null secular trends in stature. Studies from Guatemala and

Venezuela showed clear patterns of negative secular trends due to civil war. Bogin and Keep (1998) observed that between 1974 and 1983, the economic decline in Guatemala resulted in a significant decline in the mean stature of children aged between 10 and 11 years. This negative secular trend is possibly due to the general deterioration of the quality of life during this period. Furthermore, children from all SES groups (high, moderate and low) exhibited a decline in stature as the quality of nutrition as well as the health of the entire population was affected. Similarly, the civil unrest and economic crisis in Venezuela which began in 1983 resulted in a change from positive to negative secular trends due to the decline in the availability of food (Lopez-Blanco *et al*., 1995; Bogin, 1999).

Thus, the change in limb proportions, which coincides with secular trends in stature, may be more prominent in specific parts of the world while many developed countries haven't had much secular change taking place recently (Lamkaer *et al*. 2006, Steyn and Smith, 2007; Hermanussen *et al*. 2010, Staub *et al*. 2011).

2.4.2 South African secular changes in stature and limb proportions

Data from South Africa present conflicting results. Negative or reversed secular trends, first recognized by Tobias (1970, 1972, 1975, 1985), null secular trends and positive secular trends have been reported in South African population groups.

Tobias (1962) observed a positive secular trend in the stature of three Khoesan (Bushmen) groups from South Africa. He proposed both genetic and environmental influences as the cause for this increase. According to Tobias (1962), the increase in stature is largely due to changes in the diet brought about by the "settling" of Khoesan in pastoral territories. Thus, they were no greater pure hunter-gatherers and they developed a higher caloric diet consisting of increased grains, fat, dairy and proteins which resulted in greater adult heights (Steffensen, 1958).

However, other South African populations did not exhibit this increase in stature. Kark (1954) studied anthropometric data from Zulu groups in South Africa. He observed that the individuals from both sexes were heavy but not very tall and reported a decline in mean adult stature (Tobias, 1975a, 1975b). Tobias (1990) also observed no secular trend using anthropometric data from black South Africans. He found that individuals born between 1945 and 1954 were not taller than those born between 1910 and 1914 which indicated the absence of a positive secular trend. These results were confirmed by Tobias and Netscher (1976, 1977) when they analysed the maximum and physiological lengths of the femur from the skeletons of black South African cadavers. They grouped the individuals into classes based on decade of death, however, the age distribution in all cohorts were similar. They observed a significant decrease in the femoral length between the date of death cohort of 1945/1955 and the 1963/1973 cohort indicating a negative secular trend during the middle part of the century (Price et al., 1987). Price and colleagues (1987) also observed a general decline in the femoral lengths of black South Africans; however the differences in the means were not statistically significant. This indicated that no secular trend existed from 1882 to 1932. The authors ascribe this lack of positive secular trend in lower limb, which is seen in many other populations across the world, as being the result of poor nutrition, housing, education and low levels of health care brought on by the intensification of white political authority from 1907 to 1913 (Tobias, 1975; Price *et al.*, 1987).

Unlike the previous authors, Henneberg and van der Berg (1990) measured the living stature of both white and black adult South African groups born between 1880 and 1970. They found that the mean stature of white South Africans increased at a rate of 4.5 mm/decade while black South African statures increased by 2.4 mm/decade during this period. The affluent white South Africans had a positive secular trend but did not significantly deviate from a straight line. Unlike what was reported by Tobias (1975) and Price *et al*. (1987), they found the trend in black South Africans to be positive and significant. Furthermore, the trend among the Khoisan males was similar to the white South African males supporting the positive secular trend observed by Tobias in 1962. However, the magnitude of this trend was small in all three groups with no significant difference between black and white South Africans. White South Africans are predominantly of Dutch ancestry and it is expected that the secular trend in stature will follow that of white individuals living in the Netherlands (15 mm/decade) (Bogin, 1999). However, the increase in stature of white South Africans was lower than expected. Overall, the secular changes in stature in black and white South African population groups were found to be weak in comparison to secular changes taking place in countries of the northern hemisphere.

Louw and Henneberg (1997) made use of living data of white South African males from the South African Defence Force (SADF) born between 1954 and 1975. They observed, similar to Henneberg and van der Berg (1990), that no secular trend exists in stature of white South African males. Furthermore, they compared their data to the reconstructed heights of individuals from the Wynberg cemetery in Cape Town (Van der Berg, 1990), the heights of white male conscripts in the Special Service Battalion (Cluver, 1935) and the heights of white South African miners (van der Walt *et al.*, 1971). This resulted in a greater reference time frame, with individuals born in 1850 (Wynberg), 1915 (Special Services Battalion), 1915 to 1965 (white miners) and 1973 (SADF). The researchers observed an increase at a rate of 6.7 mm/decade from 1850 to 1973. This trend was well below the trends seen in Europe during the same time.

The social history of South Africa records a gradual increase in commercialization of agriculture and an intensification of white political authority (Price *et al*., 1987). This led to an improved SES for white South Africans while black South Africans had a lower SES associated with poor nutrition and levels of health for the last decade. However, a lack of a significant positive secular change in white South Africans, despite the higher SES, was still observed. This indicated that factors other than improved SES are responsible for secular changes in the stature. According to Henneberg and van der Berg (1990), Louw and Henneberg (1997) and Bogin (1999), even with the implementation of Apartheid in South Africa, poverty and lack of economic and social development influenced the country as a whole and resulted in shorter statures of white South Africans. Furthermore, any improvements taking place in South Africa are so recent that the evidence of their effects may not have been visible yet in the 1990's.

2.5 Secular trends in relative limb proportions

Secular changes are constantly taking place in the limb segments. However, few studies examine the relative secular changes that exist within the upper and lower limbs. For example, changes within the length of the lower limbs may be more variable than those within the upper limbs. According to Holliday (1999), the brachial and crural indices may not provide adequate information regarding the limb proportions in humans. Differences within the upper limbs, as reflected by the brachial index, could be the result of either a short humerus, a long radius or a combination of both (Holliday and Ruff, 2001). However, it appears that the variability in the proximal and distal limb segments is highly influenced by temperature and nutrition. Experimental studies on non-humans have shown that distal limb segments are more phenotypically plastic (Lee *at al*., 1969; Weaver and Ingram, 1969). This phenomenon is due to cold-induced vasoconstriction in the developing distal limb segments which results in reduced growth. Therefore, organisms in colder environments will have shorter distal to proximal limb segments compared to those in warmer environments.

Research by Meadows and Jantz (1995, 1999) have demonstrated an increase in lower limb in both Black and White American populations. They noted that the tibiae are relatively greater compared to the femora indicating that the distal lower limb are more strongly positive allometric. They suggest that this increase in distal lower limb is probably due to better nutrition and health care (Meadows and Jantz, 1995, 1999). This indicates that the distal limb segments may be more variable and more sensitive to environmental factors such as nutrition and SES.

Holliday and Ruff (2001) also demonstrated that the distal limb segments are relatively more variable than the proximal limb lengths. Furthermore, this difference is slightly greater in the lower limbs and the increase in length of the lower limb seems to be more pronounced in males than in females with males exhibiting a greater degree of variability between the distal segments of the lower and upper limb segments (Hauspie *et al*., 1996, Jantz & Jantz 1999; Holliday and Ruff, 2001). This difference in relative limb length between males and females is probably due to sexual dimorphism. According to Tobias (1972), sexual dimorphism is less pronounced in populations that are under more environmental stress where full potential of male growth is not reached. Under optimum conditions, with less influence of environmental stresses, males reach their full genetic potential and maximum male-female differences are thus achieved. Also, differences in the variability of the proximal and distal limb segments are demonstrated between population groups (Holliday and Ruff, 2001). Holliday and Falseletti (1999) observed similar results in European populations and they explained these phenomena with gene flow from warmer climates.

These results are confirmed by Temple *et al*. (2008) who observed differences in the relative limb lengths between two prehistoric groups from Japan. This study indicated that individuals who had a long standing colonization in a climatically mild environment exhibited greater distal relative to proximal limb lengths compared to contemporary migrants from a colder environment.

2.6 The implications of secular trends in stature and limb proportions on stature estimation

Stature estimation is important in forensic anthropology as it can be used to narrow down the number of possible unknown individuals. By providing an estimated range of stature, many individuals that do not fall into this range can be excluded as possible victims. The estimation of stature from skeletal remains is based on a relationship between the long bones and the stature of the individual (Sjovold, 2000).

Two methods exist for the estimation of stature from skeletal elements, namely the anatomical and the mathematical methods. The anatomical method involves estimating the total skeletal height by summing the elements that directly contribute to stature (Fully, 1956; Lundy, 1985). These elements include the cranium, vertebrae, femur, tibia, talus and calcaneus. In order to estimate the living stature of an individual, soft tissue correction factors are added. The mathematical method involves the use of one or more long bone lengths to estimate stature through regression equations (Dayal *et al.*, 2008). However, this method is sex and population specific and therefore requires specific regression formulae (Dupertuis and Hadden, 1951; Trotter and Gleser, 1952; Lundy, 1983; Lundy and Feldesman, 1987; Dayal *et al.*, 2008). Numerous studies have been done in South Africa to estimate stature from skeletal remains (Lundy, 1983; Lundy and Feldesman, 1983; Bidmos and Asala, 2005; Bidmos, 2006; Ryan and Bidmos, 2007), however, due to possible secular changes in long bones these formulae need to be constantly updated to represent the current living population. For example, the equations used to estimate stature from long bones which have been developed from European samples may overestimate stature in individuals of African descent due to the differences in limb proportions (Allbrook, 1961; Roberts, 1978; Ruff, 2002).

Femur/Stature ratio

Forensic anthropologists often use population specific formulae in order to estimate stature from long bones. The length of the long bones is the best indicator for the stature of an individual. Femur:stature ratio is sometimes used in cases where the sex and ancestry of an individual are not known. This method is based on the assumption that a fairly constant relationship exists between the femur and the stature of the individual (Feldesman, 1992, Feldesman and Fountain, 1996). The ratio has been calculated to be 26.75, and therefore the maximum length of the femur multiplied by 3.74 should give a fairly accurate estimation of stature (Sjovold 2000). According to Dupertius & Hadden (1951) the femur has fairly constant relationships with stature and the femur:stature ratio has been shown to be reasonably stable for many populations of the world for both sexes (Feldesman, 1992; Feldesman & Fountain, 1996). However, differences have been observed in the ratio, especially among African groups (Trotter and Gleser, 1952; Hamill *et al.*, 1973; Eveleth and Tanner, 1976; Feldesman and Fountian, 1996, Bogin, 1999; Bogin and Varela-Silva, 2010). Little research has been carried out to test the validity of this ratio and to establish whether secular trends in the different population groups in stature and limb proportions will influence this ratio as it may result in inaccurate stature estimation.

2.7 Secular changes in bone robusticity and width

The term robusticity refers to the thickness of a long bone shaft, articular surfaces or cortical area relative to its length as well as the general degree of development of the muscular attachment sites (Pearson, 2000). While robusticity and width is outside the scope of the current study, it is still important to understand all changes that occur in the long bones over time. Research have established that although secular changes are occurring the length of long bones, less is known on the changes in bone robusticity associated with the lengthening of these bones. Research on the secular changes in robusticity is important as it provides information on the shifts in activity patterns and nutritional status in modern human populations (Pearson, 2000).

Like stature and limb proportions, numerous factors influence the robusticity of long bones. In general, there is a decrease in the robusticity of the long bones has been reported (Ruff, 2002; Rühli and Henneberg, 2013). A complex interaction exists between genetics and effects during the growth which can influence the final widths and shapes of long bones. Bone morphology can be influenced by diet, genetics, climate as well as physical activity (Klepinger, 2001; Ruff *et al*., 2006).

During malnourishment, the body adapts to the lack of nutrients by slowing down the developmental growth rate. This results in a more gracile appearance of the long bones. Nutrition primarily affects the cortical bone width. During childhood, the medullary cavity size increases due to the loss of endosteal bone and the addition of periosteal bone while both are added during adolescence. Overall, malnourishment results in smaller cortical bone widths (Garn *et al*., 1964; Bogin, 1999).

Similar to stature and limb proportions, long bone robusticity varies with climate. The influence of climate on bone robusticity is again explained by the Bergman and Allen's rules. Groups from cold climates tend to have a more robust diaphysis as well as proportionally larger epiphyses than groups from warmer areas. For example, individuals of European descent will have more robust long bones than individuals of African descent (Pearson, 2000). This phenomenon is possibly due to the larger body mass to stature ratio and shorter, stockier limbs seen in individuals from colder climates. Ruff (1994) observed that Arctic populations had much higher ratios of femoral head size to length than individuals from tropical regions. This change in robusticity probably occurred as a mechanical response to accommodate the greater body weight (Pearson, 2000).

Mechanical loading and activity also contribute to changes in bone mass and shape (Pearson, 2000; Compston *et al*., 2007; Maalouf *et al*., 2007). Lack of regular weight bearing exercise results in loss of bone mass (Skedros *et al*., 2004). Population groups associated with increased mobility and physical labour are less robust with smaller cortical thicknesses than more sedentary groups. For example, greatest differences in cortical bone thickness exist between industrial (sedentary) and pre-industrial (active) people (Ruff *et al*., 1993; Lieberman, 1996; Pearson, 2000). However, Ruff and colleagues (1993) observed that the shafts of long bones exhibit more plasticity to the mechanical loading caused during physical activity than the articular ends. Thus, epiphyseal dimensions may be under a greater genetic control than the shafts.

Genetic factors are also a major influencing factor in the widths of the cortex and medulla in modern human populations. Numerous studies (Garn *et al*., 1964; Frisancho *et al*., 1970; Walker *et al*., 1973; Pawson, 1974) have been conducted on population differences in bone mass. Chinese, Japanese, Guatemalans and Alsakan Eskimos were shown to have less cortical bone than white Americans. Black South Africans also had smaller cortical bone widths while the cortical bone in white South Africans was thicker than those of white Americans (Walker *et al*., 1973). These differences are possibly due to a combination of the genetic influence of the decedents with other factors such as environmental influences, physical activity and SES contributing.

The secular changes in robusticity have serious implications for modern population groups. With a genetic plateau being reached in stature, further decreases in overall bone dimensions could be detrimental especially since an increase in the frequency of obesity is being recorded in many population groups across the world (Rühli and Henneberg, 2013). The implication of this decrease is not fully understood and requires further research which is currently being undertaken.

Chapter 3: Materials and Methods

3.1. Sample

The samples used in this study comprised of both osteometric and anthropometric data from modern populations. The sample included self-identified black and white adults (17 to 69 years) born after 1900, divided into birth cohorts of 5 years or 10 years. Skeletons of individuals over the age of 70 were not included in the study as the vertebrae become compressed with advanced age and may influence the accuracy of total skeletal height (TSH) estimations (Fully, 1956; Galloway, 1988). However, several authors (Davies *et al*., 1989, Black *et al*., 1991; Murrie *et al*., 2003; Rühli *et al*., 2005) observed no alterations of the spinal dimensions with individual age.

Most international data for comparisons consist of military conscript data with younger individuals (17 to 20 years). Although some males may continue to grow until their early twenties (Hulanicka and Kotlarz, 1983), younger individuals of 17 to 20 years were included in the current study. However, Randall (1949) suggests that the changes after 18 years of age may not be statistically significant. Furthermore, the sample of the 17 year old subgroup (n = 2) was small enough to not influence the results while the 18 to 19 year old subgroups (South African black males: n=118; South African white males: n = 138) allowed for comparisons with international military conscript data. None of the living individuals were older than 70 years. The samples were subdivided into males and females. Ethics approval (Ethics reference number 80/2014) was obtained from the Faculty of Health Sciences Research Ethics Committee, University of Pretoria.

3.1.1 Anthropometric data

3.1.1.1. Southern Hemisphere (South African) samples

Previously collected anthropometric data from Ergotech, obtained from living black and white adult South African males and females were used to compare the limb proportions of recent human populations (individuals born after 1900). Additionally, osteometric measurements were used to supplement the data for individuals born between 1900 and 1940. Ergotech (Ergonomics Technologies) is an ergonomics consultancy company based in Pretoria, South Africa. They have been conducting anthropometric surveys of the South African military population for over 20 years and maintain the South African National Defence Force (SANDF) anthropometric database. The data were collected in the late 1980's, early 1990's, 2000 and 2013, and therefore also provide the opportunity to assess secular trends in limb proportions and their relationship to stature in the last 25 years for individuals born between 1940 and 2000.

Sample sizes in the Ergotech database are large, for example the 2010 anthropometric data of the SANDF population include measurements of 2589 females and 2988 males between 17 and 68 years of age from four ancestral groups (Asian, African, Coloured and White) (Department of Defence Annual Report 2007/2008, extracted from Anthropometric Data of the SANDF Population:2010, Ergotech). Between 2000 and 2010, all measurements were recorded by students from North-West University (Potchefstroom) from the School of Biokinetics, Recreation and Sports Science. They all had at least a level 1 ISAK (International Society for the Advancement of Kinanthropometry) qualification. From 2011 to present, students from the University of Pretoria, Department of Biokinetics, Sport and Leisure Science recorded the measurements. They were all trained on the required landmark and measurement techniques by an Ergotech research facilitator and their proficiency was evaluated prior to being part of the data collection team.

After a detailed assessment, data collected during a 1986 survey were excluded in the current research. A total of 745 white males were removed from the dataset due to statures that were considerably larger than any population group during that time period. The researchers concluded that a possible measurement error occurred during the 1986 survey since this group was approximately 7 cm taller than corresponding South African samples and Dutch samples from this period.

A non-disclosure agreement was made with Ergotech which allowed limited access to the data to prevent disclosing confidential information, directly or indirectly, for the receiving party's own benefit and/or gain, or for any third party's benefit or gain, or to the detriment of the disclosing party. As such, the data were only allowed to be used in the following ways: 1.) to conduct statistical analyses; 2.) to compare the results from current analyses with results from other studies; 3.) to combine the data with other sampled data and analyse the new sample; 4.) to disseminate the analysis results, in the form of a PhD dissertation and associated publications and lectures, equally to the benefit of all interested parties and the knowledge of South African forensic anthropology.

The complete sample comprised of 6238 individuals (2706 self-identified South African black males [SABM], 726 self-identified South African white males [SAWM], 1894 self-identified South African black females [SABF] and 912 self-identified South African white females [SAWF]) with known age and age at death. In Table 3.1, the composition of the sample and average age, based on the decade in which the person was born, is shown. The complete sample composition with minimum, maximum and average age ranges for all South African groups can be seen in Appendix A1.

Table 3.1 Number of individuals and the average age in each birth cohort for all South African groups (Anthropometric data).

DOB*	Sex and Ancestry							
	Black males		White males		Black females		White females	
	n	Age	n	Age	n	Age	n	Age
1931-1940	-	-	1	68	-	-	-	-
1941-1950	15	57	23	61	13	54	35	54
1951-1960	98	51	133	52	76	46	143	47
1961-1970	498	41	119	42	461	36	205	38
1971-1980	935	30	146	31	609	29	335	27
1981-1990	1150	22	300	24	699	22	194	20
1991-2000	10	20	4	18	36	20	-	-
1990-2000	**2706**	**30**	**726**	**42**	**1894**	**29**	**912**	**32**

*Decade of birth

3.1.1.2 Northern Hemisphere Samples

Living human statures of Swiss white males (SwissWM) and Dutch white males (DutchWM) between 18 and 20 years were used to compare the statures of recent Europeans with those of white South Africans of European descent. Furthermore, North American cadaver statures and anthropometric statures were used to observe the differences in the overall stature differences between Northern Hemisphere groups and black and white South African groups of African and European descent, respectively. The North American anthropometric data comprised of mean measurements of civilian noninstitutionalized U.S. population groups collected during the years 2007 to 2010 (Fryar et al., 2012). The data were obtained from the national health and nutrition examination surveys (NHANES) conducted by the Centers for Disease Control and Prevention's National Center for Health Statistics. The sample comprised of black and white North American adult (over 20 years of age) males and females.

The European data comprised of average heights of Swiss military conscripts (Prof FJ Rühli, Institute of Evolutionary Medicine (IEM), University of Zurich, Switzerland) and Dutch military conscripts (Hoogendoorn, 1986). The measurements were recorded during a medical examination and included the use of standardised and unmodified anthropometric methods (Staub et al., 2011). The Swiss sample comprised of 886 648 individuals. The majority of the sample comprised of white males, however a low percentage of black and asian males may be included. Unfortunately these military data sets contain no information on females and Hoogendoorn (1986) did not include the number of Dutch males used in his analysis. In Table 3.2, the composition and decades of birth are shown for the South African white male and European white male samples

Table 3.2 Number of individuals in each birth cohort for Swiss and South African white males (Anthropometric data).

DOB*	Swiss males	South African white males
1946-50	39947	23
1951-55	38003	44
1956-60	8917	87
1961-65	45977	59
1966-70	41303	59
1971-75	81135	70
1976-80	160576	70
1981-85	168861	229
1986-90	179547	69
1991-95	122382	4
Total	**886648**	**714**

*Date of birth

The North American cadaver sample comprised of 2778 individuals. In Table 3.3, the composition and average age at death is shown for the sample used. The complete composition with minimum, maximum and average age ranges for black and white North American males and females can be seen in Appendix A2.

Table 3.3 The composition and average age at death of individuals for all North American groups arranged by birth cohort (Anthropometric data).

DOB*	Sex and Ancestry			
	Black males	**White males**	**Black females**	**White females**
1900-2000	877	1448	271	182
Average age	**41**	**50**	**37**	**46**

*Decade of birth

3.1.2. Osteometric data

Due to the poor availability of complete skeletons, multiple collections were used. Measurements were not taken from any element displaying features that could have affected the measurements (e.g. pathologies such as osteomalacia, kyphosis, scoliosis, osteoarthritis, surgical procedures or deformities). Furthermore, only individuals with completely fused epiphyses were used to ensure completed growth.

3.1.2.1. Southern Hemisphere (South African) samples

The sample comprised of osteological remains from modern South African collections. It is important to note the source of osteological remains as it may have an effect on the interpretation of the results. The three collections used were the Pretoria Bone Collection, housed at the Department of Anatomy, University of Pretoria (L'Abbe *et al.*, 2005); the Kirsten Collection at the Tygerberg Medical campus, University of Stellenbosch; and the Raymond A. Dart Collection from the School of Anatomical Sciences, University of the Witwatersrand (Dayal *et al.*, 2009). The majority of the skeletons in these collections are from donors and unclaimed persons which are used as cadavers for dissection and teaching purposes. More than half of the collections are made up of black males followed by white males, white females and then black females. Researchers explain the trend in large numbers of black males in the collections to being due to the large migrant-labour work force and the majority of the black individuals are probably from poor SES backgrounds. The white males and females in the collection comprise mainly of older individuals who donated their bodies to the Medical Schools and may represent individuals of middle to higher SES.

The sample comprised of 610 individuals (292 self-identified black males, 71 self-identified white males, 218 self-identified black females and 29 self-identified white females) with known age at death. In Table 3.4, the composition and average age of individuals for each decade of birth (1900 – 2000) is shown, respectively. The complete composition with minimum, maximum and average age ranges for all South African groups can be seen in Appendix A3. Unfortunately, the number of complete skeletons from white females is limited. The majority of donated white female cadavers in South African collections are over the age of 70 at death. Only birth cohorts comprised of more than 5 individuals were used for statistical comparisons.

Table 3.4 Number of individuals and average age in each birth cohort for all South African groups (Osteometric data).

DOB*	Sex and Ancestry							
	Black males		White males		Black females		White females	
	n	Age	n	Age	n	Age	n	Age
1900-1910	28	39	2	45	25	36	1	65
1911-1920	31	41	13	53	29	36	4	51
1921-1930	33	53	14	53	31	35	7	52
1931-1940	49	51	21	52	36	44	6	54
1941-1950	58	45	18	47	41	39	9	48
1951-1960	45	39	2	46	30	35	1	42
1961-1970	37	31	1	28	19	30	-	-
1971-1980	11	25	-	-	7	24	-	-
1981-1990	-	-	-	-	-	-	1	22
1900-2000	**292**	**42**	**71**	**50**	**218**	**37**	**29**	**50**

*Decade of birth

3.1.2.2 Northern Hemisphere Samples

The sample comprised of individuals sourced from the William M. Bass Donated Skeletal Collection, Department of Anthropology, Knoxville, Tennessee and The Hamann-Todd Osteological Collection, Cleveland Museum of Natural History, Cleveland, Ohio.

The remains from the Bass Donated Collection are of individuals born between 1900 and 2011 whose bodies were donated to the Forensic Anthropology Center prior to death, by family members of a deceased person or, occasionally, were obtained from the Medical Examiner. The collection contains remains of individuals from all over the United States of America with the majority from Tennessee and the South-eastern United States while the samples from the Hamann-Todd Collection mainly comprised of cadavers donated to the Western Reserve University Medical School, Case Western Reserve University.

The sample comprised of two separate datasets, one with known dates of birth from the Bass Donated Collection and one overall dataset with no known dates of birth from the Hamann-Todd Collection. The dataset with known dates of birth comprised of 118 individuals (73 self-identified North American white males [NAWM] and 45 self-identified North American white females [NAWF]), while the complete dataset contained 474 individuals (113 self-identified North American black males [NABM], 166 self-identified North American white males, 87 self-identified North American black females [NABF] and

108 self-identified North American white females). In Table 3.5, the composition, year of birth and average age at death are shown for the sample used to study secular trends. The complete data set with minimum, maximum and average age ranges for white North American males and females can be seen in Appendix A4. Table 3.6 shows the composition and average age at death for the complete dataset. The complete composition with minimum, maximum and average age ranges for all North American males and females can be seen in Appendix A5.

Table 3.5 Number of individuals and average age at death for each birth cohort for white North American males and females.

DOB*	Sex		Average Age	
	Males	**Females**	**Males**	**Females**
1931-1940	9	-	52	-
1941-1950	12	7	49	53
1951-1960	25	21	47	51
1961-1970	15	9	40	46
1971-1980	12	8	32	34
1900-2000	**73**	**45**	**44**	**47**

*Decade of birth

Table 3.6 Number of individuals and average age at death for all North American groups.

DOB*	Sex and Ancestry			
	Black males	**White males**	**Black females**	**White females**
1900-2000	113	166	87	108
Average age	**39**	**42**	**34**	**43**

*Decade of birth

3.2 Methods

3.2.1 Anthropometric data

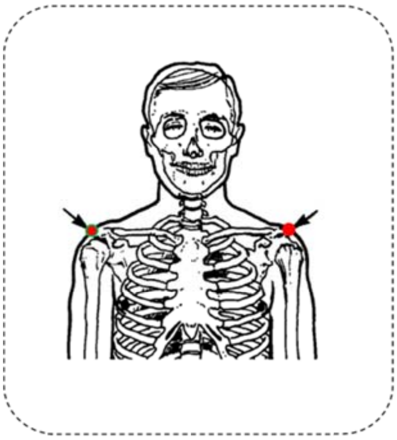
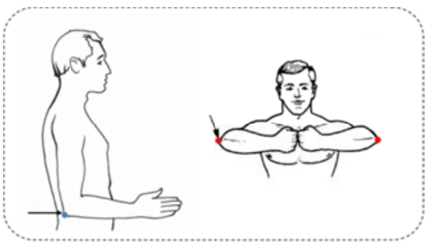
Measurements of the limb lengths, limb segments and stature were used to calculate the limb proportions relative to each other and to stature. This data were compared in order to determine the differences between South African groups, southern and northern hemisphere groups as well as the possible secular changes that are occurring.

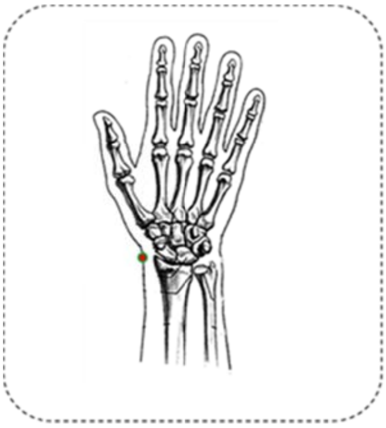
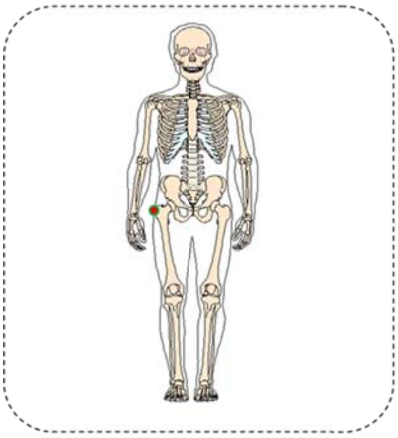
In order to take accurate measurements, a standardized subject posture and landmarks were used by Ergotech to ensure that the differences found in body sizes within a group are not due to variations in body posture or landmarks. The standardized positions and landmarks can be seen in Tables 3.7 and 3.8, respectively.

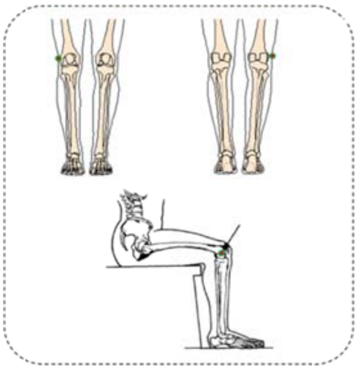
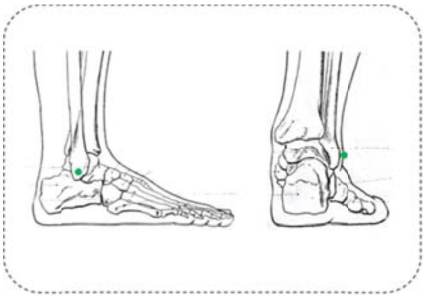
Table 3.7 Anthropometric postures and descriptions (Bredenkamp et al., 2013).

POSTURE	**PROCEDURE**
Anthropometric standing posture	The subjects stand erect, with their weight evenly distributed on both feet, heels together as close as possible, lower limbs and trunk straight without stiffness, and the head erect and looking straight ahead. The arms hang relaxed with the elbows lightly touching the sides with the palms of the hands beside, but not touching the thighs.
Anthropometric sitting posture	The subject sits on a flat surface of a chair with adjustable height, with the long axes of the thighs parallel. The feet are flat on the floor, and the knees are flexed 90 degrees. (The knee angle may be established using a plastic engineering square and three seated landmarks on the lower limb (trochanter, lateral femoral epicondyle, sitting and lateral malleolus). The subject rests the right lower limb inside the edge of the plastic engineering square on the flat sitting surface (horizontal). The other arm of the engineering square hangs over the front edge of the seat (vertical). Using the seat adjustment, the seat is moved up and down until the trochanter and lateral femoral epicondyle landmarks are horizontally in line with each other. The femoral epicondyle and lateral malleolus landmarks on the leg must be vertically aligned (parallel to the vertical arm of the engineering square). The trunk is erect without stiffness; the head is also erect and the subject looks straight ahead. The shoulders are relaxed and the upper arms are hanging loosely at the sides with elbows flexed 90 degrees and hands straight.
Frankfurt plane	This head position is similar to when the "head is erect and subject looks straight ahead." However, when the Frankfort plane is required, the anthropometrist must position the subject's head so that an imaginary line connecting the drawn landmarks at the right tragion and right infraorbitale is horizontal

Table 3.8 Anthropometric landmarks and descriptions (Bredenkamp et al., 2013).

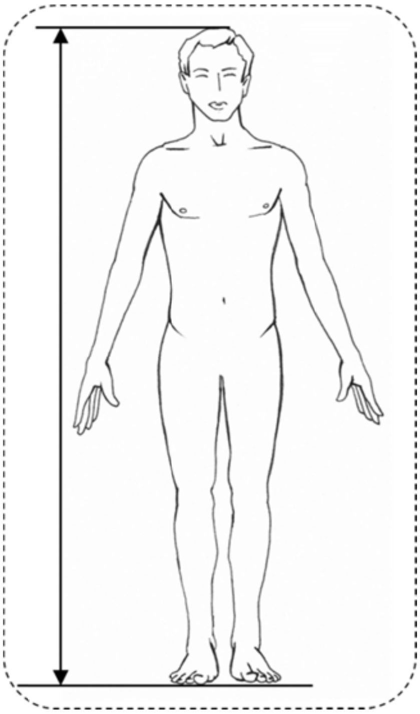
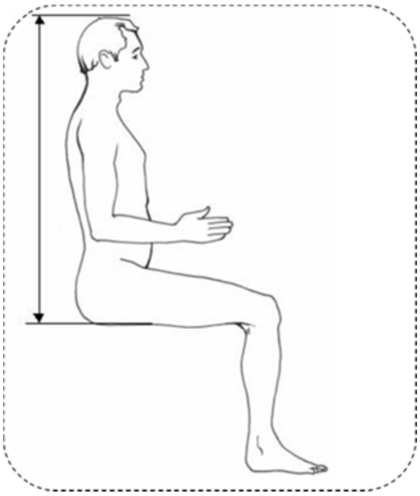
LANDMARK	**DESCRIPTION**	**PROCEDURE**
Acromion	The point of intersection of the superior lateral border of the acromial border and a line running down the middle of the shoulder from the neck to the tip of the shoulder 	Subject is in the anatomical standing position. Stand behind the subject and palpate the tips of both shoulders simultaneously. Draw a line along the lateral bony border of each shoulder. Identify the border by palpating along the ridge of the scapula towards the lateral most prominent point. Then stand at the right side of the subject and lay a tape on the shoulder originating at the trapezius point (at the base of the neck), so that the front edge of the tape lies over the clavicle (collar bone) point, and crosses the drawn acromial border at the tip of the shoulder. Draw a short line along the front edge of the tape where it crosses the acromial border. Repeat the process for the left shoulder.
Olecranon	Olecranon posterior: A point on the posterior of the curvature of the right olecranon process (the elbow) with the elbow flexed about 90 degrees. Olecranon bottom: A point on the bottom of the curvature of the right olecranon process (the elbow) with the elbow flexed about 90 degrees. Olecranon centre: A point on the right of the curvature of the right olecranon process (the elbow) with the elbow flexed about 90 degrees. 	The subject makes fists and brings them together in such a way that the metacarpophalangeal and proximal interphalangeal knuckles are touching. With the volar surfaces of the hands facing outwards and the palm sides facing inwards, the subject raises the arms until they are in a horizontal position roughly parallel to the standing surface. The forearms and fists are in a straight line. Stand at the right side of the subject. Locate the center of the curvature of the elbow by inspection and draw a short cross through the landmark (olecranon, centre).

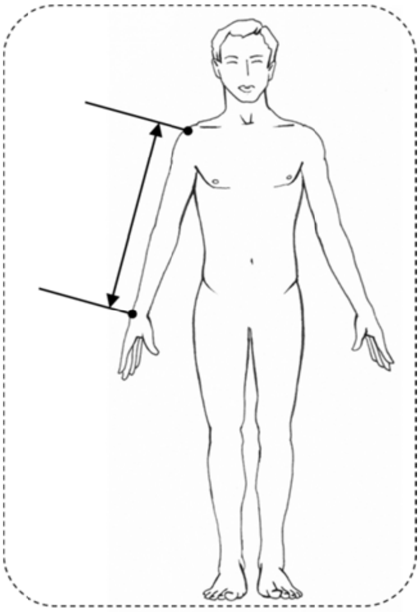
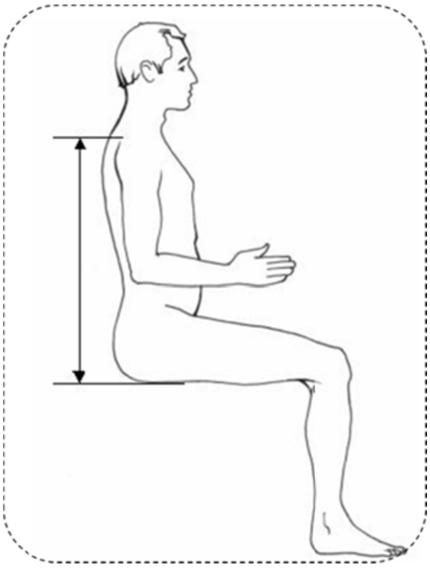
Stylion	The most distal point on the lateral margin of the styloid process of the radius. 	Subject stands with arms hanging by the sides. Stand in front of the subject and lift the subject's wrist to locate the landmark. Using the thumb, the anthropometrist palpates in the triangular space identified by the muscle tendons of the wrist immediately above the thumb (also know as the anatomical "snuff box"). Once the snuff box has been identified, palpate in the space between the distal radius and the scaphoid in order to correctly identify the styloid process. Draw a cross (+) over the landmark.
Trochanter	The superior point of the greater trochanter of the right femur of a standing subject. 	Subject stands erect with weight distributed equally on both feet. Stand behind the subject. Use the heel of the hand and palpate the lateral aspects of the gluteal muscle. Support the left side of the subject. Move to the side of the subject. Use the pads of the fingers to simultaneously locate the left and right greater trochanters (near the hip joint). Work fingers up along the front and back of the right trochanter to find its highest point. On a number of subjects it will help to have the subject move the thigh back and forth or to rotate the foot medially and laterally. Draw a short horizontal line at the level of the landmark.

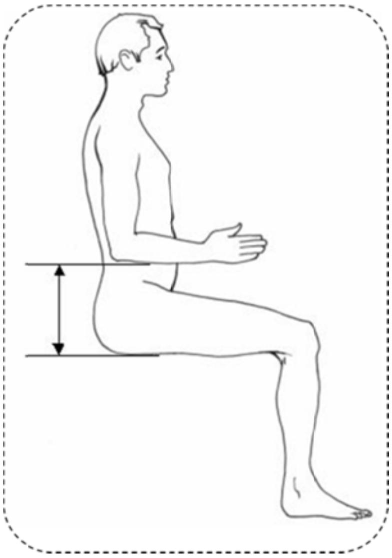
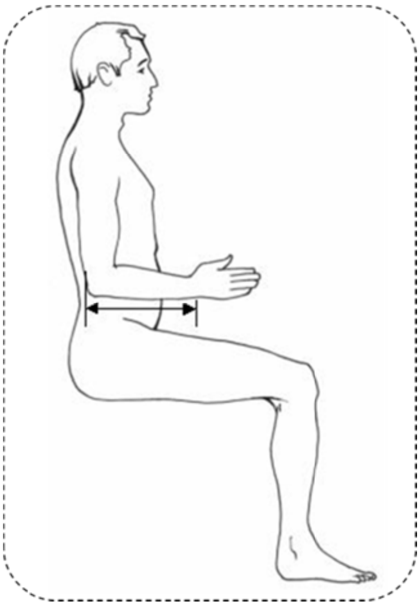
Lateral femoral epicondyle	Lateral point of the right femoral epicondyle. 	Subject stands erect on a box with the weight distributed equally on both feet. Stand in front of the subject and, with one hand, grasp the bony prominences of the bottom of the femur (femoral epicondyles) located to the medial and lateral sides of the right knee. Have the subject flex the knee to help locate these structures. The subject then extends the knee. When the lateral point of the lateral femoral epicondyle is located, use the thumb or index finger of the other hand to mark its place and draw a cross (+) through the landmark. The lateral femoral epicondyle point, when the subject is sitting, is located by the same means as when the subject stands. On this landmark draw a "0" about 5 mm in diameter.
Lateral malleolus	The lateral point of the lateral malleolus. 	Subject stands on an anthropometry box with the weight distributed equally on both feet. Stand on the subject's right side and use a marking block to locate the most protruding point on the lateral malleolus. Draw a cross (+) through the point.

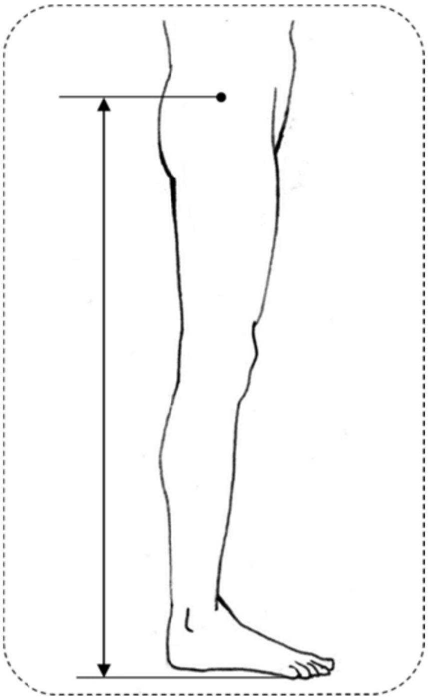
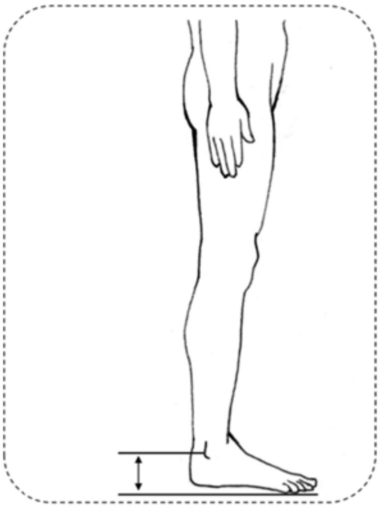
All measurements were taken from the right side of the individual and to the nearest millimetre (mm). The measurements and their descriptions can be seen in Table 3.9. The descriptions used by Ergotech are not anatomically defined. Therfore, the terminology of certain measurement were changed (original used by Ergotech is indicated by *).

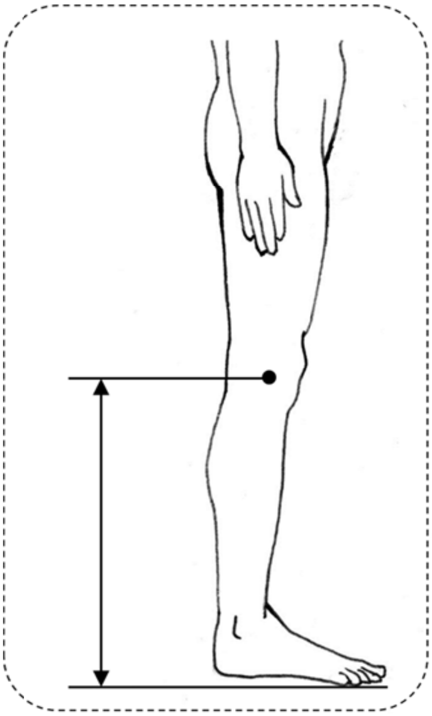
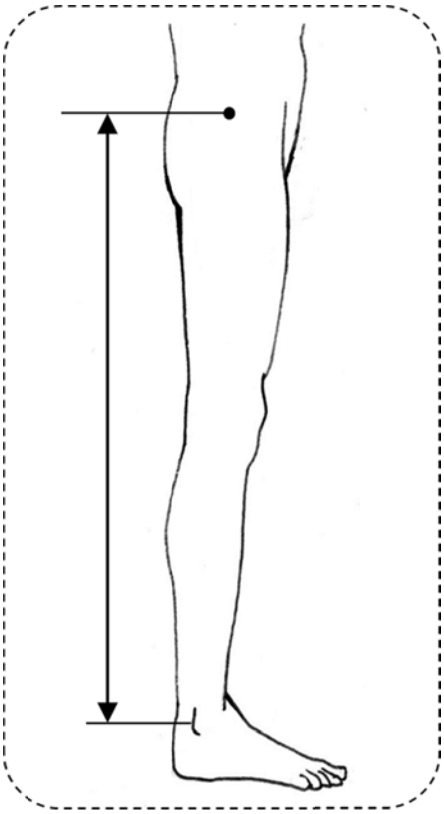
Table 3.9 Anthropometric measurements and descriptions (Bredenkamp et al., 2013).

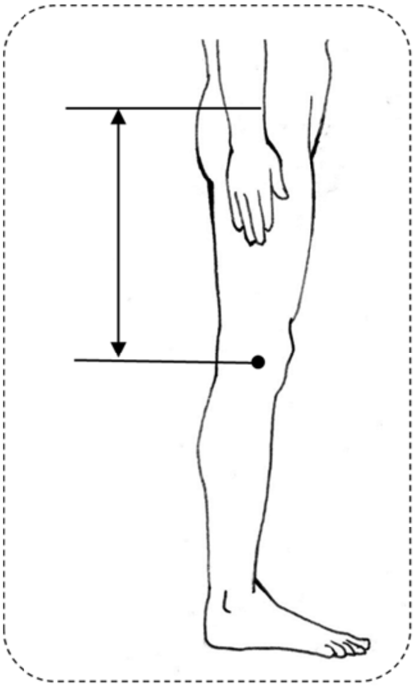
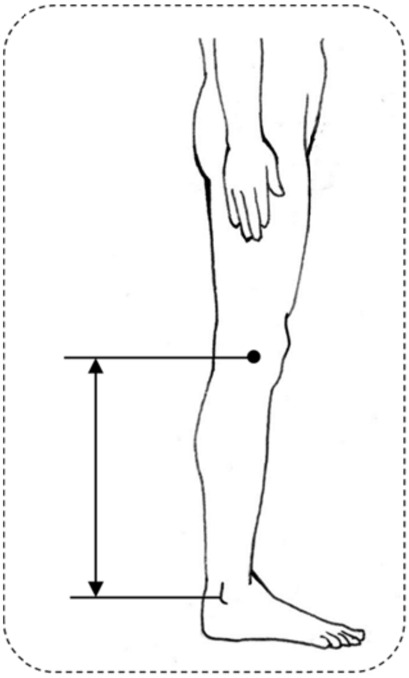
ELEMENT	MEAUSREMENT	DESCRIPTION
General	Stature 	Subject is recorded in the anthropometric standing position with the head in the Frankfort plane. Stand at one side of the subject and use a wall mounted stadiometer to measure the vertical distance between the standing surface and the top of the head (vertex). Note the blade of the anthropometer must be across the top of the head to ensure measurement of the maximum distance. Use firm pressure to compress the subject's hair. The measurement is taken at the maximum point of quiet respiration.
	Sitting height 	Subject is in the anthropometric sitting position with the head in the Frankfort plane. Stand at one side of the subject and use an anthropometer to measure the vertical distance between the sitting surface and the top of the head (vertex). Note the blade of the anthropometer should be across the top of the head to ensure measurement of the maximum distance. Use firm pressure to compress the subject's hair. The measurement is taken at the maximum point of quiet respiration.

Upper Limbs	Upper limb length  *Ergotech: Outside arm length	Acromion, right – Stylion, right. Subject is in the anthropometric standing position. Stand to the right side of the subject and use a Harpenden anthropometer (Ulijaszek *et al.*, 1998) to measure the distance between the drawn Acromion and Stylion landmarks on the right arm. The measurement is made at the maximum point of quiet respiration.
	Acromial height 	Sitting surface – acromion, right. Subject is in the anthropometric sitting position. Stand to the right side of the subject, and use an anthropometer to measure the vertical distance between the sitting surface and the drawn acromion landmark on the tip of the right shoulder. The measurement is made at the maximum point of quiet respiration.

	Elbow rest height 	Subject sits in the anthropometric sitting posture with the arms bent 90 degrees at the elbow (palms facing medially). Stand behind the subject and use an anthropometer to measure the vertical distance between the sitting surface and the bottom of the flexed elbow (olecranon bottom). The measurement is taken at the maximum point of quiet respiration.
	Arm length *Ergotech: Upper arm length	Calculated: Acromial height minus the elbow rest height
	Forearm  *Ergotech: Elbow to wrist length	Olecranon, posterior – stylion. Subject sits in the anthropometric sitting posture with the arms bent 90 degrees at the elbow (palms facing medially). Stand on the right side of the subject and use a sliding calliper (or Harpenden anthropometer) to measure the distance between the posterior olecranon landmark on the right elbow and the drawn stylion landmark on the right wrist. Ensure that the beam of the calliper is parallel to the long axis of the lower arm. Place the fixed blade on the posterior olecranon landmark. Exert only enough pressure to attain contact between the calliper and the skin.

Lower limbs	Total lower limb length  *Ergotech: Trochanteric height	Subject is in the anthropometric standing position. Stand at the right of the subject and use an anthropometer to measure the vertical distance between the standing surface and the drawn trochanterion landmark (Subject stands erect with weight distributed equally on both feet. Stand behind the subject. Use the heel of the hand and palpate the lateral aspects of the gluteal muscle. Support the left side of the subject. Move to the side of the subject. Use the pads of the fingers to simultaneously locate the left and right greater trochanters (near the hip joint). Work fingers up along the front and back of the right trochanter to find its highest point. On a number of subjects it will help to have the subject move the thigh back and forth or to rotate the foot medially and laterally. Draw a short horizontal line at the level of the landmark).
	Lateral malleolus height 	Subject is in the anthropometric standing position on a box with weight equally distributed. Stand at the right side of the subject and use a sliding calliper (or Harpenden anthropometer) to measure the vertical distance between the standing surface and the drawn lateral malleolus landmark on the outside of the right ankle.

	Lateral femoral epicondyle height 	Subject is in the anthropometric standing position on a box with weight equally distributed. Stand at the right side of the subject and use an anthropometer (or sliding calliper or Harpenden anthropometer) to measure the vertical distance between the standing surface and the marked standing lateral femoral epicondyle landmark on the outside of the right knee.
	Lower limb length 	Calculated: Total lower limb length minus the lateral malleolus height (Length of the lower limb excluding the height of the feet).

	Thigh length  *Ergotech: Thigh link	Calculated: Total lower limb length minus the lateral femoral epicondyle height The vertical distance between the trochanterion landmark on the thigh and the lateral femoral epicondyle landmark
	Leg length  *Ergotech: Calf link	Calculated: Lateral femoral epicondyle height minus the lateral malleolus height The vertical distance between the lateral femoral epicondyle landmark on the side of the knee and the lateral malleolus on the outside of the ankle

Following basic statistical analyses of the raw data, the various anthropometric limb measurements were evaluated and the following indices and ratios were calculated and compared:

A. General

- Sitting height ratio = sitting height:stature (Weiner and Lourie, 1969)
- Intermembral index = (upper limb length/lower limb length)x100 (Schultz, 1926)

B. Upper limb

- Brachial index = (forearm length/arm length)x100 (Verneau, 1906)
- Upper limb ratio= upper limb length:stature
- Arm ratio = arm length:stature
- Forearm ratio = forearm length:stature

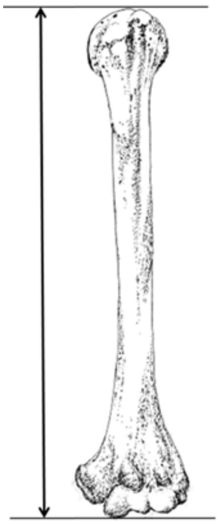
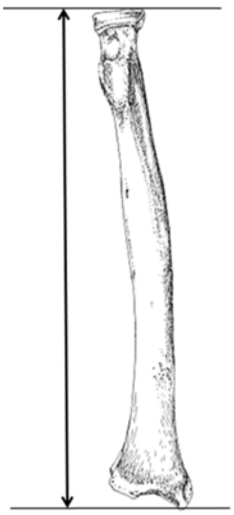
C. Lower limb

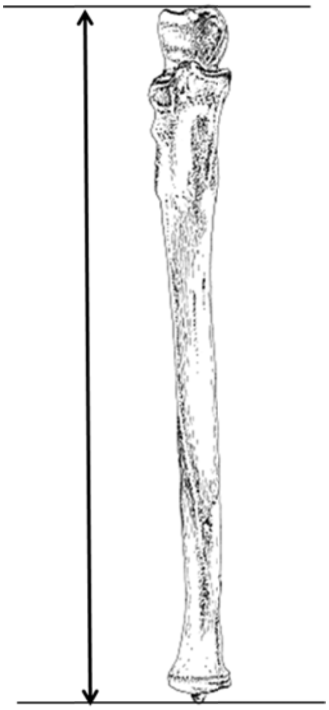
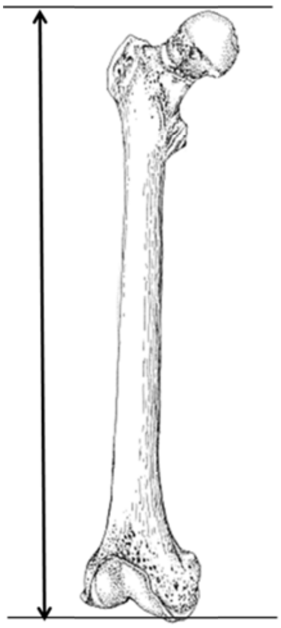
- Crural index = (leg/thigh link)x100 (Verneau, 1906)
- Total lower limb ratio = total lower limb length:stature
- Lower limb ratio = lower limb:stature (Leitch, 1951)
- Thigh ratio = thigh length:stature
- Leg ratio = leg length:stature

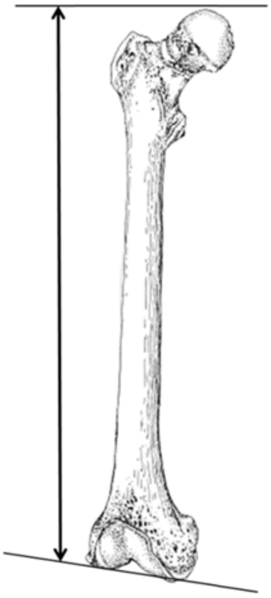
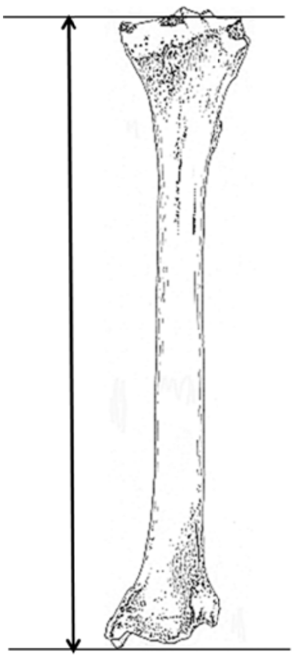
3.2.2 Osteometric data

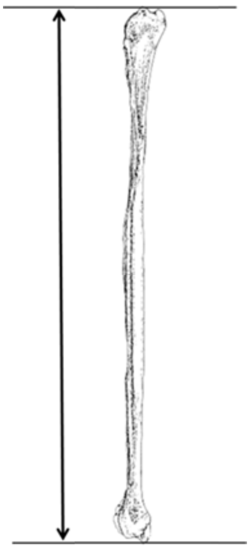
Measurements from all six major long bones were taken. The measurements and descriptions were based on established data collection protocols which are currently being used as a standard in South African laboratories to ensure comprehensibility and lack of bias (Moore-Jansen *et al.*, 1994; Bass, 1995). All measurements were taken from the left side unless, in the rare cases, where an anatomical abnormality made it necessary to measure on the right side. The measurements were taken to the nearest millimetre (mm). The descriptions, instruments used and references can be seen in Table 3.10.

Table 3.10 Osteometric measurements and descriptions (Bass, 1995).

BONE	MEASUREMENT	DISCRIPTION	INSTRUMENT
Humerus	Maximum length 	Place the head against the fixed vertical of the board and adjust the movable upright to the distal end. Raise the bone slightly and move it up and down as well as from side to side until the maximum length is obtained	Osteometric board
Radius	Maximum length 	Measuring maximum length from the head to the tip of the styloid process	Osteometric board

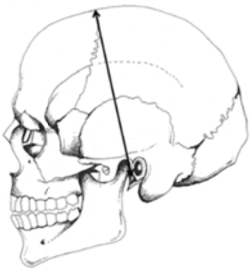
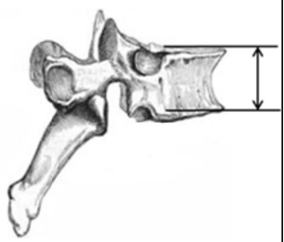
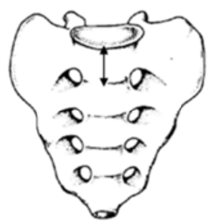
Ulna	Maximum length 	Maximum length is from the top of the olecranon process to the tip of the styloid process	Osteometric board
Upper limb	Arm length	The sum of the humerus maximum length and the radius maximum length	Calculated
Femur	Maximum length 	Distance from the most superior point on the head of the femur to the most inferior point on the distal condyles. Place the medial condyle against the fixed vertical end board while applying the movable upright to the femoral head	Osteometric board

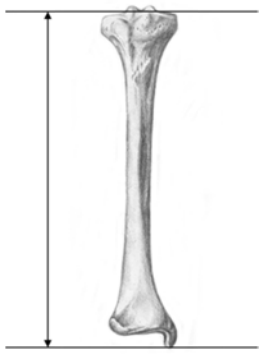
	Bicondylar length 	Distance from the most superior point on the head to a plane drawn along the inferior surfaces of the distal condyles. Place both distal condyles against the fixed vertical end board with applying the movable upright to the femoral head.	Osteometric board
Tibia	Condylo-malleolar length 	Distance from the superior articular surface of the lateral condyle to the inferior tip of the medial malleolus. Place the tibia on the board, resting on its posterior surface with the longitudinal axis parallel to the instrument. Place the lip of the medial malleolus on the vertical endboard and press the movable upright against the proximal articular surface of the lateral condyle of the medial malleolus	Osteometric board

Fibula	Maximum length 	Maximum distance between the most superior point on the fibula head and the most inferior point on the lateral malleolus	Osteometric board
Lower limb	Total lower limb length	Sum of the bicondylar length of the femur, condylo-malleolar length of the tibia and talo-calcaneal height of the foot	Calculated
	Lower limb length	Sum of the bicondylar length of the femur, condylo-malleolar length of the tibia	Calculated

Additionally, the measurements necessary to calculate the total skeletal height (TSH) were recorded according to the Fully method to estimate height from skeletal remains (Fully, 1956). The descriptions, instruments used and references can be seen in Table 3.11. The measurements for vertebral height were recorded using similar descriptions used by other South African stature studies (Bidmos and Asala, 2005) to allow future comparisons to be made.

Table 3.11 Osteometric measurements and descriptions for Total Skeletal Height (TSH) (Fully, 1956; Martin and Knussmann, 1988; Bidmos and Asala, 2005).

BONE	**MEASUREMENT**	**DISCRIPTION**	**INSTRUMENT**
Skull	Basi-bregmatic height 	The direct distance from the lowest point on the anterior margin of the foramen magnum (basion) to the point where the sagittal and coronal sutures meet (bregma)	Sliding caliper
Vertebrae	Anterior heights of C2 – L5 	The distance taken from the superior margin to the inferior margin of the vertebral bodies in the anterior midline. The 2nd cervical vertebra is measured from the most superior point on the odontoid process to the inferior margin of the body in the anterior midline	Sliding caliper
Sacrum	Anterior height of S1 	The measurement taken from the superior margin to the inferior line of the vertebral body in the anterior midline. If S1 is fused to S2, the measurement is taken in the midpoint of the fusion line.	Sliding caliper
Femur	Bicondylar length 	Distance from the most superior point on the head to a plane drawn along the inferior surfaces of the distal condyles. Place both distal condyles against the fixed vertical end board while applying the movable upright to the femoral head.	Osteometric board

Tibia	Condylo-malleolar length 	Distance from the superior articular surface of the lateral condyle to the inferior tip of the medial malleolus. Place the tibia on the board, resting on its posterior surface with the longitudinal axis parallel to the instrument. Place the lip of the medial malleolus on the vertical endboard and press the movable upright against the proximal articular surface of the lateral condyle of the medial malleolus	Osteometric board
Foot	Talo-calcaneal height 	The distance from the superior articular surface of the talus to an imaginary horizontal line touching the inferior surface of the calcaneus. The measurement is taken with the two bones articulated.	Osteometric board

In circumstances where the vertebral column was incomplete, the average of the vertebrae above and below the missing vertebra was used to estimate the measurements for the missing vertebra. In order to estimate a sitting height, the basi-bregmatic height and heights of the vertebrae C2 to S1 were summed. Since anthropometric sitting height is taken including bony elements of the pelvis in a sitting position, this measurement is only used to roughly estimate the sitting height from skeletal remains. Furthermore, the trunk height was also estimated to indicate the length of the skeletal trunk by adding the heights of the thoracic and lumbar vertebrae and the height of S1 (T1-S1).

The limb measurements were then evaluated and the following measurements, indices and ratios were calculated and compared:

A. General

- Sitting height ratio = sitting height:TSH (Weiner and Lourie, 1969)
- Intermembral index = (humerus max length+radius max length/femur max length+tibia condylo-malleolar length)x100 (Schultz, 1926)

B. Arm

- Brachial index = (radius max length/humerus max length)x100 (Verneau, 1906)
- Upper limb ratio = humerus max length+radius max length:TSH
- Arm ratio = humerus max length:TSH
- Forearm ratio 1 = radius max length:TSH
- Forearm ratio 2 = ulna max length:TSH

C. Lower limb:

- Crural index = (tibia length [min malleolus]/femur bicondylar length)x100 (Verneau, 1906)
- Total lower limb ratio = femur bicondylar length+tibia condylo-malleolar length+ talo-calcaneal height:TSH
- Lower limb ratio = femur bicondylar length+ tibia condylo-malleolar length:TSH
- Thigh ratio 1 = femur max length:TSH
- Thigh ratio 2 = femur bicondylar length:TSH
- Leg ratio 1 = tibia condylo-malleolar length:TSH
- Leg ratio 2 = fibula max length:TSH

3.3 Statistical analysis

3.3.1 Statistical tests used for data analysis

All analyses were performed using the computer package SAS® 9.3. In order to evaluate the data, basic descriptive statistics were run on the sample to determine the sample sizes, means and averages for each sex and population group. Prior to further statistical analysis, the data were explored for outliers. Outliers are measurements that are distinctly different from other observations and may be due to measurement or data entry errors. Only outliers that were exceptionally higher or lower than other observations were removed. Outliers closer to the other observations were kept in the sample as they represent the normal outer edges of human variation. Outlier detection was conducted with visual assessment through boxplots, which graphically represent summary statistics such as interquartile ranges as a measure of the spread of the data. Any value which falls outside one and a half times the length of the interquartile range was isolated and removed from the dataset.

In order to evaluate the mean differences between two groups, nonparametric statistical tests were performed using PROC NPAR1WAY in SAS® software. The NPAR1WAY procedure performs nonparametric tests for location and scale differences across a one-way classification and provides standard analysis of variance on the empirical distribution. A non-parametric test is usually performed on data which do not come from a normal distribution described by two parameters, mean and standard deviation. Since the data are classified into two independent samples (e.g. black males vs white males), tests are based on simple linear rank statistics and produce information on the number of observations and the mean. NPAR1WAY makes use of a Wilcoxon rank sum test which is a non-parametric analogue to a two sample t-test. The Wilcoxon rank sum test provides information on the number of observations, sum of the Wilcoxon scores, expected sum under the null hypothesis of no difference among class levels, standard deviation under the null hypothesis and the mean score. Finally the NPAR1WAY makes use of one-way analysis of variance (ANOVA) statistics based on the Wilcoxon scores, known as the Kruskal-Wallis test. The Kruskal Wallis test is used when there is one nominal variable with more than two categories and one measurement variable which does not meet the normality assumption of a one-way ANOVA. Thus, it is a non-parametric test which does not assume that the data come from distribution described by two parameters; mean and standard deviation.

Box plots were used to graphically view the differences between groups. A box plot is a pictorial representation of the data distribution of a metric and non-metric variable. The data distribution is represented by the upper (75^{th}) and lower (25^{th}) quartiles which form the upper and lower boundaries of the box with the median as a solid line in the box. The size of the box indicates the spread of the data (e.g. the larger the box, the greater the spread). The lines or whiskers extending from the box represents the distance to the minimum and maximum observation that are less than one quartile range from the box. All other values are outside the whiskers represent outliers that range between 1 and 1.5 quartiles away from the box (Hair *et al*., 2006). Furthermore, the statistical program STATA (StataCorp) was used to compare the average stature between white males from South Africa and Europe.

3.3.2 Analysis of intra- and inter-observer error

Ten individuals were randomly selected from the South African osteometric sample to demonstrate the differences between repeated measurements by the primary observer (intra-observer error) or the differences between a single measurement taken by a second observer (interobserver error). Intra- and inter-class correlation is a measure of intra and inter-rater agreement. Ideal results for these tests are to obtain intra-class correlation value of 1.00, which indicates that the measurements can be consistently and accurately repeated 100% of the time. According to Allen (1982), any value classified over 0.75 is considered a high correlation. Possible variables that could affect measurement error were observer experience and clarity of measurement definitions.

3.3.3 Comparisons made during statistical analysis

Due to the incomplete and limited data available, not all groups and all relationships could be compared. Therefore, as many complete comparisons as possible were made and will be discussed under separate headings in the results section. The following abbreviations will be used to refer to the different population groups: South African black males (SABM); South African white males (SAWM); South African black females (SABF); South African white females (SAWF); North American black males (NABM); North American white males (NAWM); North American black females (NABF); North American white females (NAWF); Swiss white males (SwissWM) and Dutch white males (DutchWM). The comparisons that could be made included:

Anthropometry: Population differences and secular trends in stature

South Africa

The statures of the different South African population groups were compared to each other (SABM vs SAWM and SABF vs SAWF) over the total birth period (1900-2000) as well as per decade to examine the trends in stature during the past century but also the trends that occurred per decade during this period within a population group.

Southern and Northern hemisphere population groups

The statures of the different population groups from South Africa were compared to North American (NA) groups (as represented by cadaver heights and anthropometric means) over the total birth period (SABM vs NABM, SAWM vs NAWM, SABF vs NABF, SAWF vs NAWF) and to Swiss and Dutch white males (SAWM vs SwissWM vs DutchWM) per half decade (five year periods).

Anthropometry: Population differences and secular trends in limb ratios

South Africa

The different South African population groups (SABM vs SAWM and SABF vs SAWF) were compared to each other over the total birth period (1900-2000) as well as per decade to examine the trends in limb proportions and their relationships to overall stature during the past century within a population group.

Osteometry: Population differences and trends in Total Skeletal Height (TSH)

South Africa

The TSH of the different South African population groups (SABM vs SAWM and SABF vs SAWF) were compared to each other over the total birth period (1900-2000) as well as per decade.

Southern and Northern hemisphere population groups

The statures (TSH) of white South African males and females were compared to white North American male and female groups (SAWM vs NAWM, SAWF vs NAWF) over the total birth period (1900-2000). Population groups of African descent could not be included in the osteometric analysis since only cadaver statures of black North Americans were available.

Osteometry: Population differences and secular trends in limb proportions

South Africa

The limb proportions for different South African (SA) population (SABM vs SAWM and SABF vs SAWF) groups were compared to each other over the total birth period (1900-2000) as well as per decade. All the recorded measurements and indices/ratios were compared.

Southern and Northern hemisphere population groups

The limb lengths and their relationship to stature of the different population groups from white South Africa were compared to white North American (NA) groups over the total birth period (SAWM vs NAWM, SAWF vs NAWF). All the recorded indices/ratios were compared for this sample.

3.3.4 Overall human variation as observed in the South African osteometric data

Discriminant function analysis (DFA) is used to identify relationships between qualitative dependent and quantitative independent variables to identify which variables are related to the dependent variable as well as its prediction given the independent variable. Furthermore, stepwise DFA can be applied to the discriminant function which uses a smaller set of variables which discriminate between the dependant variable and the entire data set. DFA is a useful tool to predict category membership (Green and Salkind, 2008). DFA is sensitive to outliers and the size of the smallest group should be larger than the number of predictor variables. Also, DFA assumes multivariate normality, homoscedasticity, linearity and independence (the score of one variable is assumed to be independent of the score of that variable for all other groups) (Green and Salkind, 2008; Büyüköztürk and Çokluk-Bökeoğlu, 2008). DFA was used to evaluate overall population similarities and differences using a multivariate approach. For this study, DFA was used as a classification model.

Chapter 4: Ancestry differences and secular trends in anthropometric stature

In this section differences in stature between South Africans of European and African descent and secular trends in anthropometric stature were analysed. In addition, the statures of the South African groups were compared to those from selected European and North American groups in order to analyse the differences in stature between the southern and northern hemispheres.

4.1 Ancestry differences and secular trends in the anthropometric stature of South African population groups

The anthropometric statures per birth cohort and for the overall period were compared for South African groups to determine whether differences exist between individuals of African and European descent. Also, the anthropometric stature of South African groups were analysed to observe whether any secular trends are taking place within each population group. This can possibly aid in the understanding of why certain differences are observed between the population groups.

4.1.1 Ancestry differences and trends in the anthropometric stature of South African black and white males

Ancestry differences between mean statures

The mean stature and sample sizes of both the South African black and white males are shown in Table 4.1. The sample comprised of a total of 2668 black males and 715 white males with dates of birth (DOB) ranging from 1941 to 2000. The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for anthropometric stature, classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between the mean statures of South African black males (SABM) and South African white males (SAWM). In Figure 4.1 the difference in the average stature between SABM and SAWM for all birth cohorts combined can be seen. SABM had an overall average stature of 1711.9 mm while SAWM were significantly taller with an overall average stature of 1786.1 mm (Kruskal-Wallis Chi-Squared = 581.55; $p < 0.0001$).

Table 4.1 demonstrates that across all decades the average statures of SAWM were significantly different from those of SABM with SAWM being taller than SABM. During the

1990's no significant difference could be demonstrated which is possibly due to the small sample sizes (SABM: n = 10; SAWM: n = 4) of this birth cohort.

Table 4.1 The sample sizes, mean stature and Kruskal-Wallis results for anthropometric stature between South African black and white males per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-squared value	p-value
1941-1950	SABM SAWM	15 23	1708.6 1777.7	87.36 75.83	6.98	**0.0082**
1951-1960	SABM SAWM	98 131	1702.7 1779.8	65.28 67.87	58.81	**<0.0001**
1961-1970	SABM SAWM	494 118	1707.9 1787.2	63.57 69.84	106.63	**<0.0001**
1971-1980	SABM SAWM	918 140	1709.6 1789.2	63.15 73.78	148.28	**<0.0001**
1981-1990	SABM SAWM	1133 298	1716.3 1787.3	62.30 68.63	222.85	**<0.0001**
1991-2000	SABM SAWM	10 4	1726.9 1804.5	86.32 34.54	1.81	0.1786
1941-2000	SABM SAWM	2668 715	1711.9 1786.1	61.25 65.66	581.55	**<0.0001**

DOB = Date of birth

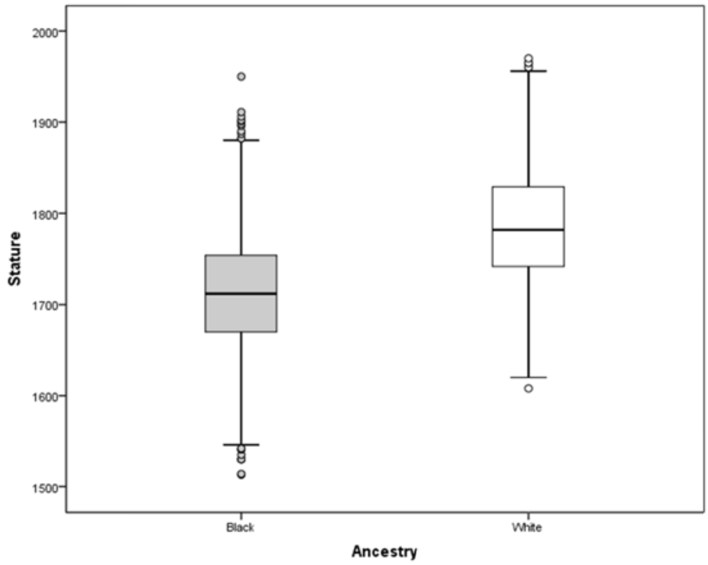


Figure 4.1 Ancestry differences in the overall anthropometric stature between South African black and white males for the all birth cohorts combined.

Secular trends in mean statures

Comparison of the average anthropometric stature plotted against Date of Birth (DOB) cohort of a decade using the SAS NPAR1WAY procedure for SABM and SAWM indicated that the average stature increased between 1941 and 2000 from 1708.6 mm to 1726.9 mm and from 1777.7 mm to 1804.5 mm for SABM and SAWM, respectively (Table 4.1). Figure 4.2 demonstrates the differences in the secular trend between SABM and SAWM. From 1941 to 2000 the stature of SABM has demonstrated a significant positive secular trend (Kruskal-Wallis Chi-squared = 11.3872; p = 0.0442). The average stature initially decreased with 6 cm from the 1940's to the 1950's. After this period there has been a gradual increase in the stature with an average increase of 5 mm, 1.7 mm, 6.7 mm and 10.6 mm per decade. However, due to the small sample size of people born in the 1990's (n = 10), the stature in this birth cohort may be overestimated.

The results from 1931 – 1940 for the SAWM were excluded since only one individual was available and there were no data for SABM. From 1941 to 2000 the stature of SAWM has demonstrated no significant positive secular trend (Kruskal-Wallis Chi-Squared =2.8574; p = 0.8265). The stature increased and decreased during the whole period, showing non-directional fluctuations. The stature increased with 2.1 mm, 7.3 mm and 2.0 mm per decade from the 1940's to the 1970's. From the 1970's to the 1980's the stature decreased with 1.9 mm and then increased again with 17.2 mm in the 1990's. However, due to the small sample size (n=4) of individuals born in the 1990's, the stature may not be accurately represented.

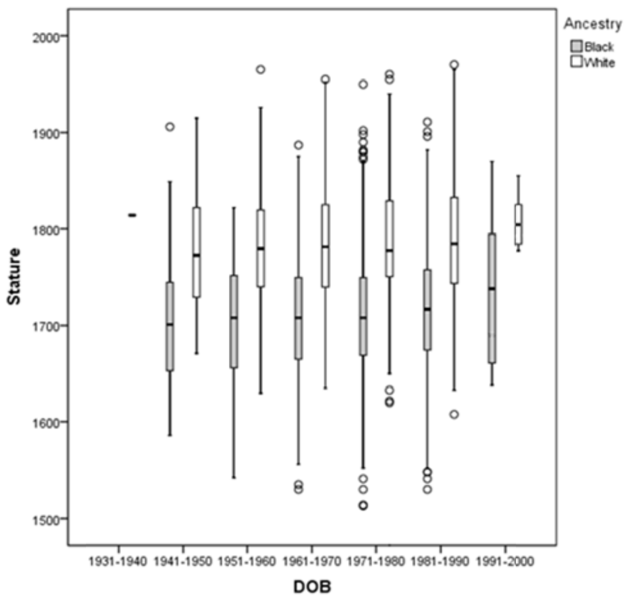


Figure 4.2 Secular trends in anthropometric stature of South African black and white males.

4.1.2 Ancestry differences and secular changes in the anthropometric stature of South African black and white females

Ancestry differences between mean statures

The mean stature and sample sizes of the South African black and white females are shown in Table 4.2. The sample comprised of a total of 1881 black females and 895 white females. The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for anthropometric stature, classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between overall statures of South African black females (SABF) and South African white females (SAWF). Table 4.2 demonstrates the differences in stature between SABF and SAWF per decade of birth. Across all decades SAWF were significantly taller than SABF. In Figure 4.3 the difference in the average stature between SABF and SAWF for the combined birth cohort can be seen. SABF had an overall average stature of 1598.1 mm while white females were significantly taller with an overall average stature of 1661.5 mm (Kruskal-Wallis Chi-Squared = 551.15; $p < 0.0001$).

Table 4.2 The sample sizes, mean stature and Kruskal-Wallis results for anthropometric stature between South African black and white females per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-squared value	p-value
1941 - 1950	SABF	13	1582.6	51.15	12.43	**0.0004**
	SAWF	31	1646.4	59.30		
1951 - 1960	SABF	75	1592.4	71.72	46.85	**<0.0001**
	SAWF	142	1661.0	57.06		
1961 - 1970	SABF	460	1592.4	58.74	160.24	**<0.0001**
	SAWF	204	1667.7	63.22		
1971 - 1980	SABF	604	1598.3	60.48	188.61	**<0.0001**
	SAWF	327	1659.4	59.98		
1981 - 1990	SABF	693	1602.6	60.97	110.90	**<0.0001**
	SAWF	191	1661.4	67.85		
1941 - 1990	SABF	1881	1598.1	58.91	551.15	**<0.0001**
	SAWF	895	1661.5	57.47		

DOB = Date of birth

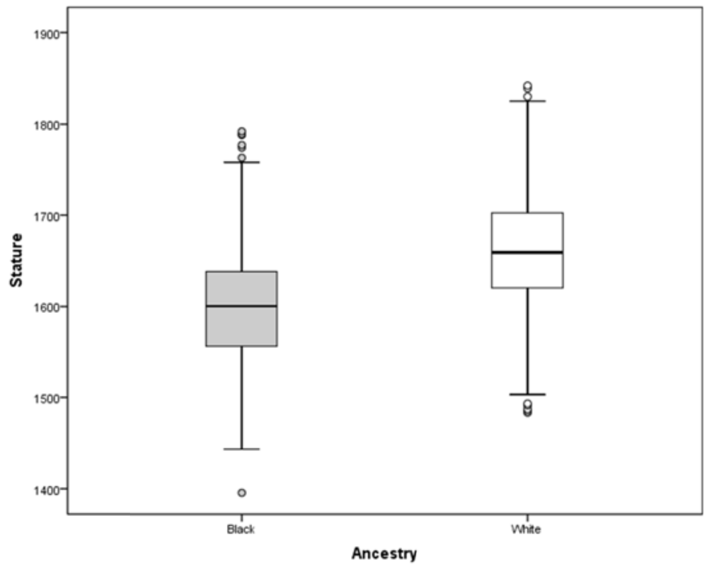


Figure 4.3 Ancestry differences in the anthropometric stature between South African black and white females for the overall period.

Secular trends in mean statures

Comparison of the average anthropometric stature plotted against DOB using the SAS NPAR1WAY procedure for SABF and SAWF indicated that the average stature increased between 1941 and 2000 from 1582.6 mm to 1597.8 mm for SABF and from 1646.4 mm to 1661.4 mm for SAWF (Table 4.2 and Figure 4.4). However, none of these increases were statistically significant ($p > 0.05$). The stature of SABF fluctuated with an initial increase of 9.8 mm from the 1940's to 1950's and remained approximately unchanged from the 1950's to 1960's. Between the 1960's to 1970's and 1970's to the 1980's the stature again increased with 5.9 and 4.3 mm per decade, respectively. From the 1980's to 1990's the stature again decreased with 4.8 mm (overall Kruskal-Wallis Chi-Squared = 10.5863; $p = 0.0602$).

The stature for SAWF also demonstrated no significant positive secular trend (Kruskal-Wallis Chi-Squared = 5.2251; $p = 0.2650$). The stature increased from the 1940's to 1960's with 14.6 mm and 6.7 mm per decade. From the 1960's to the 1970's the stature decreased with 8.3 mm and then increased again with 2.0 mm. Unfortunately there were no SAWF in the 1990's birth cohort.

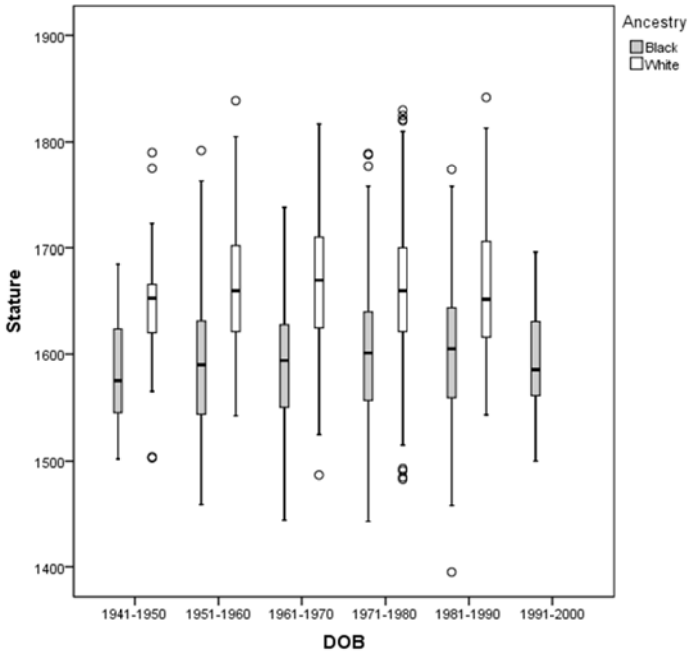


Figure 4.4 Secular trends in anthropometric stature of South African black and white females.

4.1.3 Comparison of the differences in secular trends in the anthropometric stature of South African population groups

The differences in the mean stature between males and females are clearly illustrated in Figure 4.5. Individuals of European descent have greater mean statures than their counterparts of African descent. In both groups, males are taller than the females. Although SABM are the only group that exhibits a significant positive secular trend, their mean stature is still much lower than those of SAWM. Of the four groups, SAWF appear to exhibit the greatest lack of a positive secular trend.

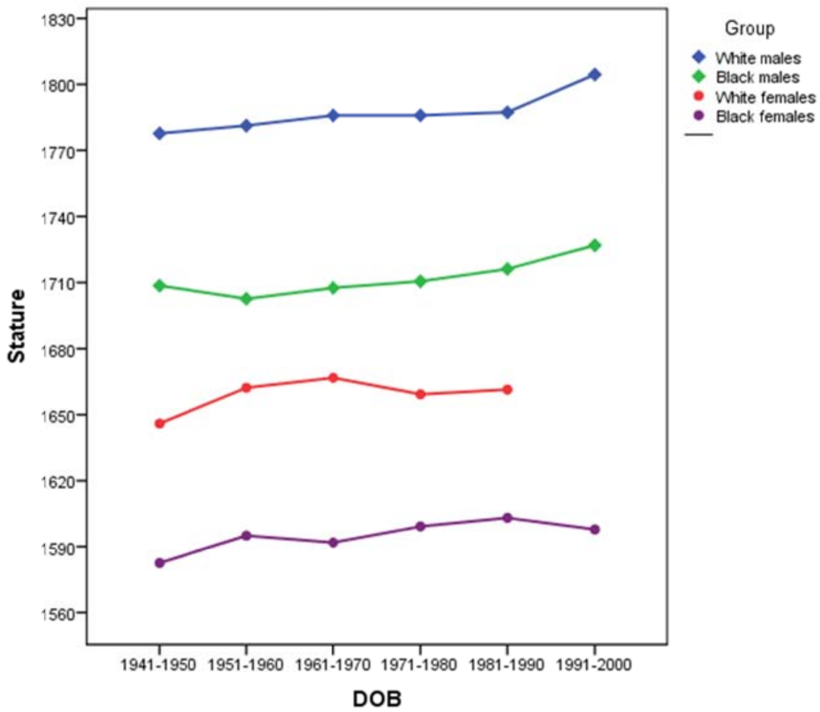


Figure 4.5 Comparisons of the differences in the secular trends in anthropometric stature for South African population groups.

4.2 Differences and secular trends in the anthropometric stature of Southern and Northern hemisphere population groups

In this section the anthropometric statures of the different population groups from South Africa (SA) were compared to the corrected cadaver heights of North American (NA) groups over the total birth period in order to determine whether differences exist between Northern and Southern hemisphere groups. The cadaver heights of North American groups were downward adjusted with 2.5 cm as recommended by Trotter and Gleser (1951, 1952). Due to possible errors associated with using cadaver heights, the anthropometric stature of SA populations groups will also be compared to the mean statures of North Americans as recorded by the National Center for Health Statistics (Frayr *et al.*, 2012). Unfortunately no dates of birth data are available for the North American group, so no assessment could be made with regard to similarities or differences in trends.

Anthropometric statures of South African white males were also compared to Swiss (CH) and Dutch (NL) white males to determine whether differences exist. Also, the groups were compared by birth cohorts of half a decade (five year periods) to compare the secular trends that are taking place within each population group.

4.2.1 Differences in stature between South African and North American population groups

4.2.1.1 Differences in stature between South African and North American black and white males

Differences in South African anthropometric stature and North American cadaver height

The sample sizes and mean anthropometric statures of South Africans and the corrected cadaver heights of North Americans are shown in Table 4.3. The non-parametric Kruskal-Wallis test classified by ancestry using the SAS NPAR1WAY procedure was used to determine whether significant differences exist between South African black males (SABM) and North American black males (NABM) and between South African white males (SAWM) and North American white males (NAWM).

Table 4.3 and Figure 4.6 demonstrate a significant difference between overall stature of SABM and NABM ($p < 0.0001$) and SAWM and NAWM ($p < 0.0001$). On average, SABM are 12.1 mm shorter than NABM while SAWM are taller than NAWM with an average difference of 101.2 mm.

In the South African group, as described above, the white males are taller than black males. However, the opposite is observed in North American males where black males are taller than white males. Furthermore, SAWM were slightly taller than the NABM while SABM and NAWM had similar average statures (Figure 4.6).

Table 4.3 The sample sizes, mean statures and Kruskal-Wallis results for anthropometric stature and cadaver height between South African and North American black and white males for overall period.

Ancestry	N	Mean	SD	Chi-Squared	p-value
NABM SABM	877 2668	1724.07 1711.93	75.44 61.25	23.03	**<0.0001**
NAWM SAWM	1448 715	1684.90 1786.10	70.52 65.66	742.04	**<0.0001**

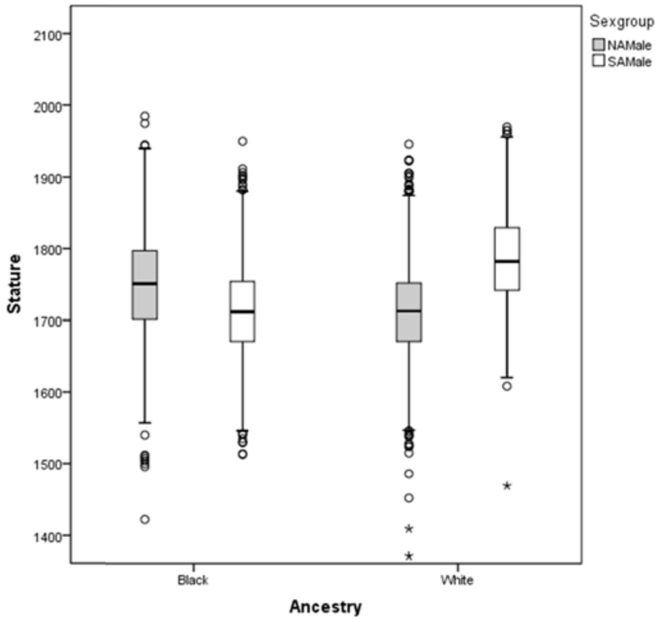


Figure 4.6 Differences in the anthropometric statures and cadaver heights between South African and North American black and white males for the overall period.

Differences in anthropometric stature between South African and North American males

The sample sizes, mean anthropometric statures and standard errors of South Africans and North Americans (as reflected in the NHANES database) are shown in Table 4.4. Figure 4.6 demonstrates that SAWM are significantly ($p < 0.0001$) taller than both NAWM and NABM while SABM were significantly ($p < 0.0001$) shorter than all other groups. On average, NABM were 52.3 mm taller than SABM while SAWM were only 10 mm taller than NAWM with overlapping 95% confidence intervals. The data differ from the cadaver heights in that the average anthropometric statures of NA males are taller than the cadaver heights while the NAWM were 10 mm taller than the NABM as well as 62.3 mm taller than the SABM.

Table 4.4 The sample sizes and mean statures for anthropometric stature between North American and South African black and white males for overall period.

Ancestry	N	Mean	SE	SD
NAWM	2738	1774.0	1.90	99.42
SAWM	714	1784.0	2.44	65.17
NABM	1091	1764.0	2.50	82.58
SABM	2653	1711.7	1.17	60.17

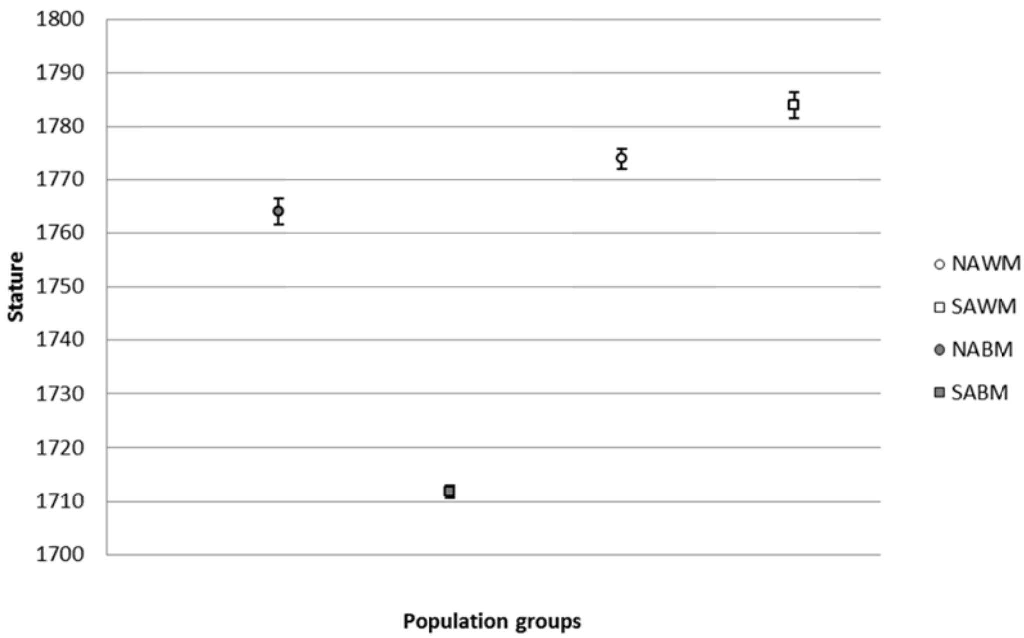


Figure 4.7 Differences in the anthropometric stature between South African and North American (NHANES) black and white males for the overall period.

4.2.1.2 Differences in the stature between South African and North American black and white females

Differences in South African anthropometric stature and North American cadaver heights

Similar results were observed when comparing the differences in stature between South African black females (SABF) and North American black females (NABF) and between South African white females (SAWF) and North American white females (NAWF).

SABF are significantly ($p < 0.0001$) shorter than NABF with an average difference of 14.9 mm. SAWF are significantly ($p < 0.0001$) taller than NAWM with an average difference of 89.7 mm (Table 4.5 and Figure 4.8). Figure 4.7 also demonstrates that SAWF are taller than the SABF while the NABF are taller than the NAWF. Furthermore, SAWF are taller than all other female groups while SABF are similar in stature to NAWF.

Table 4.5 The sample sizes and mean statures for anthropometric stature and cadaver heights between South African and North American black and white females for overall period.

Ancestry	N	Mean	SD	Chi-Squared	p-value
NABF	271	1612.94	69.15	9.81	**0.0017**
SABF	1881	1598.06	58.91		
NAWF	182	1571.80	80.54	187.20	**<0.0001**
SAWF	895	1661.53	57.47		

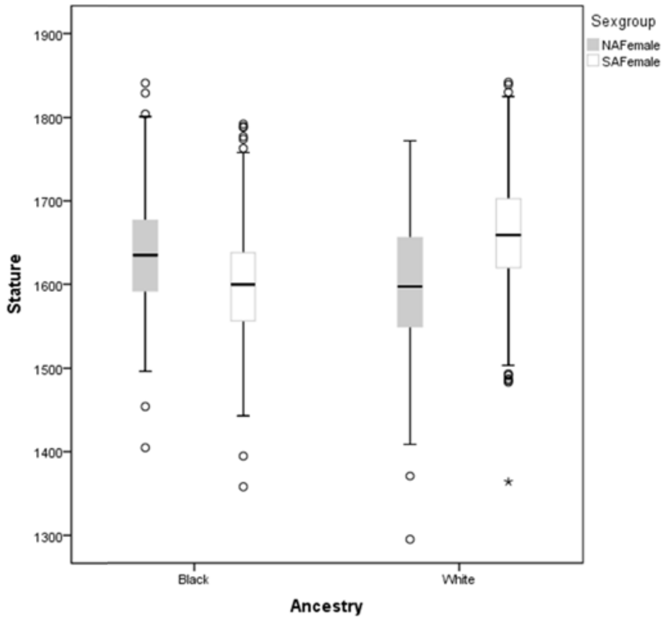


Figure 4.8 Differences in the anthropometric stature between North American and South African black and white males for the overall period.

Differences in anthropometric stature between South African and North American females

The sample sizes, mean anthropometric statures and standard errors of South Africans and North Americans are shown in Table 4.5. Figure 4.7 demonstrates that SAWF are significantly ($p < 0.0001$) taller than both NAWF and NABF and that SABM were significantly ($p < 0.0001$) shorter than all other groups. On average, NABF were 32.3 mm taller than SABF while SAWF were 30.3 mm taller than NAWF and 31.3 mm taller than NABF. The data differ from the cadaver heights in that the average anthropometric statures of NA females are higher than the cadaver heights and NAWF were 33.3 mm taller than SABF but had mean statures similar to NABF.

Table 4.6 The sample sizes and mean statures for anthropometric stature between North American and South African black and white females for overall period.

Ancestry	N	Mean	SE	SD
NAWF	2764	1631.0	1.50	78.87
SAWF	894	1661.3	1.91	57.01
NABF	1154	1630.0	2.50	84.93
SABF	1868	1597.7	1.34	57.69

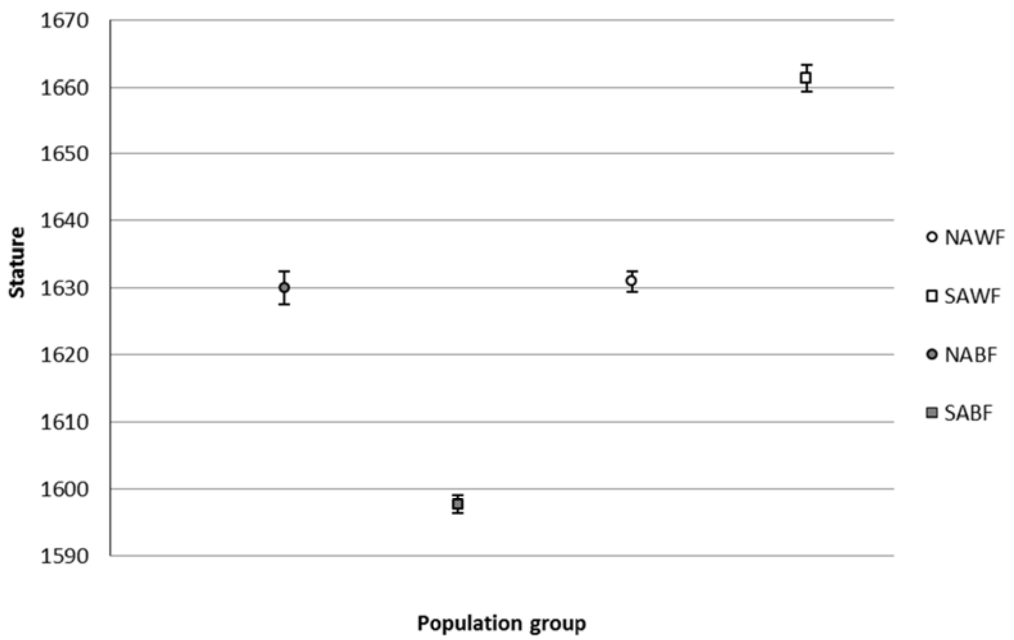


Figure 4.9 Differences in the anthropometric stature between South African and North American (NHANES) black and white females for the overall period.

4.2.2 Differences in the secular trends in stature between South African, Swiss and Dutch white males

Using the statistical program STATA, the anthropometric stature was compared between white males from South Africa (SAWM), Switzerland (CHWM) and the Netherlands (NLWM) for the overall period and by date of birth (DOB) cohorts of five years.

Table 4.7 indicates the sample sizes, average statures and standard errors of the SA and CH groups as well as the mean statures of the NL group (other data not available). For the overall period, significant differences (p = < 0.0001) were observed between all groups.

NLWM were the tallest with an average height of 180.28 cm followed by SAWM and CHWM with average statures of 178.74 cm and 176.53 cm, respectively.

Between 1946 and 1950 and 1951 and 1955, no significant difference was observed between SAWM and NLWM (p = 0.640 and p = 0.470, respectively). In the period between 1946 and 1950, SAWM were only 0.75 cm taller than NLWM while CHWM were the shortest with a significant difference of 4.27 cm when compared to SAWM (p = 0.013). From 1946 to 1980, the average height of CHWM and NLWM increased by 4.73 cm and 5.68 cm, respectively. However, the average stature of SAWM only increased by 1.35 cm during this period. Over the total period, 1946 to 1995, the average stature of CHWM increased by 4.73 cm while SAWM had a much smaller increase of only 2.68 cm.

From 1946 to 1980 the stature of NLWM increased with 1.51 cm, 1.35 cm, 0.63 cm, 0.92 cm, 0.47 cm and 0.8 cm respectively for each 5 year period. Although the stature increased during this period, the magnitude gradually declined with smaller increments of stature increases being observed over time. A similar trend is observed in CHWM with a gradual increase in stature where the magnitude decreased over time (1.2 cm, 0.8 cm, 0.6 cm, 0.7 cm, 0.44 cm) until a slight plateau phase was reached from 1971 to 1995 (0.18 cm, 0.26 cm, 0.45 cm, 0.1 cm) when only minor increases in stature took place.

Figure 4.10 demonstrates the patterns of secular trends of the mean statures of the three population groups as well as the standard errors for SAWM and CHWM. Due to the large sample size of CHWM much narrower standard errors than those of SAWM are observed. Although SAWM were slightly taller than NLWM in 1946, due to the lack of a significant positive secular trend in the stature of SAWM, the NLWM overtook the SAWM in 1951 and 1955 to become significantly taller (p = 0.013) than SAWM in 1956-1960. Furthermore, by 1981 to 1985 CHWM were almost similar in stature to SAWM with a difference of only 0.82 cm. In 1981-1985, 1986-1990 and 1991-1995, the CHWM had mean statures that did not differ significantly from those of SAWM (p = 0.069; p = 0.089 and p = 0.289). A summary of the significance values (two-tailed) for the one sample t-tests between SAWM and CHWM and SAWM and NLWM per 5 year period and the overall period can be seen in Table 4.8.

Table 4.7 The mean statures and standard error and standard deviation of South African (SA), Swiss (CH) and Dutch (NL) white males over 5 year periods.

DOB	South African (SA)				Swiss (CH)			Dutch (NL)
	N	Mean	Standard error	SD	N	Mean	Standard error	Mean
1946-1950	23	177.8	3.10	6.20	39947	173.5	0.06	177.0
1951-1955	44	177.9	1.65	3.29	38003	174.7	0.07	178.5
1956-1960	87	178.0	1.44	2.88	8917	175.5	0.13	179.9
1961-1965	59	178.2	1.81	3.62	45977	176.1	0.06	180.5
1966-1970	59	179.3	1.54	3.07	41303	176.8	0.06	181.4
1971-1975	70	178.7	1.38	2.76	81135	177.2	0.05	181.9
1976-1980	70	179.1	1.57	3.14	160576	177.4	0.03	182.7
1981-1985	229	178.5	0.88	1.75	168861	177.7	0.03	-
1986-1990	69	179.5	1.56	3.12	179547	178.1	0.03	-
1991-1995	4	180.5	3.39	6.77	122382	178.2	0.04	-
1946-1995	**714**	**178.74**	**1.83**	**0.99**	**886648**	**176.53**	**0.056**	**180.28**

Table 4.8 The significance values (two-tailed) for comparisons of the means of South African (SA) with Swiss (CH) and Dutch (NL) white males over 5 year periods using one sample T tests.

DOB	p-value	
	SA vs CH	SA vs NL
1946-1950	**0.013**	0.640
1951-1955	**0.000**	0.470
1956-1960	**0.001**	**0.013**
1961-1965	**0.029**	**0.014**
1966-1970	**0.003**	**0.008**
1971-1975	**0.040**	**0.000**
1976-1980	**0.037**	**0.000**
1981-1985	0.069	-
1986-1990	0.089	-
1991-1995	0.289	-
1946-1995	**0.000**	**0.000**

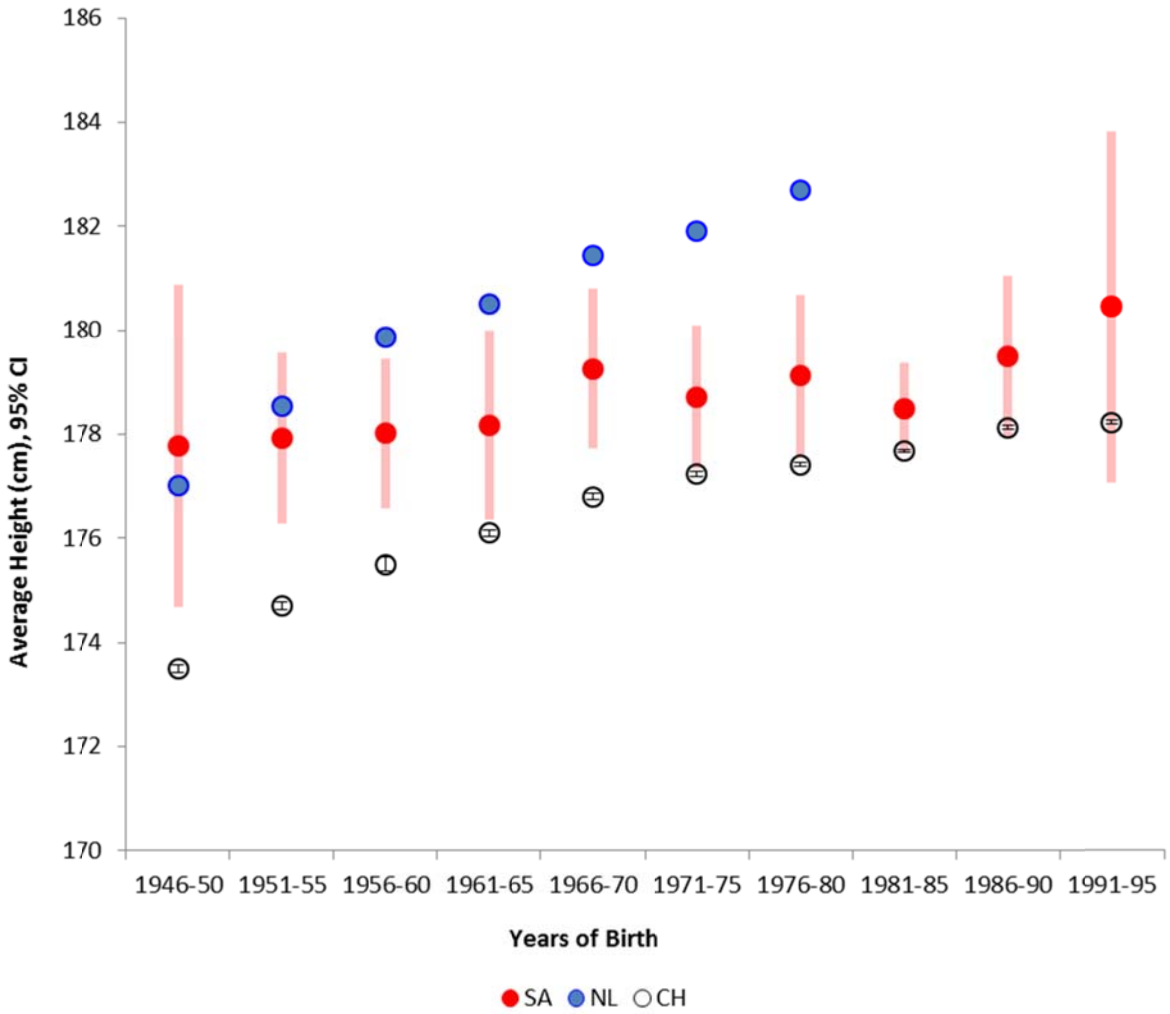


Figure 4.10 Differences in the secular trends between South African (SA), Swiss (CH) and Dutch (NL) white males over 5 year periods.

Chapter 5: Ancestry differences and secular trends in the anthropometric limb proportions of South African population groups

In this chapter the anthropometric limb proportions per birth cohort and for the overall period were compared for South African groups to determine whether differences exist between individuals of African and European descent. Also, the anthropometric limb proportions of South African groups were analysed to observe whether any secular trends are taking place within each population group. This can possibly aid in the understanding of why differences are observed between the population groups. Due to a lack of available anthropometric data on limb proportions from the northern hemisphere, no comparisons were made to analyse the secular differences between southern hemisphere and northern hemisphere groups.

5.1 Ancestry differences and secular trends in the anthropometric limb proportions of South African black and white males

In this section the results of the anthropometric limb proportions per birth cohort and for the overall period for South African males groups were compared. The anthropometric proportions are divided into four categories namely the arm proportions (brachial index, upper limb ratio, arm ratio and forearm ratio), lower limb proportions (crural index, total lower limb ratio, lower limb ratio, thigh ratio and leg ratio), intermembral index and the sitting height ratio.

5.1.1 Ancestry differences and secular trends in the anthropometric upper limb proportions of South African black and white males

Ancestry differences in upper limb proportions

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for brachial index ([forearm/arm] x100), upper limb ratio (upper limb length/stature), arm ratio (arm length/stature) and forearm ratio (forearm length/stature), classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between South African black males (SABM) and South African white males (SAWM).

Over the combined birth cohort, a significant difference was observed in the upper limb lengths (upper limb length, arm length and forearm length) with SAWM having overall larger arm measurements than SABM (Appendix B1; Table B1.1 and Figures B1.1 and B1.2). In Table 5.1 the ancestry differences between SABM and SAWM can be seen for all four arm proportions. Figure 5.1 illustrates the difference in the arm proportions between SABM and SAWM for all birth cohorts combined. SABM had a brachial index, upper limb ratio and forearm ratio which were significantly higher than those of SAWM ($p < 0.0001$). This indicates that SABM have greater forearm lengths relative to arm lengths than SAWM. Also, SABM have greater upper limb lengths relative to stature and greater forearm lengths relative to stature than SAWM. However, no significant difference was observed in the arm ratio ($p = 0.7112$) which indicates that the arm lengths relative to stature are the same in both groups.

Table 5.1 also demonstrates that across all decades, except 1991-2000, the brachial index and forearm ratio of SABM were significantly different from those of SAWM. The upper limb ratio was more variable with no significant differences observed during 1940's, 1960's and 1990's. The lack of a significant difference during the 1990's may possibly be due to the small sample sizes (SABM: n = 10; SAWM: n = 4) of this birth cohort. No significant differences were observed in any of the birth cohorts for the arm length.

Table 5.1 The sample sizes, mean anthropometric upper limb proportions and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Brachial index					Upper limb ratio					Arm ratio					Forearm ratio				
		N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
1941-1950	SABM	12	83.77	9.96	3.9597	**0.0466**	12	0.337	0.016	0.0161	0.8989	12	0.209	0.027	0.1147	0.7348	12	0.172	0.008	5.6213	**0.0177**
	SAWM	18	77.30	4.28			18	0.339	0.017			18	0.214	0.010			18	0.165	0.006		
1951-1960	SABM	94	82.99	7.63	6.7910	**0.0092**	96	0.358	0.033	18.1691	**<0.0001**	96	0.205	0.018	0.1505	0.6981	94	0.170	0.007	25.7138	**<0.0001**
	SAWM	125	80.17	6.37			120	0.339	0.019			123	0.206	0.015			123	0.165	0.006		
1961-1970	SABM	466	82.17	6.73	9.2772	**0.0023**	467	0.345	0.018	1.2627	0.2611	465	0.208	0.016	0.2850	0.5934	467	0.171	0.006	38.9552	**<0.0001**
	SAWM	99	79.88	6.25			101	0.343	0.013			99	0.207	0.014			100	0.165	0.008		
1971-1980	SABM	879	81.36	6.38	26.8297	**<0.0001**	877	0.346	0.017	34.0628	**<0.0001**	877	0.211	0.015	0.3840	0.5355	874	0.171	0.008	68.2596	**<0.0001**
	SAWM	137	78.30	5.76			134	0.336	0.015			135	0.212	0.015			135	0.165	0.007		
1981-1990	SABM	1057	79.55	6.80	32.7477	**<0.0001**	1086	0.347	0.018	32.7773	**<0.0001**	1087	0.213	0.016	1.9793	0.1595	1049	0.169	0.007	65.0989	**<0.0001**
	SAWM	285	76.98	6.47			288	0.340	0.017			287	0.215	0.018			285	0.165	0.007		
1991-2000	SABM	10	83.70	9.39	2.8800	0.0897	10	0.337	0.013	0.0200	0.8875	10	0.201	0.019	2.8800	0.0897	10	0.166	0.007	0.0200	0.8875
	SAWM	4	76.17	2.66			4	0.337	0.010			4	0.217	0.009			4	0.165	0.003		
1941-2000	SABM	2518	80.83	6.80	77.1836	**<0.0001**	2548	0.346	0.018	71.8383	**<0.0001**	2547	0.211	0.016	0.1371	0.7112	2506	0.170	0.007	229.4693	**<0.0001**
	SAWM	669	78.28	6.33			666	0.339	0.016			667	0.212	0.016			666	0.165	0.007		

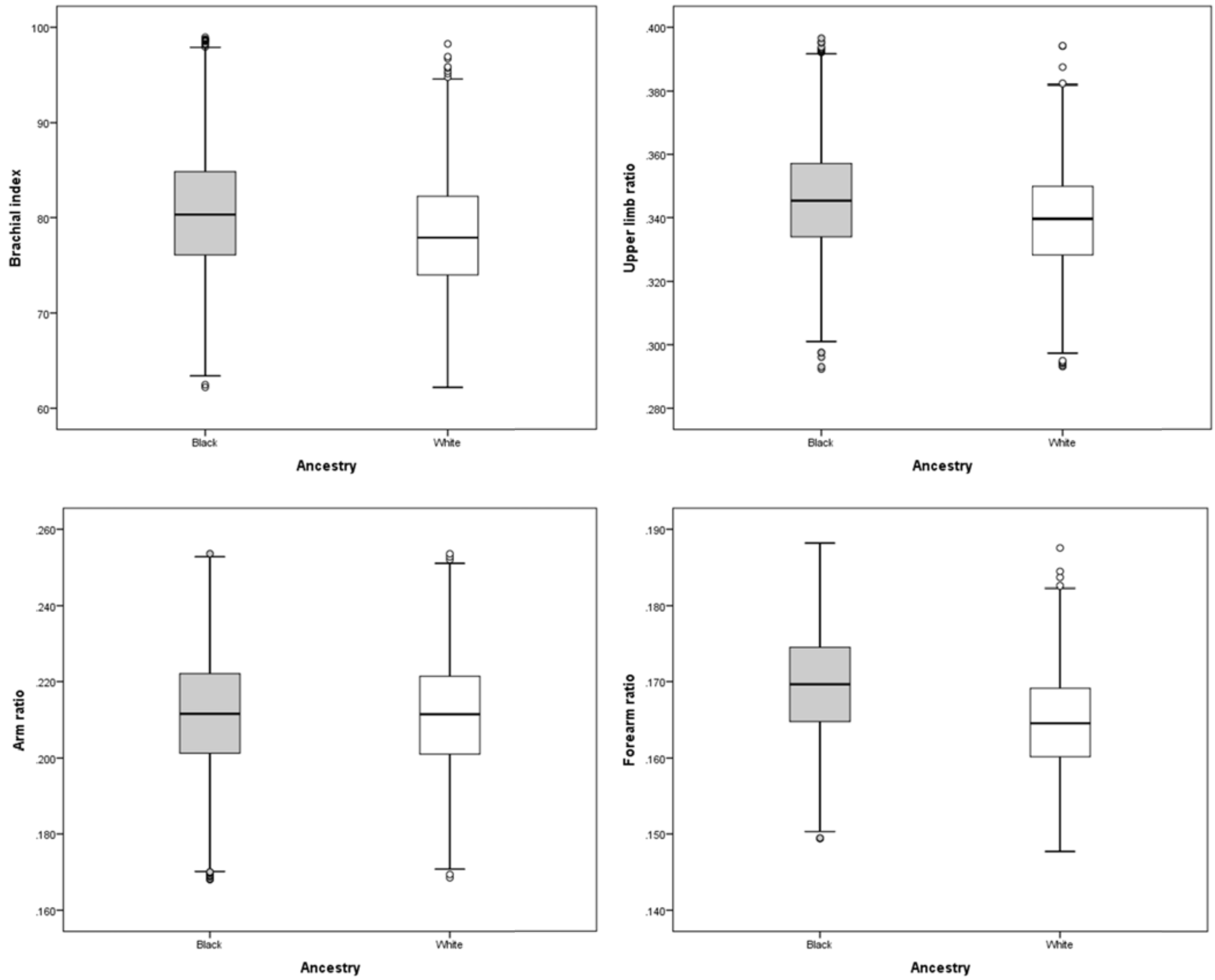


Figure 5.1 Ancestry differences in the anthropometric upper limb ratios between South African black and white males over the total period.

Secular trends in upper limb proportions

Comparison of the brachial index, upper limb ratio, arm ratio and forearm ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM indicated both positive and negative secular trends in the arm proportions from 1941 to 2000. The values for the 1990's are not discussed in this section due to the small sample size of people born in this cohort (SABM: n = 10 and SAWM: n = 4) which may not be an accurate representation of the means for the population during this period.

As seen in Table 5.1, the brachial index over the total period showed significant negative secular trends in both SABM (Kruskal-Wallis Chi-squared = 69.3095; p < 0.0001) and SAWM (Kruskal-Wallis Chi-squared = 30.9315; $p < 0.0001$) indicating that forearm lengths are decreasing relative to the arm lengths in both groups. Figure 5.2 demonstrates the decrease in the ratio from 83.77 in the 1940's to 79.55 in the 1980's for SABM. SAWM demonstrated an increase from 77.30 in the 1940's to 80.17 in the 1950's followed by a gradual decrease to 76.98 in the 1980's. The small mean in the 1940's is possibly due to the small sample size of SAWM (n = 18) during this birth cohort.

A significant positive secular trend is observed in the upper limb ratio for SABM (Kruskal-Wallis Chi-squared = 18.2726; $p < 0.0026$) with no significant secular trends observed for SAWM (Kruskal-Wallis Chi-squared = 12.2666; $p < 0.0563$). This indicates that the upper limb length relative to stature is increasing in SABM while it remains unchanged in SAWM. Figure 5.3 illustrates the increase in the upper limb ratio from 0.337 in the 1940's to 0.347 in the 1980's for SABM while a non-significant change from 0.339 in the 1940's to 0.340 in the 1980's is observed for SAWM.

A positive secular trend is observed in the arm ratio of both SABM (Kruskal-Wallis Chi-squared = 49.8528; $p < 0.0001$) and SAWM (Kruskal-Wallis Chi-squared = 35.5350; $p < 0.0001$), also indicating a relative increase in the length of the arm relative to the stature. In Table 5.1 and Figure 5.4 the secular trend in the arm ratio can be seen. Initially the arm ratio for SABM and SAWM decreased from the 1940's to the 1950's and then gradually increased over the following decades. Overall, the arm ratio increased from 0.209 to 0.213 and 0.214 to 0.217 from the 1940's to the 1980's for SABM and SAWM, respectively. The small sample size in the 1940's (SABM: n = 12; SAWM: n = 18) should be taken into account. If the 1940's sample is excluded, the arm ratio exhibits a strong positive significant trend with an increase from 0.205 to 0.213 for SABM and 0.206 to 0.217 for SAWM from the 1950's to the 1980's.

In Figure 5.5 it can be seen that no significant secular change was observed in the forearm ratio for SAWM (Kruskal-Wallis Chi-squared = 3.5055; $p = 0.7432$) while a negative secular trend is observed for SABM (Kruskal-Wallis Chi-Squared 46.2275; $p < 0.0001$). The forearm ratio for SAWM remained unchanged from the 1940' to the 1980 while it decreased from 0.172 in the 1940's to 0.169 in the 1980's for SABM. This indicates that no changes occurred in the forearm length relative to stature in SAWM while the forearm length decreased relative to stature in SABM.

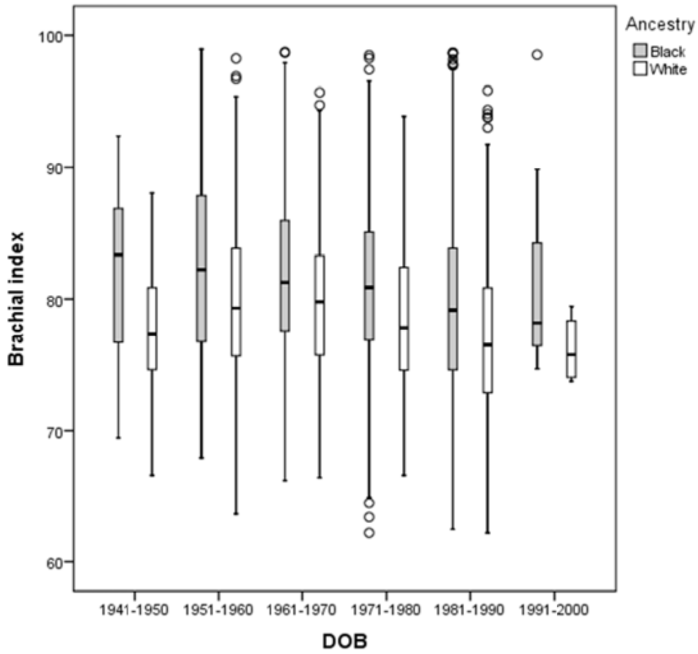


Figure 5.2 Secular trends in the anthropometric brachial index of South African black and white males.

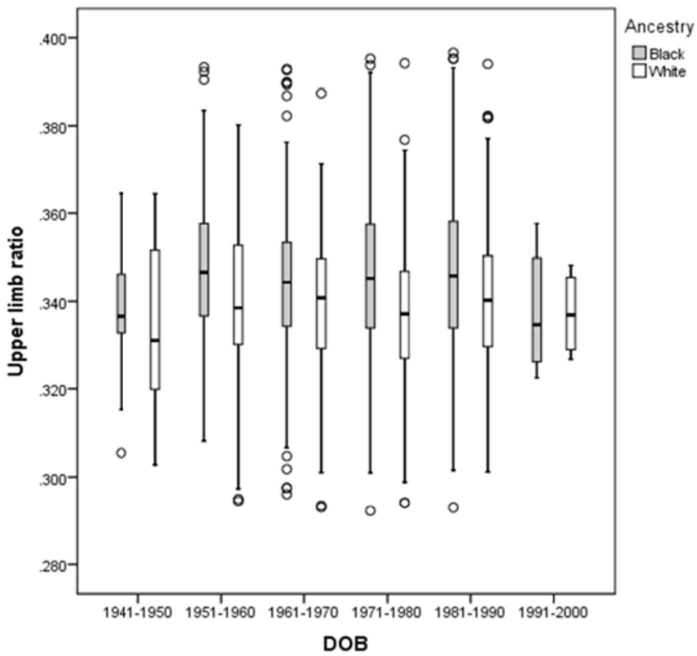


Figure 5.3 Secular trends in the anthropometric upper limb ratio of South African black and white males.

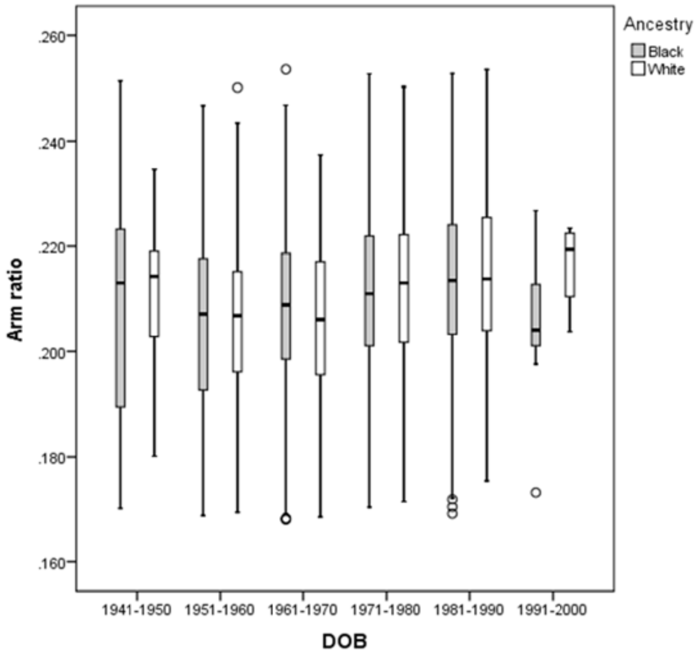


Figure 5.4 Secular trends in the anthropometric arm ratio of South African black and white males.

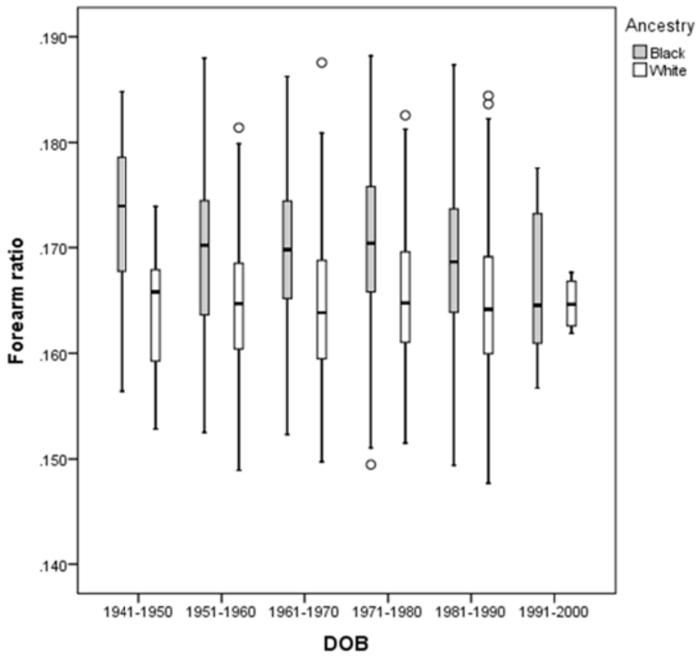


Figure 5.5 Secular trends in the anthropometric forearm ratio of South African black and white males.

5.1.2 Ancestry differences and secular trends in the anthropometric lower limb proportions of South African black and white males

Ancestry differences in lower limb proportions

The mean crural index ([leg length/thigh length] x100), total lower limb ratio (total lower limb length/stature), lower limb ratio (lower limb length/stature), thigh ratio (thigh length/stature) and leg ratio (leg/stature) of both SABM and SAWM are shown in Table 5.2. The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the lower limb proportions, classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant ancestry differences exist between SABM and SAWM.

Over the combined birth cohort, a significant difference was observed in all the lower limb lengths with SAWM having overall larger lower limb measurements than SABM (Appendix B1; Table B1.2 and Figures B1.3 and B1.4). Figure 5.6 illustrates the difference in the lower limb proportions between SABM and SAWM for all birth cohorts combined. SABM had total lower limb ratios, lower limb ratios, thigh ratios and leg ratios which were significantly higher than those of SAWM ($p < 0.0001$). This indicates that SABM have greater total lower limb lengths and lower limb lengths relative to stature than SAWM as well as greater proximal and leg lengths relative to stature than SAWM. However, no significant difference was observed in the crural index ($p = 0.4532$) for the overall period which indicates that both groups have similar leg lengths relative to the thigh lengths.

In the 1940's, 1950's, 1960's and 1990's no significant differences were observed in the total lower limb ratio, thigh ratio and the distal lower leg ratio between the ancestry groups. No significant differences were observed in the 1950's, 1960's and 1990's for the lower limb ratio while a significant difference as observed in the crural index in the 1980's only. The lack of a significant difference for all lower limb proportions during the 1990's may possibly be due to the small sample sizes (SABM: n = 10; SAWM: n = 4) of this birth cohort.

Table 5.2 The sample sizes, mean anthropometric lower limb proportions and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Crural index					Total lower limb ratio					Lower limb ratio				
		N	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**
1941-1950	SABM	14	110.36	16.32	0.0014	0.9697	14	0.527	0.017	3.0576	0.0804	14	0.494	0.018	5.7807	**0.0162**
	SAWM	18	111.45	15.83			19	0.514	0.021			19	0.476	0.020		
1951-1960	SABM	93	106.16	14.05	0.1775	0.6735	93	0.532	0.022	3.6863	0.0549	93	0.496	0.024	3.2423	0.0718
	SAWM	127	106.21	18.06			128	0.527	0.024			128	0.491	0.025		
1961-1970	SABM	472	104.61	11.80	2.6389	0.1043	474	0.529	0.019	1.1761	0.2782	470	0.492	0.021	1.8982	0.1683
	SAWM	110	104.03	18.18			110	0.527	0.020			109	0.490	0.022		
1971-1980	SABM	889	98.28	12.85	1.1749	0.2784	882	0.531	0.017	31.5587	**<0.0001**	879	0.494	0.018	35.5969	**<0.0001**
	SAWM	129	99.88	14.75			130	0.522	0.019			126	0.483	0.020		
1981-1990	SABM	1084	97.88	11.85	13.1088	0.0003	1077	0.535	0.016	92.5252	**<0.0001**	1075	0.499	0.017	132.3218	**<0.0001**
	SAWM	288	95.71	13.19			289	0.524	0.017			288	0.485	0.017		
1991-2000	SABM	10	105.25	10.19	0.0200	0.8875	10	0.532	0.010	0.3200	0.5716	10	0.495	0.010	0.0000	1.0000
	SAWM	4	104.18	7.52			4	0.530	0.010			4	0.497	0.013		
1941-2000	SABM	2562	99.66	12.64	0.5626	0.4532	2550	0.532	0.017	109.5839	**<0.0001**	2541	0.496	0.019	135.3484	**<0.0001**
	SAWM	677	100.32	16.04			681	0.525	0.019			675	0.486	0.021		

Table 5.2 (continued) The sample sizes, mean anthropometric lower limb proportions and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Thigh ratio					Leg ratio				
		N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value
1941-1950	SABM	14	0.236	0.024	1.2989	0.2544	14	0.257	0.016	0.9674	0.3253
	SAWM	18	0.227	0.020			19	0.250	0.019		
1951-1960	SABM	93	0.242	0.025	0.3180	0.5728	93	0.254	0.015	2.1245	0.1450
	SAWM	127	0.240	0.028			128	0.251	0.019		
1961-1970	SABM	473	0.242	0.020	0.0224	0.8811	472	0.251	0.013	2.7161	0.0993
	SAWM	110	0.242	0.025			110	0.248	0.021		
1971-1980	SABM	881	0.251	0.020	15.9450	**<0.0001**	882	0.244	0.016	6.8979	**0.0086**
	SAWM	130	0.243	0.023			126	0.240	0.017		
1981-1990	SABM	1073	0.253	0.019	8.8306	**0.0030**	1080	0.246	0.015	98.4571	**<0.0001**
	SAWM	288	0.249	0.020			288	0.236	0.015		
1991-2000	SABM	10	0.242	0.013	0.1800	0.6714	10	0.253	0.013	0.0800	0.7773
	SAWM	4	0.244	0.014			4	0.253	0.006		
1941-2000	SABM	2544	0.250	0.020	26.7659	**<0.0001**	2551	0.246	0.015	46.8204	**<0.0001**
	SAWM	678	0.244	0.024			676	0.242	0.018		

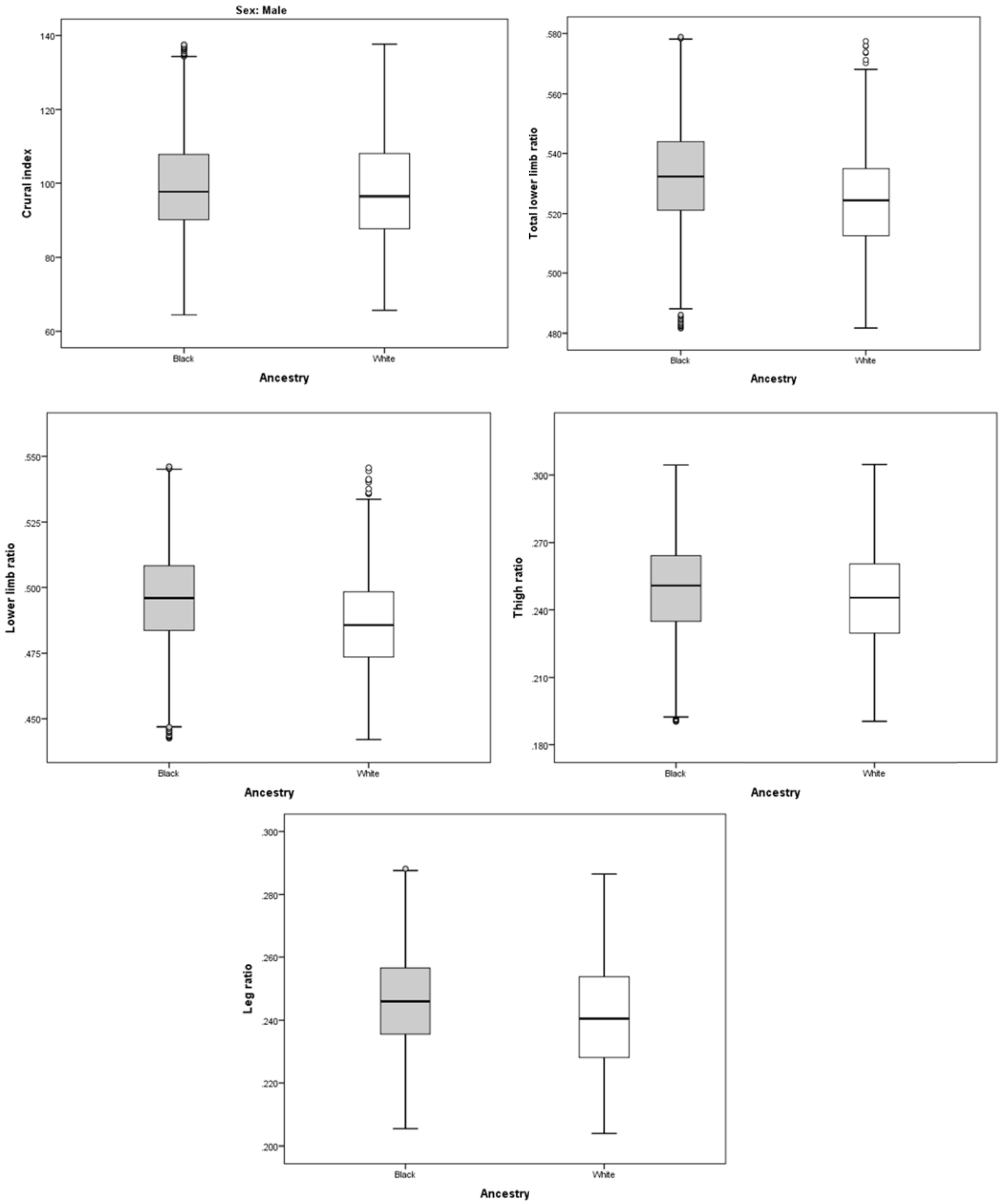


Figure 5.6 Ancestry differences in the anthropometric lower limb proportions between South African black and white males over the total period.

Secular trends in lower limb proportions

Comparison of the crural index, total lower limb ratio, lower limb ratio, thigh ratio and leg ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM indicated both positive and negative secular trends in the lower limb proportions from 1941 to 2000 (Table 5.2). The values for the 1990's are not discussed due to the small sample size of people born in this cohort (SABM: n=10 and SAWM: n=4) which may produce inaccurate results and patterns.

Overall the crural index showed significant negative secular trends in both SABM (Kruskal-Wallis Chi-squared = 147.7754; $p < 0.0001$) and SAWM (Kruskal-Wallis Chi-squared = 54.9876; $p < 0.0001$) indicating that the leg (calf link) is decreasing relative to the thigh (thigh link) for both groups. Figure 5.7 demonstrates the decrease in the ratio from 110.36 in the 1940's to 97.88 in the 1980's for SABM and a decrease from 111.45 in the 1940's to 95.71 in the 1980's for SAWM.

A significant positive secular trend is observed in the total lower limb ratio for SABM (Kruskal-Wallis Chi-squared = 51.0670; $p < 0.0001$) with no significant secular trends observed for SAWM (Kruskal-Wallis Chi-squared = 11.0913; $p = 0.0856$). This indicates that the total lower limb lengths relative to stature are increasing in SABM but remained unchanged in SAWM. Figure 5.8 illustrates the increase in the total lower limb ratio from 0.527 in the 1940's to 0.535 in the 1980's for SABM. The secular trend of SAWM initially increased from 0.514 in the 1940's to 0.527 the 1950's and then gradually decreased again to 0.524 in the 1980's.

A positive secular trend is observed in the lower limb ratio of both SABM (Kruskal-Wallis Chi-squared = 48.2003; $p < 0.0001$) and SAWM (Kruskal-Wallis Chi-squared = 16.5866; $p = 0.0109$), indicating that the lower limb lengths (minus the foot height) relative to stature is increasing in both ancestry groups. Figure 5.9 demonstrates the secular trend in the lower limb ratio between SABM and SAWM. The pattern is similar to the total lower limb with an increase from 0.494 in the 1940's to 0.499 in the 1980's for SABM while SAWM exhibited an initial increase from 0.476 in the 1940's to 0.491 in the 1950's. The lower limb ratio then gradually decreased to 0.485 in the 1980's.

Table 5.2 also demonstrates the significant positive secular change which was observed in the thigh ratio for SABM (Kruskal-Wallis Chi-squared = 133.4214; $p < 0.0001$) and SAWM (Kruskal-Wallis Chi-Squared 31.7982; $p<0.0001$). This indicates that the thigh lengths increased relative to stature in both SABM and SAWM. Overall, the thigh ratio increased from 0.236 and 0.227 in the 1940's to 0.242 and 0.244 in the 1980's for SABM and SAWM, respectively (Figure 5.10).

A significant negative secular trend is observed in the leg ratio for SABM (Kruskal-Wallis Chi-squared = 108.5924; $p < 0.0001$) and SAWM (Kruskal-Wallis Chi-squared = 86.0956; $p < 0.0001$) indicating a decrease in the leg lengths relative to stature in both ancestry groups. Figure 5.11 illustrates the decrease in the leg ratio from 0.257 in the 1940's to 0.246 in the 1980's for SABM. However, a slight increase is observed from 0.244 in the 1970 to 0.246 in the 1980's which was still lower than in the previous decades. The leg ratio of SAWM demonstrated a small increase from 0.250 in the 1940's to 0.251 in the 1950's followed by a decrease to 0.236 in the 1980's.

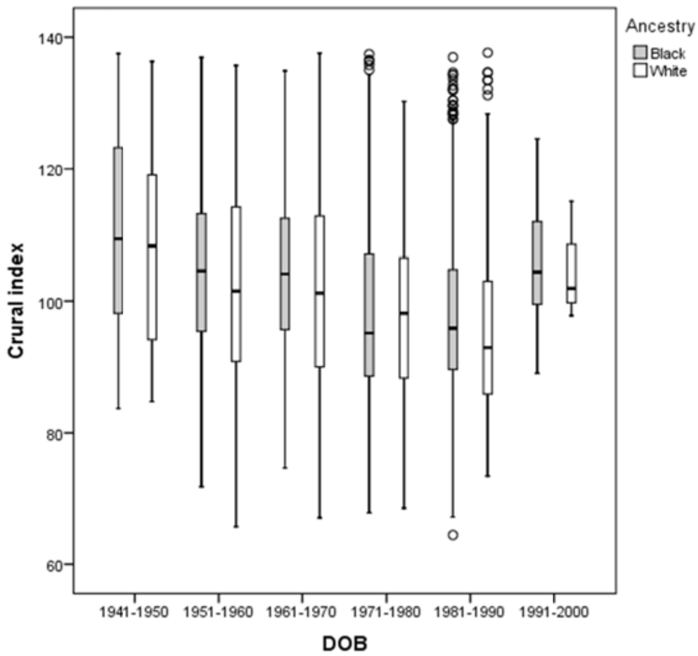


Figure 5.7 The secular trends in the anthropometric crural index of South African black and white males.

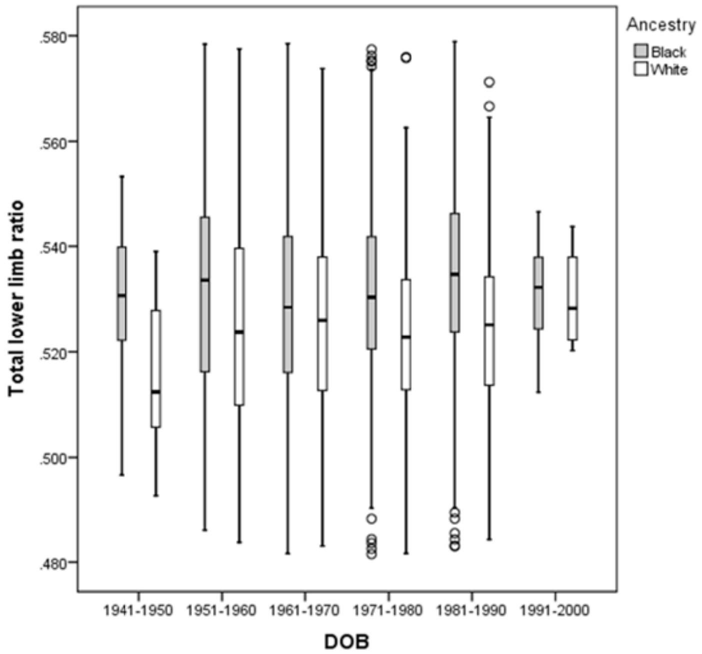


Figure 5.8 Secular trends in the anthropometric total lower limb ratio of South African black and white males.

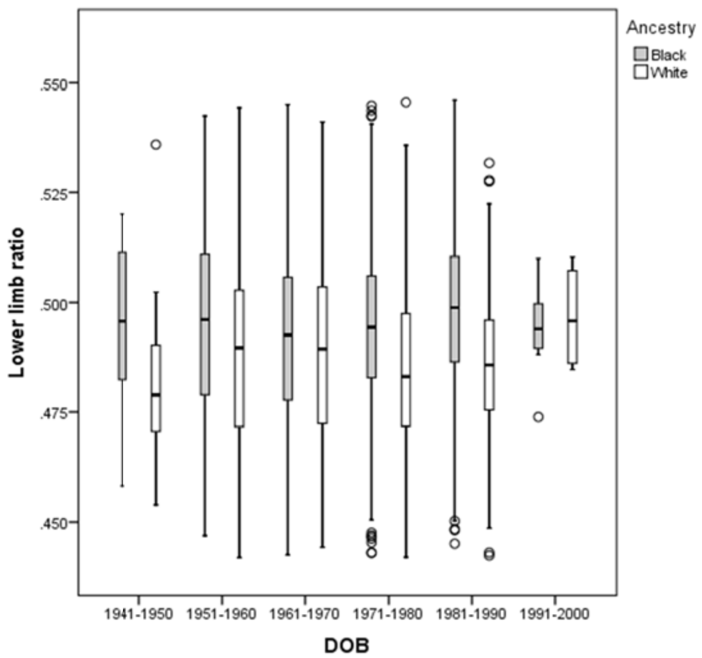


Figure 5.9 Secular trends in the anthropometric lower limb ratio of South African black and white males.

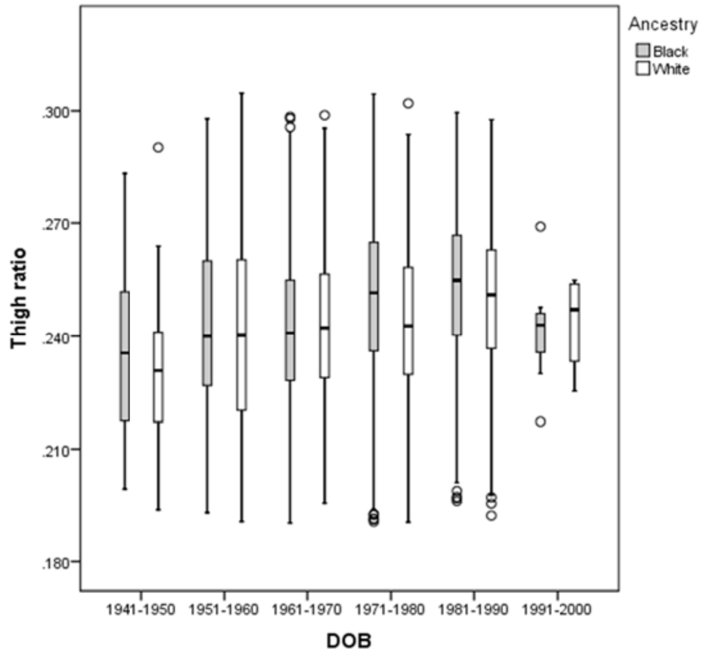


Figure 5.10 Secular trends in the anthropometric thigh ratio of South African black and white males.

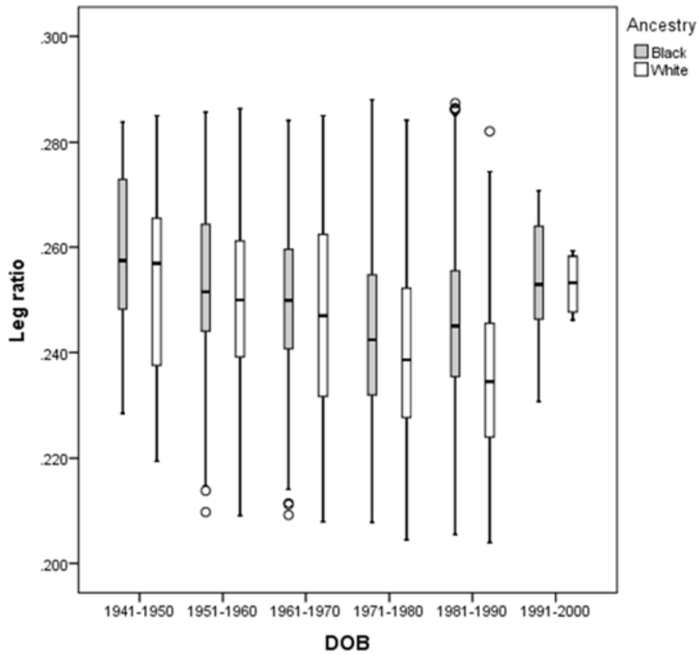


Figure 5.11 Secular trends in the anthropometric leg ratio of South African black and white males.

5.1.3 Ancestry differences and secular trends in the anthropometric intermembral index of South African black and white males

Ancestry differences in the intermembral index

The mean intermembral index ([upper limb length/lower limb length] x100) of both SABM and SAWM are shown in Table 5.2. The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the intermembral index, classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant ancestry differences exist between SABM and SAWM.

As seen in Table 5.3 and Figure 5.12, no significant difference was observed in the intermembral index between SABM and SAWM (Kruskal-Wallis Chi-squared = 0.1115; p = 0.7385) for the combined birth cohorts. Table 5.3 also demonstrates that no significant differences were observed in all decades except for the 1950' (p = 0.0002) and the 1980's (p = 0.0183).

Table 5.3 The sample sizes, mean anthropometric intermembral indices and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared	p-value
1941-1950	SABM SAWM	12 17	68.43 70.47	3.40 3.59	2.4026	0.1211
1951-1960	SABM SAWM	91 119	72.31 69.17	5.91 4.64	14.1167	**0.0002**
1961-1970	SABM SAWM	449 97	70.19 69.97	4.16 4.08	0.0612	0.8046
1971-1980	SABM SAWM	849 122	70.11 69.71	3.81 4.47	1.8564	0.1730
1981-1990	SABM SAWM	1036 282	69.65 70.13	3.93 3.96	5.5645	**0.0183**
1991-2000	SABM SAWM	10 4	68.19 67.88	2.83 0.34	0.3200	0.5716
1941-2000	SABM SAWM	2447 642	70.00 69.84	4.05 4.19	0.1115	0.7385

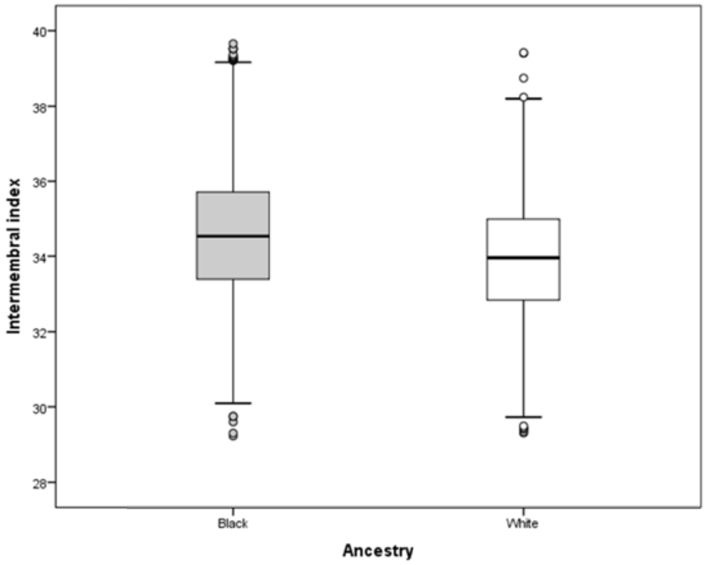


Figure 5.12 Ancestry difference in the anthropometric intermembral index between South African black and white males over the total period.

Secular trends in the intermembral index

Comparison of the intermembral index plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM indicated a negative secular trend for SABM and no secular trend for SAWM. The values for the 1990's are not discussed in this section due to the small sample size of people born in this cohort (SABM: n=10 and SAWM: n=4) which may produce inaccurate results and patterns.

Overall the intermembral index showed a significant negative secular trend in SABM (Kruskal-Wallis Chi-squared = 28.6905; $p < 0.0001$) while no significant secular change was observed in SAWM (Kruskal-Wallis Chi-squared = 9.3797; $p = 0.1533$). This indicates that the upper limb lengths relative to lower limb lengths are decreasing in SABM while it remains unchanged in SAWM. Figure 5.13 demonstrates an initial increase in the intermembral index for SABM from 68.43 in the 1940's to 72.31 in the 1950's. However, due to the small sample size of SABM (n = 12), the low intermembral index observed in the 1940's may not be an accurate representation of the population. The intermembral index then decreased to 70.19 and 70.11 in the 1960's and 1970's with a final value of 69.65 in the 1980's. The intermembral index of SAWM remained almost unchanged with a decrease from 70.47 in the 1940's to 70.13 in the 1980's.

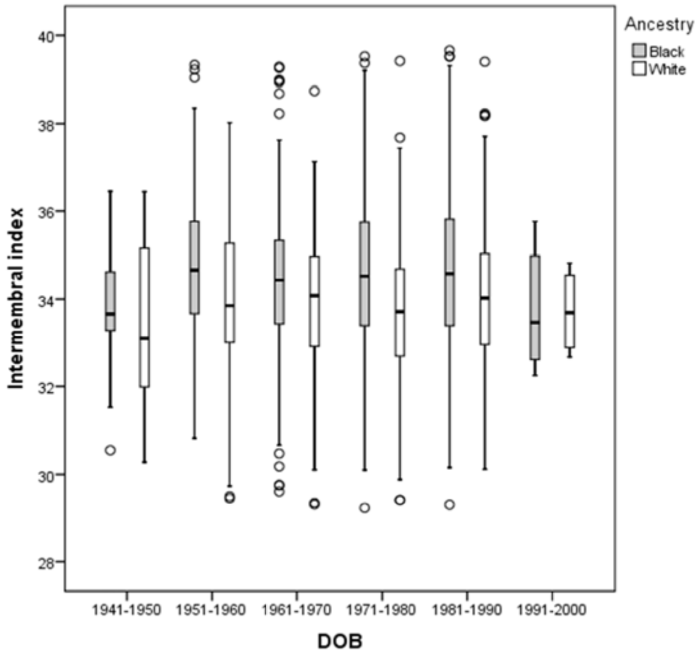


Figure 5.13 Secular trends in the anthropometric intermembral index of South African black and white males.

5.1.4 Ancestral differences and secular trends in the anthropometric sitting height ratio of South African black and white males

Ancestry differences in the sitting height ratio

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the sitting height ratio (sitting height/stature), classified by ancestry using the SAS NPAR1WAY procedure was used to determine whether significant differences exist between SABM and SAWM. Over the combined birth cohort, a significant difference was observed in the sitting heights with SAWM having overall larger measurements than SABM (Appendix B1; Table B1.3 and Figures B1.5 and B1.6).

As seen in Table 5.4 and Figure 5.14, a significant difference was observed in the sitting height ratio between SABM and SAWM (Kruskal-Wallis Chi-squared = 511.9896; $p < 0.0001$) for the combined birth cohorts. Overall, SAWM had higher sitting height ratios than SABM. This indicates that SAWM had higher sitting heights relative to stature than SABM. For all decades, except the 1990's, a significant difference in sitting height ratio is observed between SABM and SAWM. Suring the 1990's, the sitting height relative to stature did not differ between the ancestry groups which indicate that the contribution of lower limb lengths to stature was similar. The lack of a significant difference during the 1990's may possibly be due to the small sample sizes (SABM: n = 10; SAWM: n = 4) of this birth cohort.

Table 5.4 The sample sizes, anthropometric sitting height ratios and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared	p-value
1941-1950	SABM	15	51.15	1.88	4.9511	**0.0261**
	SAWM	23	52.38	0.98		
1951-1960	SABM	97	50.99	1.51	36.6434	**<0.0001**
	SAWM	130	52.38	1.78		
1961-1970	SABM	493	50.54	1.58	122.3055	**<0.0001**
	SAWM	116	52.46	1.34		
1971-1980	SABM	904	50.69	1.52	94.9972	**<0.0001**
	SAWM	138	52.14	1.43		
1981-1990	SABM	1118	50.46	1.48	206.8940	**<0.0001**
	SAWM	295	52.01	1.50		
1991-2000	SABM	9	50.76	2.05	0.0952	0.7576
	SAWM	4	51.15	1.43		
1941-2000	SABM	2636	50.58	1.52	511.9896	**<0.0001**
	SAWM	707	52.18	1.52		

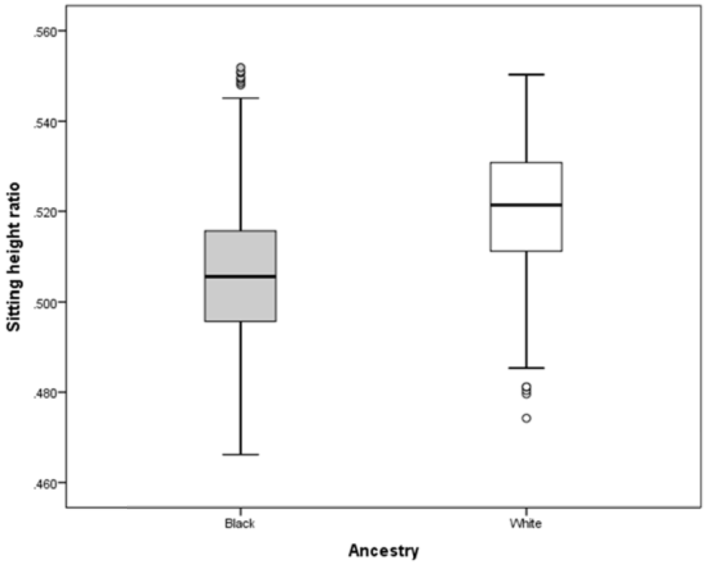


Figure 5.14 Ancestry difference in the anthropometric sitting height ratio between South African black and white males over the total period.

Secular trends in the sitting height ratio

Comparison of the sitting height ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM indicated a negative secular trend for both SABM and SAWM (Table 5.4 and Figure 5.15). This indicates that the sitting heights relative to stature decreased for both groups. Thus, the lower limb lengths had an increasing contribution to the stature compared to sitting height. The values for the 1990's are not discussed in this section due to the small sample size of people born in this cohort (SABM: n = 10 and SAWM: n = 4) which may produce inaccurate results and patterns.

A significant negative secular trend is observed in the sitting height ratio for SABM (Kruskal-Wallis Chi-squared = 24.4127; $p < 0.0001$) with a decrease from 51.15 in the 1940's to 50.46 in the 1980's. The sitting height ratio of SAWM also exhibited a significant negative secular trend (Kruskal-Wallis Chi-squared = 13.4317; $p = 0.0367$ with a gradual decrease of 52.39 in the 1940's to 52.01 in the 1980's.

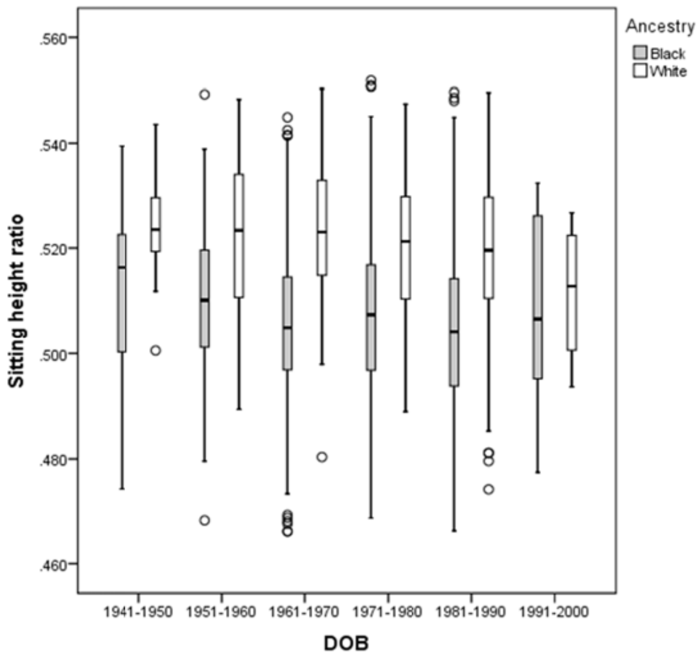


Figure 5.15 Secular trends in the anthropometric sitting height of South African black and white males.

5.2 Ancestry differences and secular trends in the anthropometric limb proportions of South African black and white females

In this section the results the anthropometric limb proportions per birth cohort and for the overall period for South African females groups were compared. The anthropometric proportions are reported under four categories namely the arm proportions (brachial index, upper limb ratio, arm ratio and forearm ratio, lower limb proportions (crural index, total lower limb ratio, lower limb ratio, thigh ratio and leg ratio), intermembral index and the sitting height ratio.

5.2.1 Ancestry differences and secular trends in the anthropometric upper limb proportions of South African black and white females

Ancestry differences in upper limb proportions

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for brachial index ([forearm/arm] x100), upper limb ratio (upper limb length/stature), arm ratio (arm length/stature) and forearm ratio (forearm length/stature), classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between South African black females (SABF) and South African white females (SAWF).

As seen in Appendix B2; Table B2.1 and Figures B2.1 and B2.2, over the combined birth cohort, a significant ancestry difference was observed in the arm length ($p < 0.0001$) and forearm length ($p = 0.0284$) of SABF and SAWF, with SAWF having larger arm lengths and shorter forearm lengths than SABF. However, no significant difference was observed in the upper limb length ($p = 0.1781$). In Table 5.5 the ancestry differences between SABF and SAWF can be seen for all four arm proportions while Figure 5.16 demonstrates the difference in the arm ratios between SABF and SAWF for all birth cohorts combined. SABF had a brachial index, upper limb ratio, arm ratio and forearm ratio which were significantly higher than those of SAWF ($p < 0.0001$). This indicates that SABF have greater forearm lengths relative to arm lengths than SAWF. Also, SABF have greater upper limb lengths, arm lengths and forearm lengths relative to stature than SAWF. Table 5.1 also demonstrates that across all decades, the upper limb ratio and forearm ratio of SABF were significantly different from those of SAWF. Significant differences were observed in the brachial index for all decades except the 1980's ($p = 0.8448$) when no difference was observed in the forearm lengths relative to the arm lengths in both ancestry groups. The proximal limb ratio was more variable with no significant differences observed during the 1940's to 1960's with SAWF having slightly greater arm lengths relative to stature than SABF. However, significant differences were observed during the 1970's and 1980's with higher ratios in SABF than SAWF.

Table 5.5 The sample sizes, mean anthropometric upper limb proportions and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Brachial index					Upper limb ratio					Arm ratio					Forearm ratio				
		N	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**
1941-1950	SABF	11	85.03	6.31	7.8372	**0.0051**	11	0.343	0.011	7.0917	**0.0077**	11	0.199	0.014	0.1948	0.6589	11	0.169	0.011	4.4883	**0.0341**
	SAWF	34	79.49	6.64			30	0.330	0.013			30	0.203	0.014			30	0.162	0.007		
1951-1960	SABF	70	84.41	6.90	18.6685	**<0.0001**	70	0.346	0.021	24.3364	**<0.0001**	70	0.203	0.013	0.8577	0.3544	72	0.171	0.009	39.4089	**<0.0001**
	SAWF	128	79.75	6.80			130	0.332	0.015			128	0.205	0.015			130	0.162	0.007		
1961-1970	SABF	432	84.76	7.56	48.4210	**<0.0001**	430	0.343	0.020	54.9732	**<0.0001**	433	0.201	0.016	0.3754	0.5401	435	0.169	0.008	116.5430	**<0.0001**
	SAWF	192	80.47	6.58			190	0.331	0.015			192	0.201	0.014			191	0.161	0.007		
1971-1980	SABF	560	83.96	7.36	47.8864	**<0.0001**	568	0.342	0.018	135.9756	**<0.0001**	565	0.202	0.016	6.9878	**0.0082**	566	0.169	0.008	231.8622	**<0.0001**
	SAWF	310	80.46	6.34			308	0.328	0.014			308	0.200	0.014			308	0.160	0.007		
1981-1990	SABF	640	80.47	7.08	0.0383	0.8448	653	0.341	0.018	39.7476	**<0.0001**	649	0.210	0.016	19.6289	**<0.0001**	638	0.168	0.007	65.9969	**<0.0001**
	SAWF	177	80.20	6.64			179	0.331	0.017			178	0.204	0.015			176	0.163	0.007		
1991-2000	SABF	36	78.80	4.66	-	-	36	0.343	0.011	-	-	36	0.212	0.011	-	-	36	0.166	0.006	-	-
1941-1990	SABF	1749	82.80	7.49	68.6582	**<0.0001**	1768	0.342	0.019	259.0935	**<0.0001**	1764	0.205	0.017	22.4460	**<0.0001**	1758	0.169	0.008	461.4327	**<0.0001**
	SAWF	841	80.26	6.53			837	0.330	0.015			836	0.202	0.014			835	0.161	0.007		

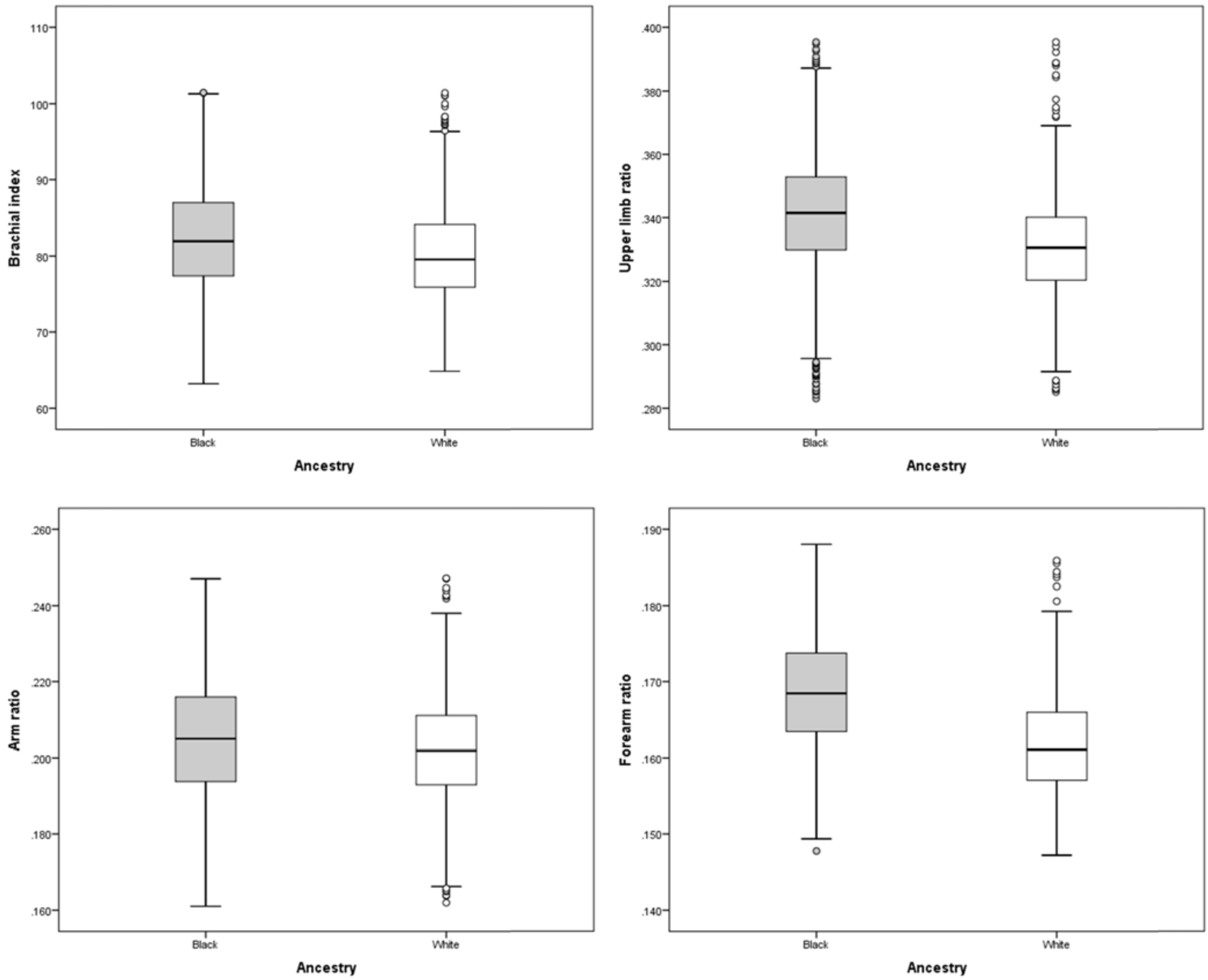


Figure 5.16 Ancestry differences in the anthropometric upper limb ratios between South African black and white females over the total period.

Secular trends in upper limb proportions

Comparison of the brachial index, upper limb ratio, arm ratio and forearm ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABF and SAWF indicated both positive and negative secular trends in the arm proportions from 1941 to 1990.

Table 5.5 and Figure 5.17 demonstrates that the brachial index showed significant negative secular trends for SABF (Kruskal-Wallis Chi-squared = 124.9054; $p < 0.0001$) with a decrease from 85.03 in the 1940's to 78.80 in the 1990's indicating a decrease in the forearm lengths relative to the arm lengths. However, no significant secular trend was observed for SAWF (Kruskal-Wallis Chi-squared = 2.0182; p = 0.7324) indicating no change in the lengths of the forearm relative to the arm. The brachial index only increased minimally from 79.49 in the 1940's to 80.20 in the 1980's for SAWF.

A significant positive secular trend is observed in the upper limb ratio for SAWF (Kruskal-Wallis Chi-squared = 11.7792; p < 0.0191) with no significant secular trends observed for SABF (Kruskal-Wallis Chi-squared = 5.6528; p = 0.3415) indicating that while the upper limb lengths relative to stature increased in SAWF, no change took place in SABF. Figure 5.18 illustrates the increase in the upper limb ratio from 0.330 in the 1940's to 0.331 in the 1980's for SAWF while the upper limb ratio for SABF was 0.343 in the 1940's and 1990's.

A significant positive secular trend is observed in the arm ratio of both SABF (Kruskal-Wallis Chi-squared = 108.5727; p < 0.0001) and SAWF (Kruskal-Wallis Chi-squared = 16.8045; p = 0.0021). This indicates that the arm lengths are increasing relative to stature in both ancestry groups. In Figure 5.19 the secular trend in the arm ratio can be seen. Initially the arm ratio for SABF increased from 0.199 in the 1940's to 0.203 in the 1950's and then decreased to 0.201 in the 1960's, followed by a gradual increase to 0.212 in the 1990's. A similar pattern is observed in SAWF with an initial increase from 0.203 in the 1940's to 0.205 in the 1950's followed by a decrease to 0.201 in the 1960's and 0.200 in the 1970's and then a gradual increase to 0.204 in the 1980's.

Figure 5.20 demonstrates the secular changes in the forearm ratio for SABF and SAWF. A significant negative secular trend is observed in SABF (Kruskal-Wallis Chi-squared = 13.3626; p = 0.0202) while a positive secular trend is observed in SAWF (Kruskal-Wallis Chi-Squared 22.4434; p = 0.0002). This indicates that while the forearm lengths are decreasing relative to stature in SABF, an increase is observed in the forearm lengths relative to stature in SAWF. The forearm ratio in SABF initially increased from 0.169 in the 1940's to 0.203 in the 1950's and then gradually decreased to 0.166 in the 1990's. The forearm ratio of SAWF remained unchanged from the 1940' to the 1950's (0.162) followed by a gradual decrease to 0.160 in the 1970's. The forearm ratio then increased rapidly to 0.163 in the 1980's.

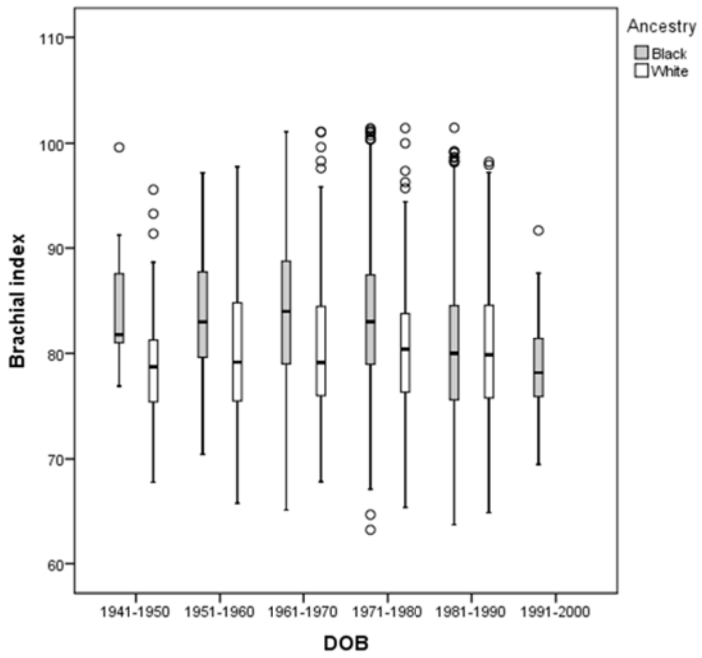


Figure 5.17 Secular trends in the anthropometric brachial index of South African black and white females.

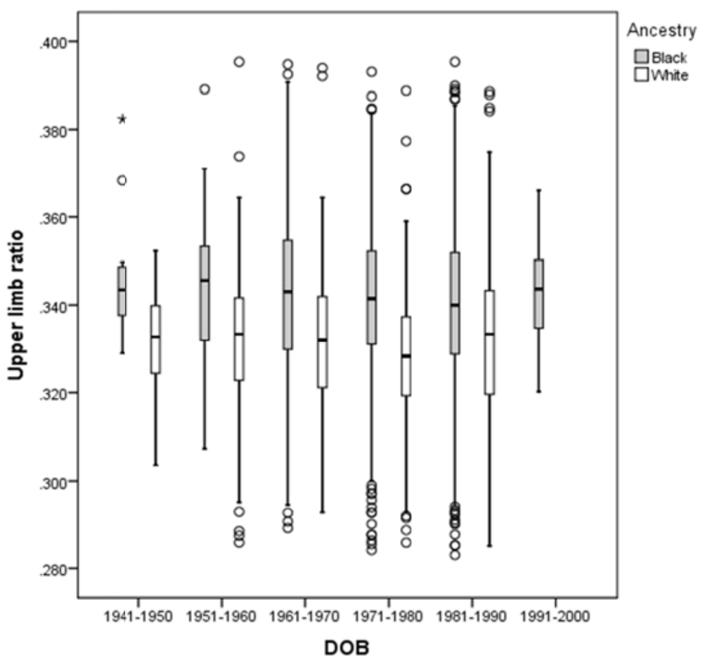


Figure 5.18 Secular trends in the anthropometric upper limb ratio of South African black and white females.

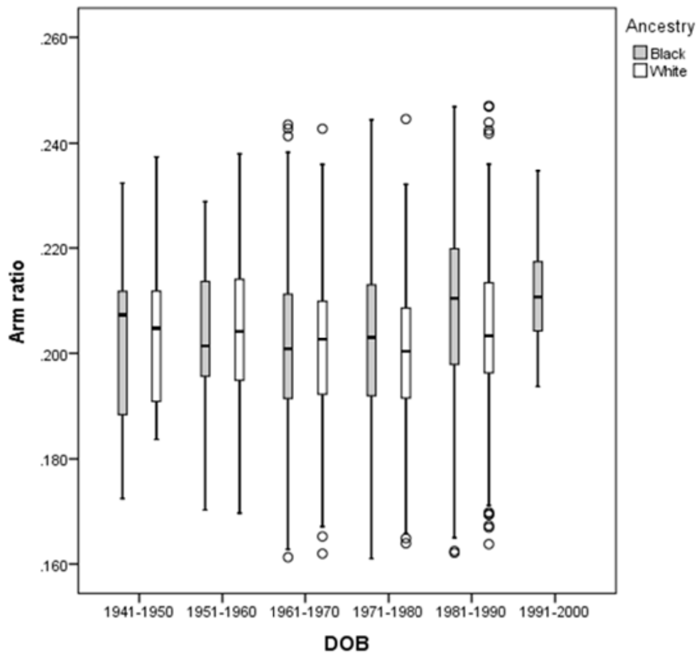


Figure 5.19 Secular trends in the anthropometric arm ratio of South African black and white females.

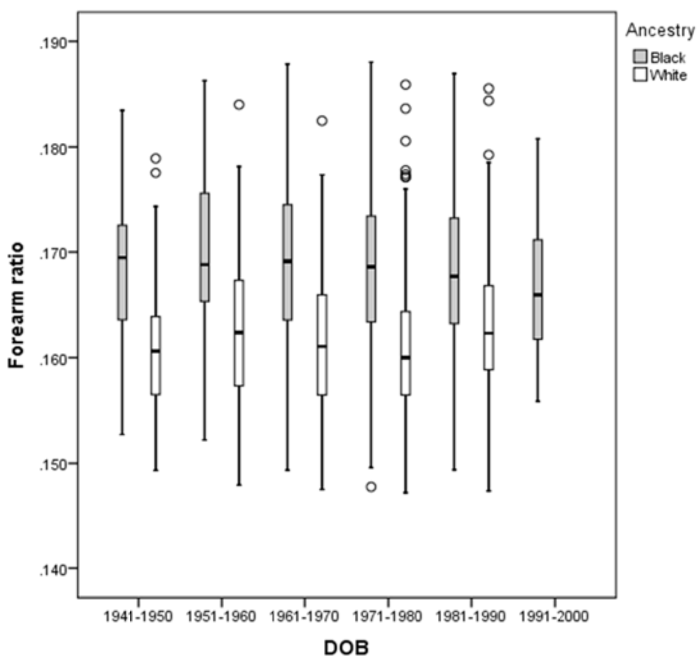


Figure 5.20 Secular trends in the anthropometric forearm ratio of South African black and white females.

5.2.2 Ancestry differences and secular trends in the anthropometric lower limb proportions of South African black and white females

Ancestry differences in lower limb proportions

The mean crural index ([leg length/thigh length] x100), total lower limb ratio (total lower limb length/stature), lower limb ratio (lower limb length/stature), thigh ratio (thigh length/stature) and leg ratio (leg length/stature) of both SABF and SAWF are shown in Table 5.6. The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the lower limb proportions, classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between SABF and SAWF.

Over the combined birth cohort, a significant difference was observed in the total lower limb length, lower limb length, leg length and lateral femoral epicondyle length with SAWF having overall larger lower limb measurements than SABF (Appendix B2; Table B2.2 and Figures B2.3 and B2.4). However, no significant difference was observed in the thigh length (0.0805). In Table 5.6 the difference in the lower limb proportions between SABF and SAWF for all birth cohorts combined can be seen. All lower limb proportions were significantly different between SABF and SAWF ($p < 0.0001$). SABF had total lower limb ratios, lower limb ratios, thigh ratios and leg ratios which were higher than those of SAWF. This indicates that SABF have greater total lower limb lengths, lower limb lengths, proximal lengths and leg lengths relative to stature than SAWF. A higher crural index was observed in SAWF compared to SABF which indicates greater leg lengths relative to thigh lengths in SAWF.

Table 5.6 and Figure 5.21 demonstrate that in the 1940's to 1970's no significant difference was observed in the crural index between SABF and SAWF ($p > 0.005$). This indicates slightly shorter leg lengths relative to thigh lengths up to the 1970's after which the leg lengths became significantly greater relative to thigh lengths in SAWF. No significant difference was observed in the 1940's and 1950's for the total lower limb ratio and no significant differences was observed in the thigh ratio from the 1940's to 1960' with slightly higher values still observed in SABF. The differences in the thigh ratio only changed significantly after the 1960's. The leg ratio exhibited no significant differences in the 1940's, 1950's and 1980's. During the 1980's, SAWF had leg ratios which were slightly higher than those of SABF indicating slightly greater leg lengths relative to stature.

Table 5.6 The sample sizes, mean anthropometric lower limb proportions and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Crural index					Total limb ratio					Lower limb ratio				
		N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
1941-1950	SABF	7	107.80	12.05	0.4893	0.4842	7	0.531	0.027	2.9755	0.0845	7	0.502	0.025	5.1923	**0.0227**
	SAWF	29	114.64	21.25			27	0.514	0.019			27	0.479	0.021		
1951-1960	SABF	72	108.04	22.58	1.6879	0.1939	73	0.529	0.033	3.6776	0.0551	72	0.497	0.034	6.6687	**0.0098**
	SAWF	132	111.87	23.63			135	0.519	0.031			134	0.484	0.034		
1961-1970	SABF	448	110.94	21.19	0.0000	0.9960	456	0.524	0.031	13.9594	**0.0002**	450	0.493	0.031	24.2181	**<0.0001**
	SAWF	196	112.80	26.35			201	0.514	0.032			199	0.479	0.033		
1971-1980	SABF	572	108.82	20.32	0.0984	0.7538	576	0.525	0.029	30.9589	**<0.0001**	572	0.492	0.029	42.1303	**<0.0001**
	SAWF	319	108.68	20.42			314	0.514	0.025			313	0.479	0.026		
1981-1990	SABF	678	96.32	14.27	34.4388	**<0.0001**	673	0.528	0.026	41.9932	**<0.0001**	673	0.494	0.028	37.8009	**<0.0001**
	SAWF	181	103.56	15.65			181	0.514	0.024			181	0.480	0.025		
1991-2000	SABF	36	93.64	6.02	-	-	36	0.546	0.016	-	-	36	0.512	0.017	-	-
1941-1990	SABF	1813	104.33	19.55	31.3757	**<0.0001**	1821	0.527	0.029	98.0117	**<0.0001**	1810	0.493	0.030	121.6708	**<0.0001**
	SAWF	857	109.23	21.83			858	0.515	0.027			854	0.480	0.029		

Table 5.6 (continued) The sample sizes, mean anthropometric lower limb proportions and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Thigh ratio					Leg ratio				
		N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
1941 - 1950	SABF	7	0.243	0.023	2.2862	0.1305	7	0.260	0.013	0.5556	0.4561
	SAWF	27	0.225	0.029			27	0.253	0.020		
1951-1960	SABF	73	0.243	0.038	3.1429	0.0763	72	0.255	0.013	3.5174	0.0607
	SAWF	134	0.233	0.039			131	0.251	0.014		
1961-1970	SABF	453	0.237	0.035	3.3422	0.0675	448	0.256	0.014	23.1767	**<0.0001**
	SAWF	197	0.230	0.038			195	0.250	0.016		
1971-1980	SABF	576	0.239	0.033	6.8177	**0.0090**	573	0.254	0.018	44.4041	**<0.0001**
	SAWF	314	0.233	0.032			316	0.246	0.015		
1981-1990	SABF	673	0.253	0.024	53.7339	**<0.0001**	672	0.241	0.021	0.5685	0.4509
	SAWF	181	0.238	0.024			178	0.242	0.019		
1991-2000	SABF	36	0.265	0.015	-	-	36	0.247	0.008	-	-
1941-1990	SABF	1818	0.244	0.031	71.9677	**<0.0001**	1808	0.249	0.019	16.8542	**<0.0001**
	SAWF	853	0.233	0.033			847	0.247	0.016		

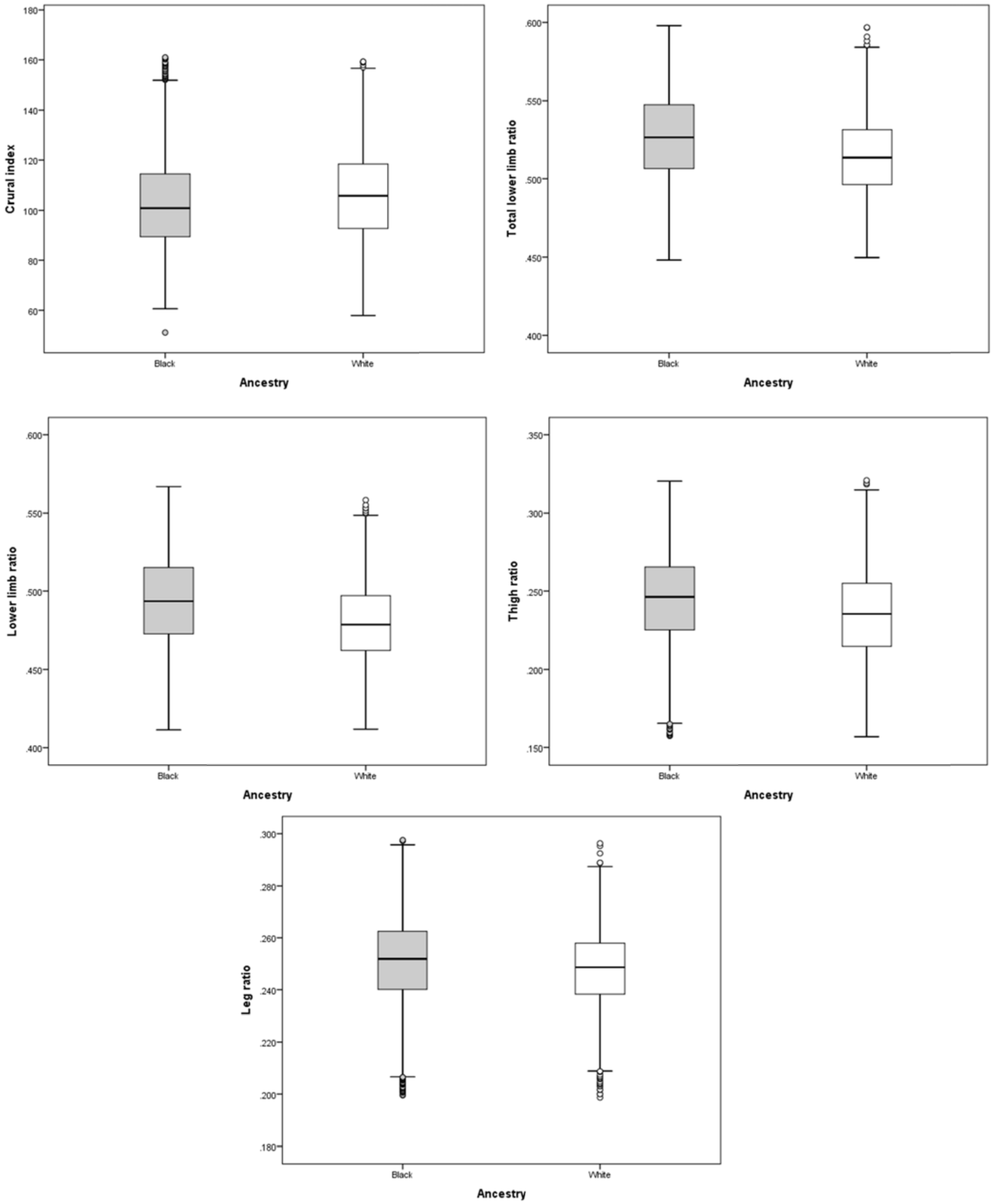


Figure 5.21 Ancestry differences in the anthropometric lower limb proportions between South African black and white females over the total period.

Secular trends in lower limb proportions

Comparison of the crural index, total lower limb ratio, lower limb ratio, thigh ratio and leg ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABF and SAWF indicated both positive and negative secular trends in the lower limb proportions from 1941 to 1990.

Overall the crural index showed significant negative secular trends in both SABF (Kruskal-Wallis Chi-squared = 214.6804; $p < 0.0001$) and SAWF (Kruskal-Wallis Chi-squared = 14.8246; $p = 0.0051$) indicating a decrease in the leg lengths relative to the thigh lengths in both groups. Figure 5.22 demonstrates that the crural index in SABF initially increased from 107.80 in the 1940's to 110.94 in the 1960's followed by a decrease to 93.64 in the 1990's while the crural index of SAWF decreased from 114.64 in the 1940's to 103.56 in the 1980's. This indicates that during the 1940's to 1960's, the crural index of SABF were becoming more similar to those of SAWF until the 1970's (SABF index: 108.82; SAWF index: 108.68) when SABF had slightly greater leg lengths relative to thigh lengths. However, the leg lengths relative to thigh lengths became significantly less after the 1970's in SABF.

A significant positive secular trend is observed in the total lower limb ratio for SABF (Kruskal-Wallis Chi-squared = 28.9985; $p < 0.0001$) with no significant secular trends observed for SAWF (Kruskal-Wallis Chi-squared = 4.9320; $p = 0.2943$). Figure 5.23 illustrates the initial decrease in the total lower limb ratio from 0.531 in the 1940's to 0.524 in the 1960's. This is followed by a large increase to 0.546 in the 1990's. The total lower limb ratio of SAWF remained unchanged from the 1940's to 1980's (0.514) with a small increase observed in the 1950's (0.519).

A similar pattern is observed in the lower limb ratio with a significant positive secular trend for SABF (Kruskal-Wallis Chi-squared = 20.8982; $p = 0.0008$) while no significant change is observed for SAWF (Kruskal-Wallis Chi-squared = 4.1981; $p = 0.3799$). Figure 5.24 demonstrates the secular trend in the lower limb ratios between SABF and SAWF. The lower limb ratio of SABF decreased from 0.0.502 in the 1940's to 0.492 in the 1970's followed by a large increase to 0.512 in the 1990's. A small, non-significant increase from 0.479 in the 1940's to 0.480 in the 1980's is observed for SAWF.

Figure 5.25 demonstrates a significant positive secular change in the thigh ratio for SABF (Kruskal-Wallis Chi-squared = 117.7335; $p < 0.0001$) while a non-significant increase was observed for SAWF (Kruskal-Wallis Chi-Squared = 6.7571; $p = 0.1493$). The thigh ratio for SABF decreased from 0.243 in the 1940's to 0.237 in the 1960's followed by a major increase to 0.265 in the 1990's. A small increase from 0.225 in the 1940's to 0.238 in the 1980's was observed in SAWF. This indicates that the thigh lengths decreased relative to stature until the 1960's followed by a significant increase in the thigh lengths while no changes took place in SAWF.

A significant negative secular trend is observed in the leg ratio for SABF (Kruskal-Wallis Chi-squared = 211.0495; $p < 0.0001$) and SAWF (Kruskal-Wallis Chi-squared = 28.4660; $p < 0.0001$). Figure 5.26 illustrates the decrease in the leg ratio from 0.260 in the 1940's to 0.247 in the 1990's for SABM and a decrease from 0.253 in the 1940's to 0.242 in the 1980's for SAWF. This indicates that in both groups the leg lengths relative to stature continued to gradually decrease with a large decrease observed in SABF in the 1980's.

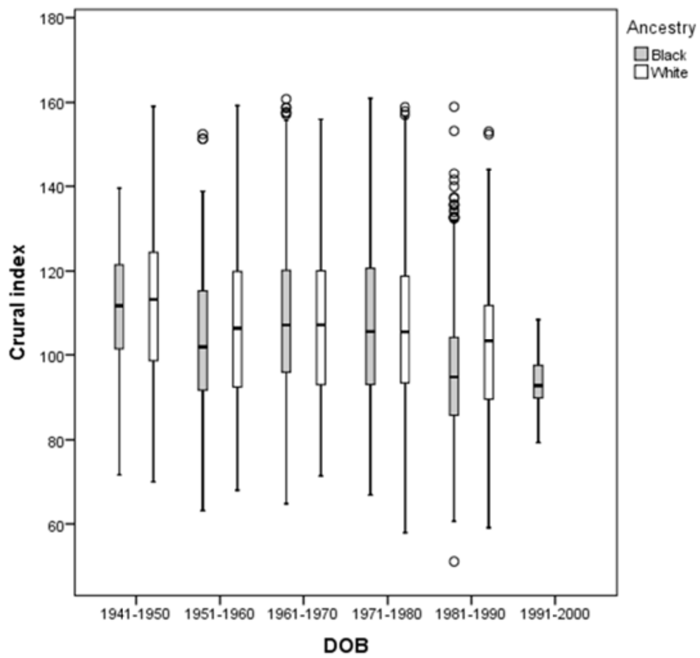


Figure 5.22 Secular trends in the anthropometric crural index of South African black and white females.

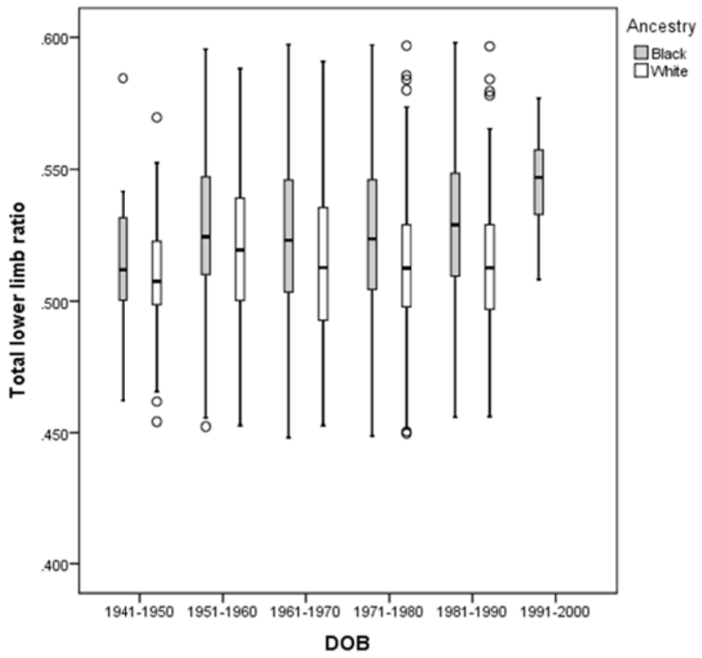


Figure 5.23 Secular trends in the anthropometric total lower limb ratio of South African black and white females.

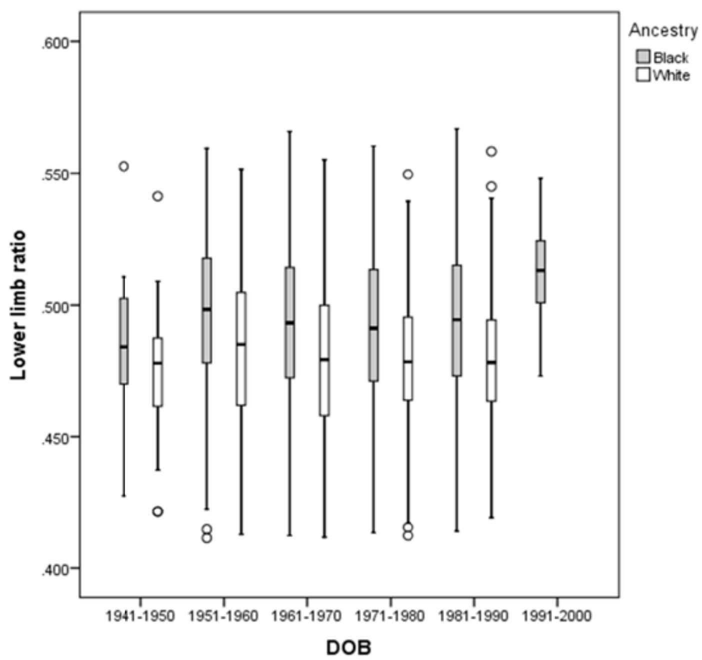


Figure 5.24 Secular trends in the anthropometric lower limb ratio of South African black and white females.

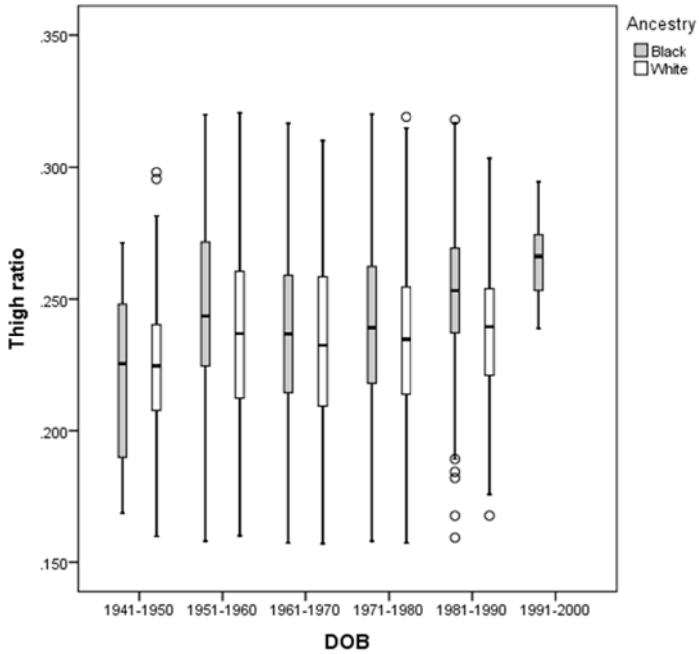


Figure 5.25 Secular trends in the anthropometric thigh ratio of South African black and white females.

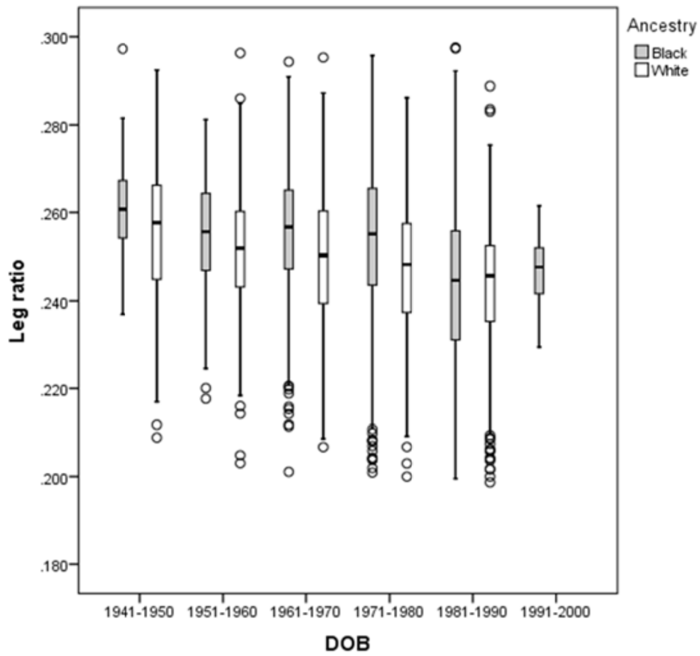


Figure 5.26 Secular trends in the anthropometric leg ratio of South African black and white females.

5.2.3 Secular changes and ancestry differences in the anthropometric intermembral index of South African black and white females

Ancestry differences in the intermembral index

The mean intermembral index ([upper limb length/lower limb length] x100) of both SABF and SAWF are shown in Table 5.7. The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the intermembral index, classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between SABF and SAWF.

As seen in Table 5.7 and Figure 5.27, no significant difference was observed in the intermembral index between SABF and SAWF (Kruskal-Wallis Chi-squared = 3.0563; p = 0.0804) for the combined birth cohorts. This indicates that SAWF and SABF have similar arm lengths relative to lower limb lengths. However, SABF had slightly higher intermembral indices. Table 5.7 also demonstrates that no significant differences were observed for all decades except in the 1970's (p = 0.0063) when SABF had a significantly higher intermemebral index (greater arm lengths relative to lower limb lengths than SAWF).

Table 5.7 The sample sizes, anthropometric intermembral indices and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared	p-value
1941 - 1950	SABF SAWF	6 29	69.00 69.71	2.26 3.98	0.3755	0.5400
1951-1960	SABF SAWF	67 123	70.36 68.92	6.00 5.20	2.6945	0.1007
1961-1970	SABF SAWF	422 186	70.02 69.58	5.84 5.31	1.0112	0.3146
1971-1980	SABF SAWF	541 298	69.75 68.63	5.59 4.62	7.4528	**0.0063**
1981-1990	SABF SAWF	639 173	69.29 69.18	5.49 4.81	0.2486	0.6181
1991-2000	SABF	36	66.96	2.63	-	-
1941-1990	SABF SAWF	1711 809	69.60 69.05	5.60 4.90	3.0563	0.0804

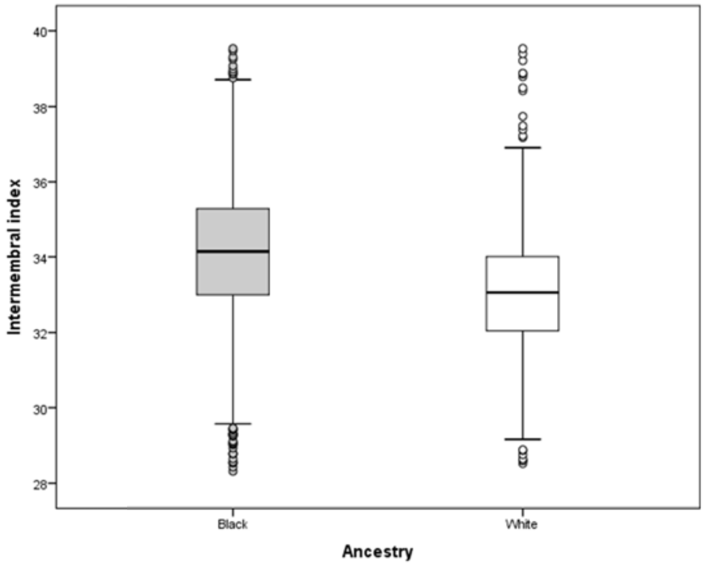


Figure 5.27 Ancestry difference in the anthropometric intermembral index between South African black and white females over the total period.

Secular trends in the intermembral index

Comparison of the intermembral index plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABF and SAWF indicated a negative secular trend for SABF (Kruskal-Wallis Chi-squared = 22.6175; p = 0.0004) while no significant secular change was observed in SAWF (Kruskal-Wallis Chi-squared = 3.5126; p = 0.4760). This indicates that the upper limb lengths relative to lower limb lengths are decreasing in SABF while it remains unchanged in SAWF. Figure 5.28 demonstrates the initial increase in the intermembral index for SABF from 69.00 in the 1940's to 70.36 in the 1960's followed by a gradual decrease to 66.96 in the 1990's which indicates a faster increase in the arm relative to the lower limbs followed by a slower increase in the arm lengths relative to the lower limb lenghts. The intermembral index of SAWM remained almost unchanged with a decrease from 69.71 in the 1940's to 69.18 in the 1980's.

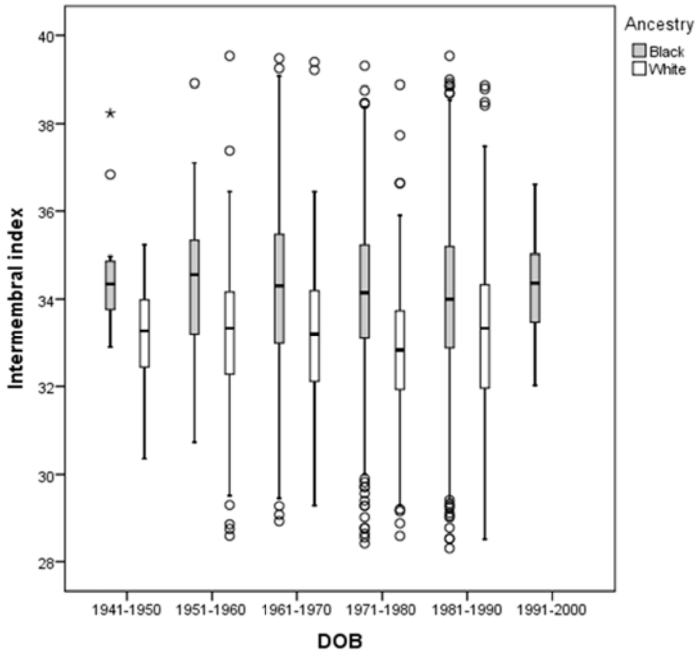


Figure 5.28 Secular trends in the anthropometric intermembral index of South African black and white females.

5.2.4 Ancestry differences and secular trends in the anthropometric sitting height ratio of South African black and white females

Ancestry differences in the sitting height ratio

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the sitting height ratio (sitting height/stature), classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between SABF and SAWF. Over the combined birth cohort, a significant ancestry difference ($p < 0.0001$) was observed between SAWF and SABF with SAWF having overall larger sitting heights than SABF (Appendix B2; Table B2.3 and Figures B2.5 and B2.6).

As seen in Table 5.8 and Figure 5.29, a significant difference was observed in the sitting height ratio between SABF and SAWF (Kruskal-Wallis Chi-squared = 30.9092; $p <0.0001$) for the combined birth cohorts with higher values in SAWF except in the 1950s when SABF had a higher value. This indicates that SAWF have higher sitting heights relative to stature than SABF except in the 1950's when SABF had higher sitting heights relative to stature. However, no significant differences were observed between SABF and SAWF in the 1940's, 1960's and 1970's which indicates that during these periods SAWF and SABF had similar sitting heights relative to stature.

Table 5.8 The sample sizes, anthropometric sitting height ratios and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared	p-value
1941 - 1950	SABF SAWF	12 29	52.95 52.31	2.47 2.79	0.5985	0.4391
1951-1960	SABF SAWF	75 142	53.24 52.39	2.68 2.16	4.2990	**0.0381**
1961-1970	SABF SAWF	456 202	53.42 52.76	2.97 1.98	0.9429	0.3315
1971-1980	SABF SAWF	585 318	52.87 52.86	2.81 1.90	3.2194	0.0728
1981-1990	SABF SAWF	686 190	51.78 53.05	1.70 1.62	87.5616	**<0.0001**
1991-2000	SABF	36	52.22	1.31	-	-
1941-1990	SABF SAWF	1850 881	52.60 52.79	2.56 1.95	30.9092	**<0.0001**

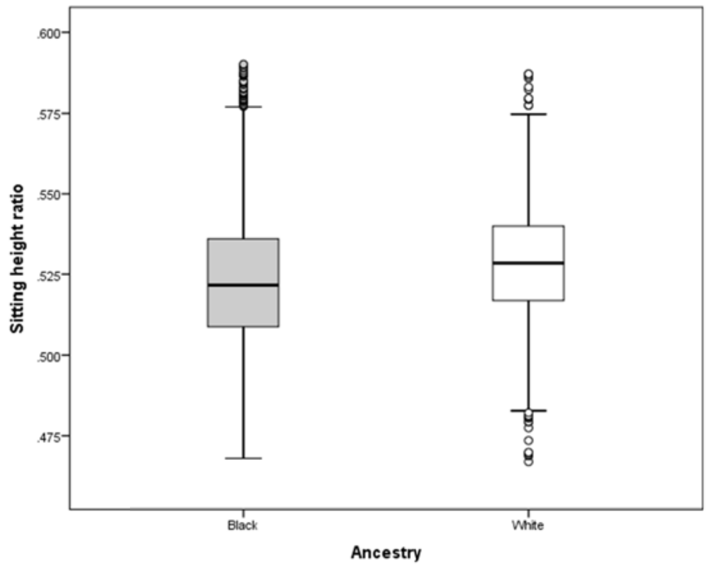


Figure 5.29 The ancestral difference in the anthropometric sitting height ratio between South African black and white females over the total period.

Secular trends in the sitting height ratio

Comparison of the sitting height ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM indicated both negative and positive secular trends.

As seen in Table 5.8 and Figure 5.30, a significant negative secular trend is observed in the sitting height ratio for SABF (Kruskal-Wallis Chi-squared = 109.9169; p < 0.0001) while a positive secular trend was observed for SAWF (Kruskal-Wallis Chi-squared = 12.0839; p = 0.0167). This indicates that sitting heights to stature is decreasing in SABM while it is increasing in SAWF. Thus, the sitting heights of SABF are contributing less to the stature over time. Initially the sitting height ratio for SABF increased from 52.95 in the 1940's to 53.42 in the 1960's and then gradually decreased to 51.78 in the 1980's indicating a smaller contribution of the sitting height to stature from the 1970's to 1980's. The sitting height ratio then increased to 52.22 in the 1990's. The sitting height ratio of SAWF increased from 52.31 in the 1940's to 53.05 in the 1980's.

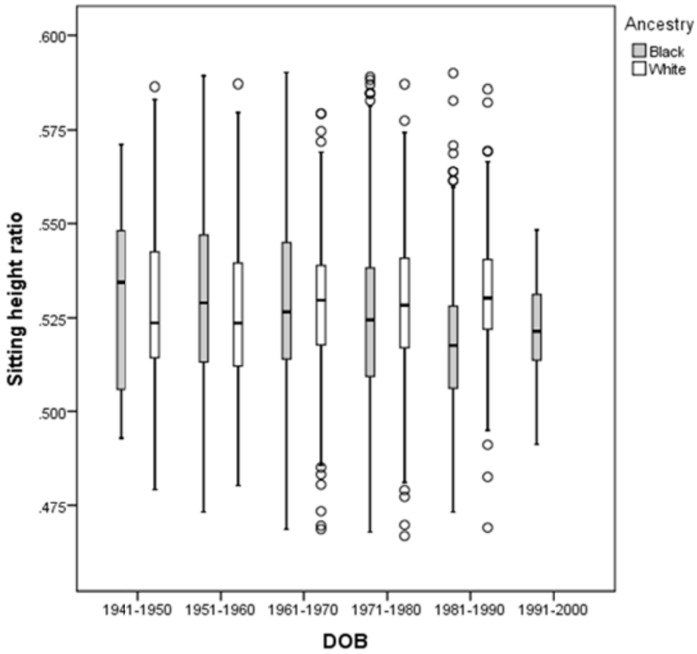


Figure 5.30 Secular trends in the anthropometric sitting height ratio of South African black and white females.

5.3 Comparisons of the secular changes in the anthropometric limb proportions of South African population groups combined

The differences in the mean brachial index between males and females and its associated trends over the past six decades are clearly illustrated in Figure 5.31. Individuals of African descent have greater brachial indices than their counterparts of European descent. This means that they have relatively greater forearm lengths relative to arm lengths than individuals of European descent. In all groups, a significant negative secular trend was observed except for SAWF who exhibited no secular trend. This indicates that the forearm lengths are decreasing relative to the arm lengths in SAWM, SABM and SABF. Overall, SABF have greater brachial indices compared to the SABM while SAWF also had a higher brachial index than SAWM except in 1950's. In the 1980's, SAWF had higher brachial indices than SABM and were on par with SABF.

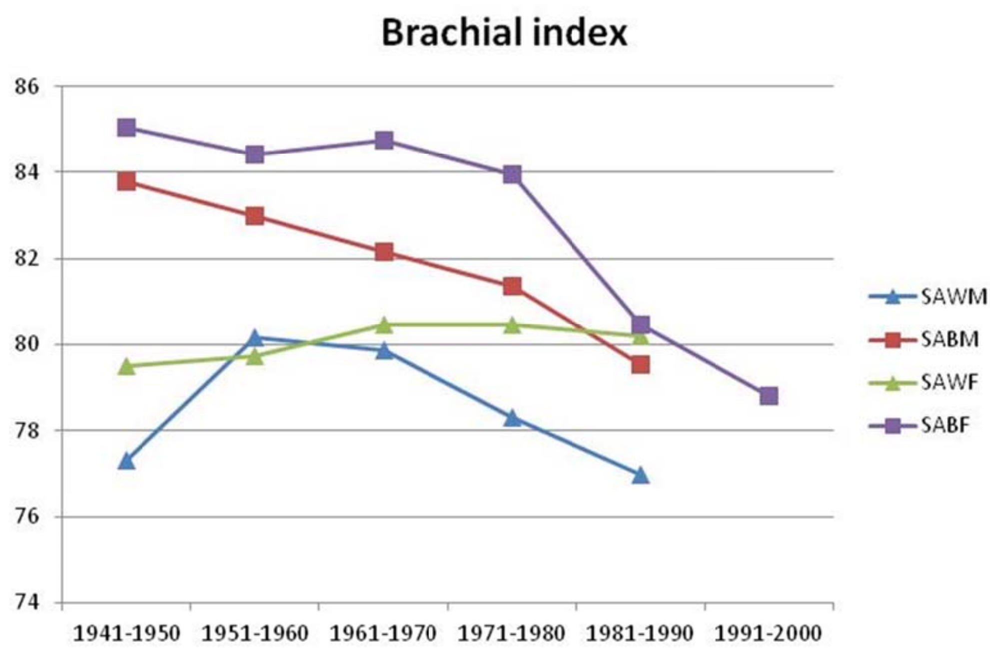


Figure 5.31 Comparisons of the differences in the secular trends of anthropometric brachial index for South African population groups.

The differences in the upper limb index between males and females can be seen in Figure 5.32. Individuals of African descent have greater upper limb indices than their counterparts of African descent. In both groups, males have slightly higher upper limb ratios than the females. This means that individuals of African descent have greater upper limb lengths relative to stature than individuals of European descent. The same is true for males compared to females. Significant positive secular trends are only observed in SABM and SAWF while no secular trends are observed in SAWM and SABF indicating an increase in the upper limb lengths relative to stature in SABM. In the 1940's, SABM had an upper limb ratio similar to SAWM, however, this may be an inaccurate representation of the upper limb ratio for this group due to the small sample size (n = 12). In the 1960's and 1980's, SAWM and SABF had similar upper limb ratios.

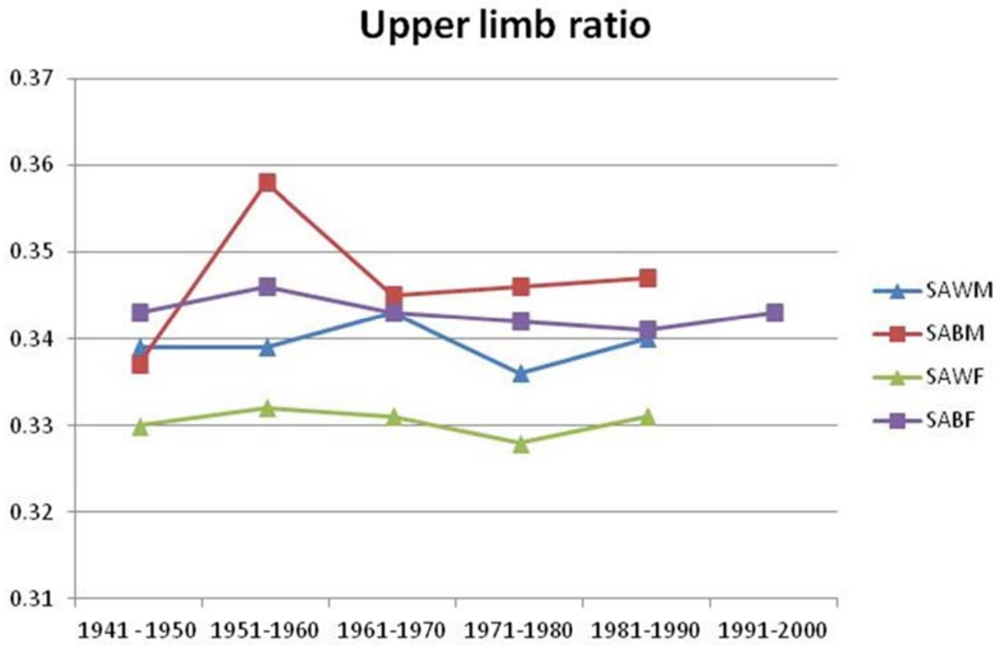


Figure 5.32 Comparisons of the differences in the secular trends of anthropometric upper limb ratio for South African population groups.

The differences in the arm ratio between males and females are clearly illustrated in Figure 5.33. Overall, all groups exhibited a significant positive secular trend ($p < 0.05$) with males having a higher arm ratio compared to females. No significant difference is observed in the arm ratio between ancestry groups indicating no differences in the arm lengths relative to stature. Similar arm ratios were observed in SAWM and SABM. Both groups have very high arm ratios in the 1940's which is possibly due to the small sample sizes (SABM: n = 12; SAWM: n = 18). SABF had the lowest arm ratio in the 1940's but exhibited a gradual increase while SAWF exhibited an initial decrease in upper limb ratio. In the 1960's, SABF and SAWF had similar arm ratios but SABF had a higher rate of positive secular trend than SAWF. For this reason, SABF have arm ratios that are significantly higher than those of SAWF in the 1980's indicating a rapid increase in the upper limb lengths relative to stature in SABF.

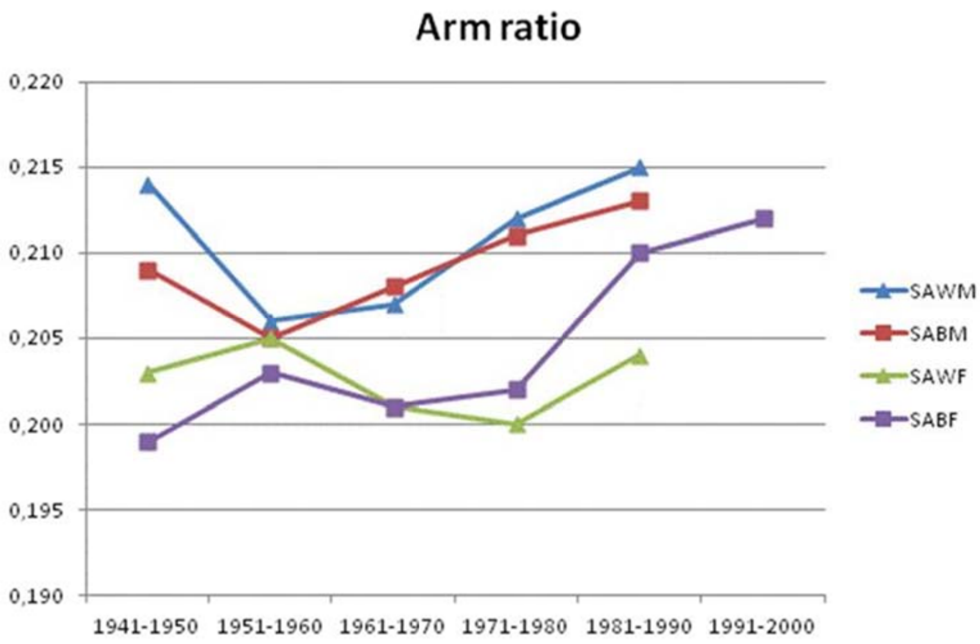


Figure 5.33 Comparisons of the differences in the secular trend of anthropometric arm ratio for South African population groups.

The differences in the forearm ratio between males and females are clearly illustrated in Figure 5.34. Individuals of African descent have greater forearm ratios (i.e., relatively greater forearm lengths relative to stature) than their counterparts of European descent. In both groups, males have larger forearm ratios than females; however the difference is very small in individuals of African descent with SABF having a larger forearm ratio to SABM in the 1950's. Significant negative secular trends are observed in SABM and SABF while no secular trend was observed in SAWM. SAWF was the only group with a significant positive secular trend in the forearm ratio although the trend is only visible from the 1980's when a rapid increase in the forearm lengths relative to stature took place.

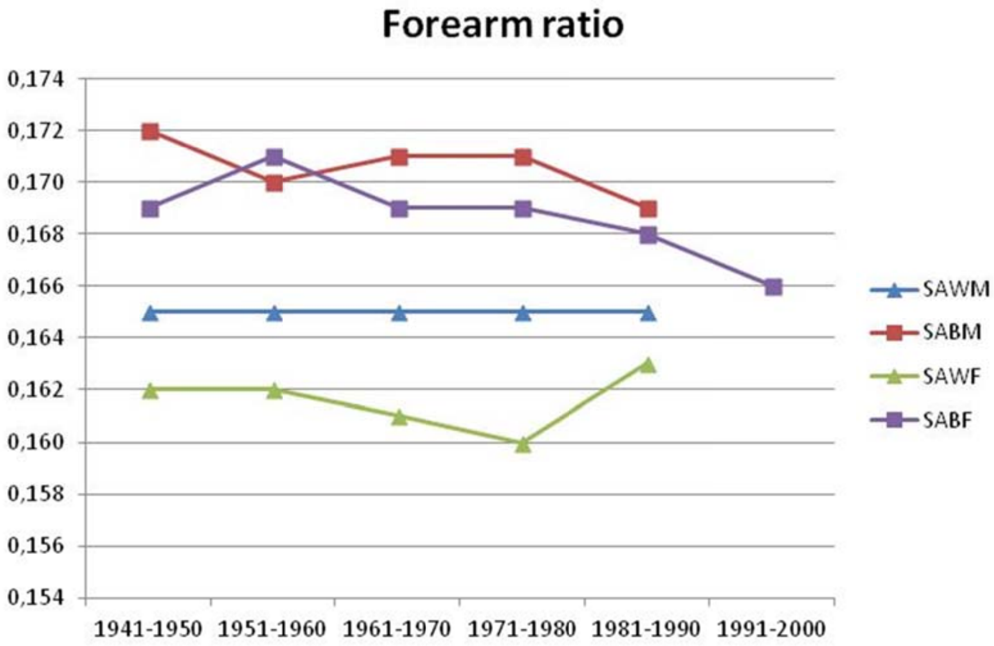


Figure 5.34 Comparisons of the differences in the secular trend of anthropometric forearm ratio for South African population groups.

Figure 5.35 illustrates the differences in the crural index between SA males and females. The crural index is greater in females than males, indicating that females have greater leg lengths relative to thigh lengths than males. Although a significant difference is observed between SABF and SAWF, no significant ancestry differences are observed between SABM and SAWM. This means that SAWF have the highest leg lengths relative to thigh lengths than SABF, SAWM and SABM. For all groups, significant negative secular trends are observed. However, SABF and SAWF exhibited a slight increase in the crural index during the 1960's. No significant difference is observed in SABM, SABF and SAWM in the 1980's while SAWF differed significantly from all groups.

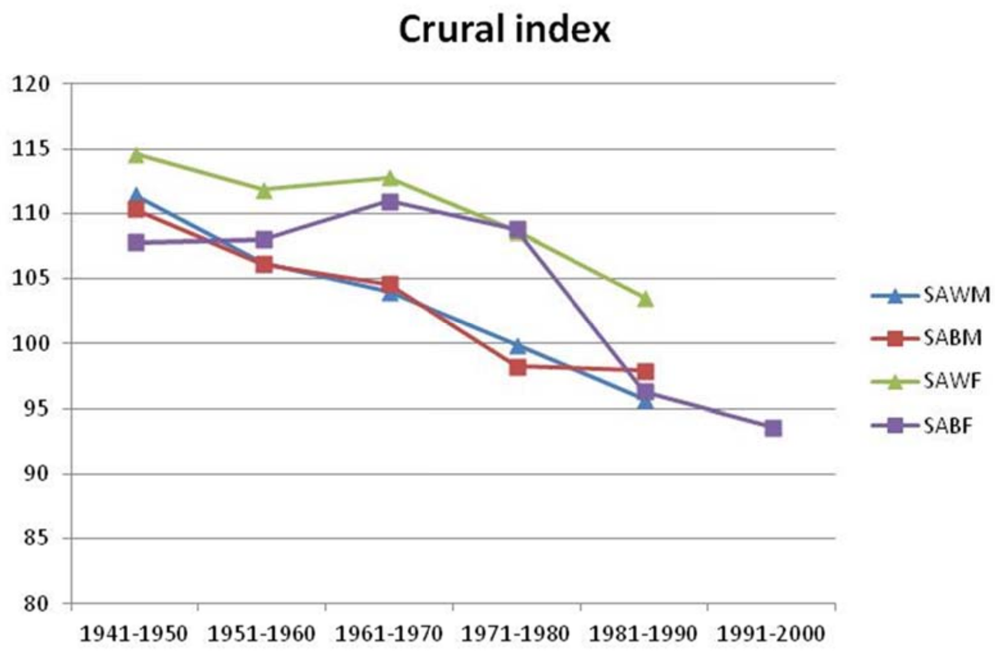


Figure 5.35 Comparisons of the differences in the secular trends of anthropometric crural index for South African population groups.

The differences in the total lower limb ratio between SA males and females are illustrated in Figure 5.36. Individuals of African descent have greater total lower limb ratios (i.e., greater trochanteric lengths relative to stature) than their counterparts of European descent except in the 1960's when SAWM had higher total lower limb ratios than SABF. In both groups, males have an overall higher total lower limb ratio than the females indicating that the total lower limb length is larger relative to stature than in females). In the 1940's, SABF had total lower limb ratios which were higher than those of SABM while SAWM and SAWF had similar ratios; however this could possibly be due to the small sample sizes for the males (SABM: n = 12; SAWM: p = 18) during this period. Individuals of African descent exhibited significant positive secular trends in the total lower limb ratio while no significant secular trends were observed in individuals of European descent indicating an increase in the total lower limb length relative to stature in individuals of African ancestry. A significant increase is observed in the total lower limb ratio of SABF in the 1990's. Due to a lack of available data no comparisons could be made to determine whether this change would also have been observed in SABM.

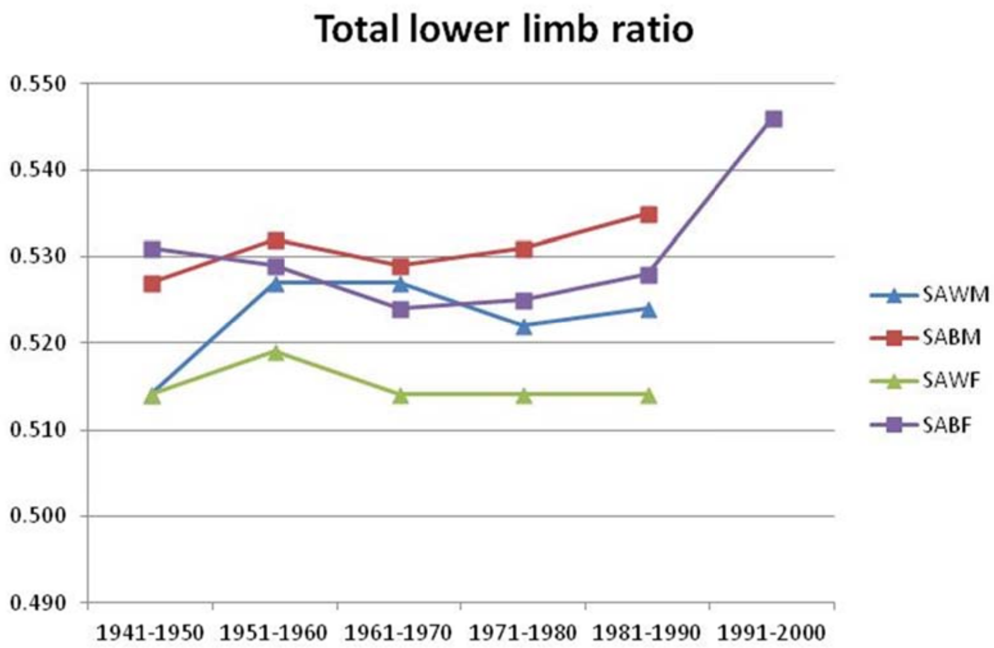


Figure 5.36 Comparisons of the differences in the secular trend of anthropometric total lower limb ratio for South African population groups.

The differences in the lower limb ratio between SA males and females are seen in Figure 5.37. Similar to the total lower limb ratio, individuals of African descent have greater lower limb ratios (i.e., greater lower limb lengths relative to stature) than their counterparts of European descent. Significant positive secular trends are observed in all groups except SAWF who exhibited no secular trend. However, the trend was negative in SABF until 1970's followed by a rapid increase from the 1980's. This indicates that the lower limb lengths relative to stature decreased gradually but was followed by a rapid increase during the 1980's. SABF had slightly higher lower limb ratios that SABM from the 1940's to the 1960's due to the initial negative secular trend. During the 1970's and 1980's, SABM exhibited higher lower limb ratios than SABF indicating a larger increase in lower limb lengths relative to stature. In SA white groups, males have higher ratios than the females except during the 1940's. The small lower limb ratios during the 1940's in SA males are possibly due to the small sample sizes.

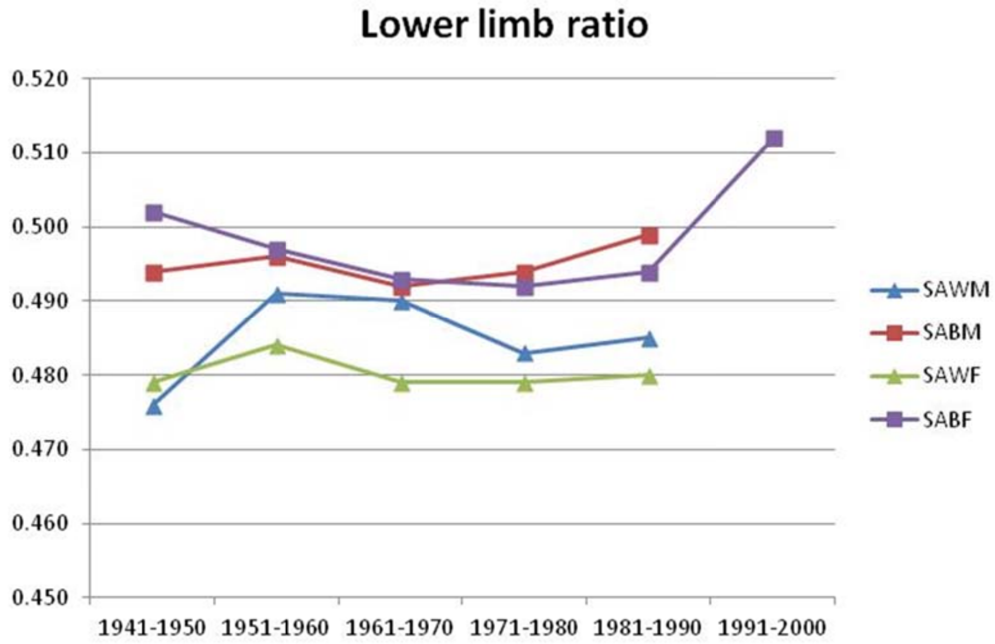


Figure 5.37 Comparisons of the differences in the secular trend of anthropometric lower limb ratio for South African population groups.

In Figure 5.38 the differences in the thigh ratio between SA males and females are clearly illustrated. Except for SAWF, a significant overlap in the thigh ratio is observed between the groups indicating similar thigh lengths relative to stature in SAWM, SABM and SABF. Significant positive secular trends are observed in SAWM, SABM and SABF. Although an increase is seen in the thigh ratio of SAWF, this change is not statistically significant ($p > 0.05$). The thigh ratio was the lowest in SAWF indicating the shortest thigh lengths relative to stature. SAWM exhibited significantly higher ratios over the total period than SAWF. However, SABF had higher ratios than both SABM and SAWM in the 1940's and 1950's. From the 1950's to 1970's, SAWM and SABM had higher ratios after which the ratio increased in SABF indicating a rapid increase in the thigh lengths relative to stature in SABF from the 1980's. Overall, SABM had slightly higher ratios compared to SAWM but the difference only became significant during the 1970's and 1980's. This indicates that individuals of African descent have greater thigh lengths relative to stature than individuals of European descent from the 1980's.

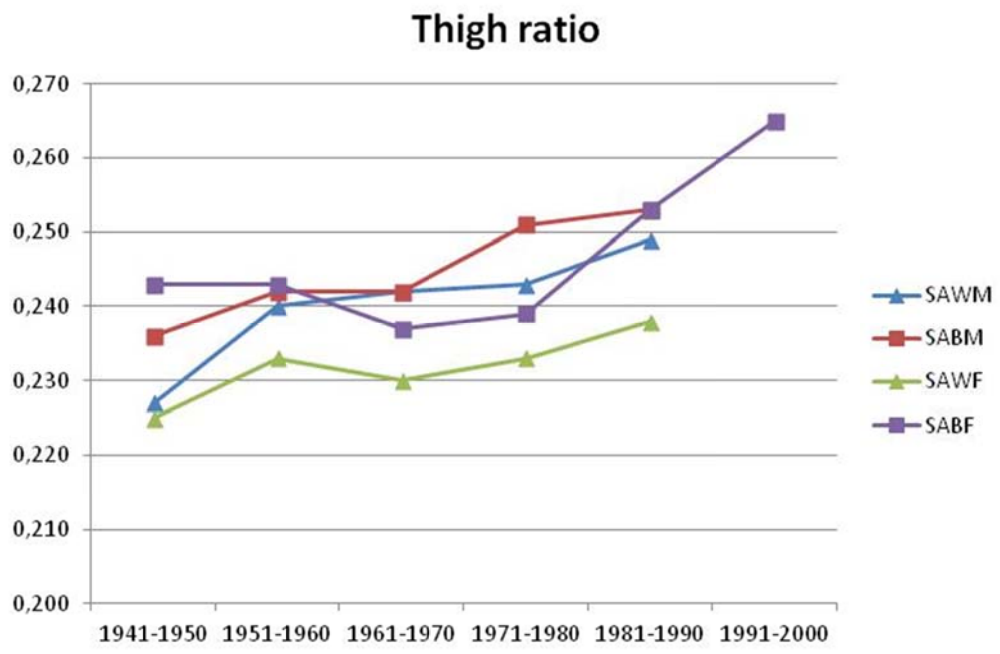


Figure 5.38 Comparisons of the differences in the secular trends of anthropometric thigh ratio for South African population groups.

The differences in the leg ratio between SA males and females are clearly illustrated in Figure 5.39. Significant negative secular trends are observed in all groups with females having a slightly higher leg ratio (i.e., greater leg lengths relative to stature) than their corresponding male groups. Although individuals of African descent have higher leg ratios, an overlap is seen between SABM and SAWF during the 1960’s and 1970’s. A small increase in the leg ratio is observed in SABM and SABF during the 1970’s and 1990’s, respectively. Thus, SABM had the highest leg ratio compared to the other groups in the 1980’s. Significant ancestry differences are still visible between male groups and females groups except in the 1980’s when SABF and SAWF had similar leg ratios.

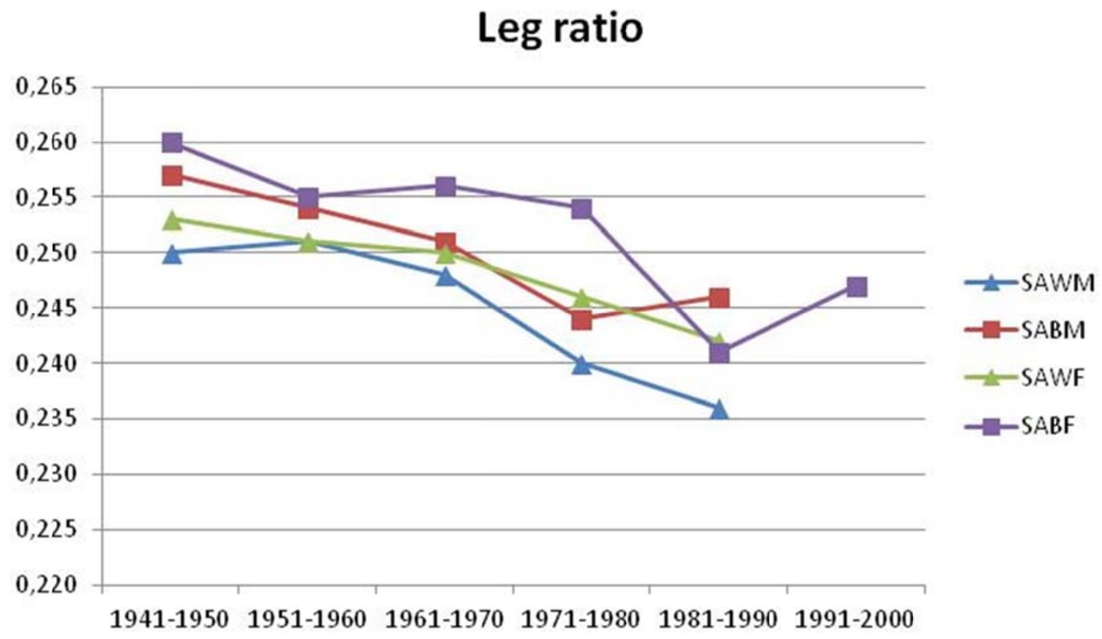


Figure 5.39 Comparisons of the differences in the secular trend of anthropometric leg ratio for South African population groups.

The differences in the intermembral index between SA males and females are illustrated in Figure 5.40. Individuals of African descent have slightly higher intermembral indices than their counterparts of European descent and in both ancestry groups, males have higher intermembral indexes than the females. This indicates that individuals of African descent have slightly greater upper limb lengths relative to lower limb lengths than individuals of European descent while females have slightly shorter upper limb lengths relative to lower limb lengths than males. However, the differences are not statistically significant ($p > 0.05$). Similar intermembral indexes are observed between SAWM and SABF during the 1960's and 1970's. A significant negative secular trend is observed in the intermembral index of SABF and SABM. No significant trends are observed in SA white groups. The low intermembral index in the 1940's is possibly due to the small sample size of SABM (n = 12).

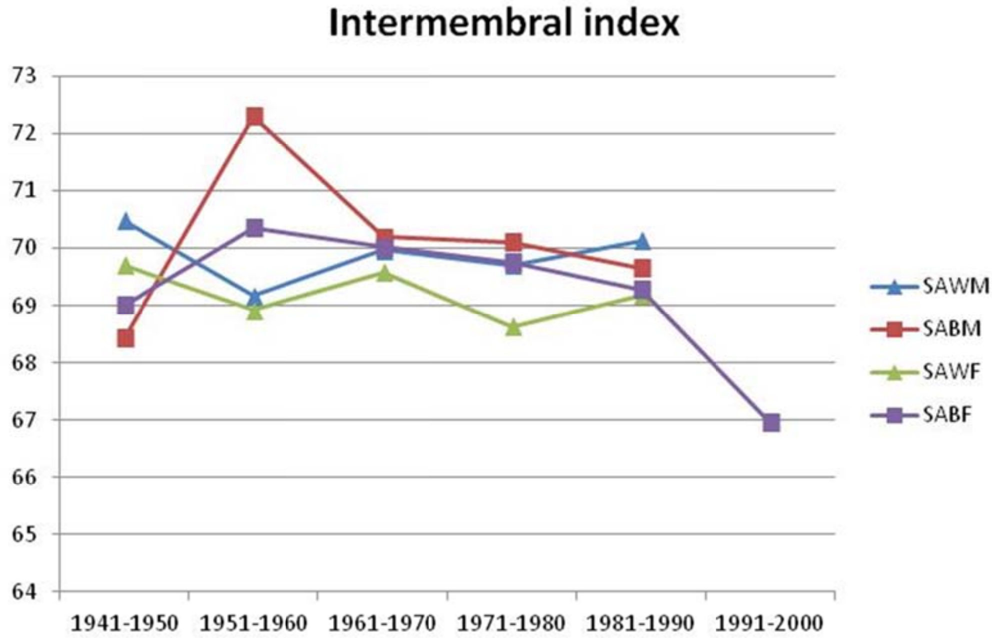


Figure 5.40 Comparisons of the differences in the secular trend of anthropometric intermembral index for South African population groups.

Figure 5.41 demonstrates the differences in the sitting height ratio between SA black and white males and females. Significant negative secular trends are observed in the sitting height ratio of SAWM, SABM and SABF while a significant positive secular trend is seen in SAWF. This indicates that while the sitting height is decreasing relative to stature in SAWM, SABM and SABF, it is increasing in SAWF. Overall, females had sitting height ratios that were significantly higher than those males However, SAWM and SAWF had similar ratios in the 1940's and the 1950's. Due to the positive secular trend in SAWF, a difference is observed during the 1960's to 1980's with SAWM having distinctly lower sitting height ratios. Although SABF had the highest sitting height ratio in the 1940's to 1960, the rapid negative secular trend resulted in lower ratios in the 1980's when compared to SAWM and SAWF. A small increase is again observed in the sitting height ratio of SABF in the 1990's. From the 1980's, individuals of European descent had higher intermembral indices than their counterparts of African descent indicating higher sitting heights relative to stature in individuals of European descent. Over the entire period, SABM had the lowest sitting height ratio.

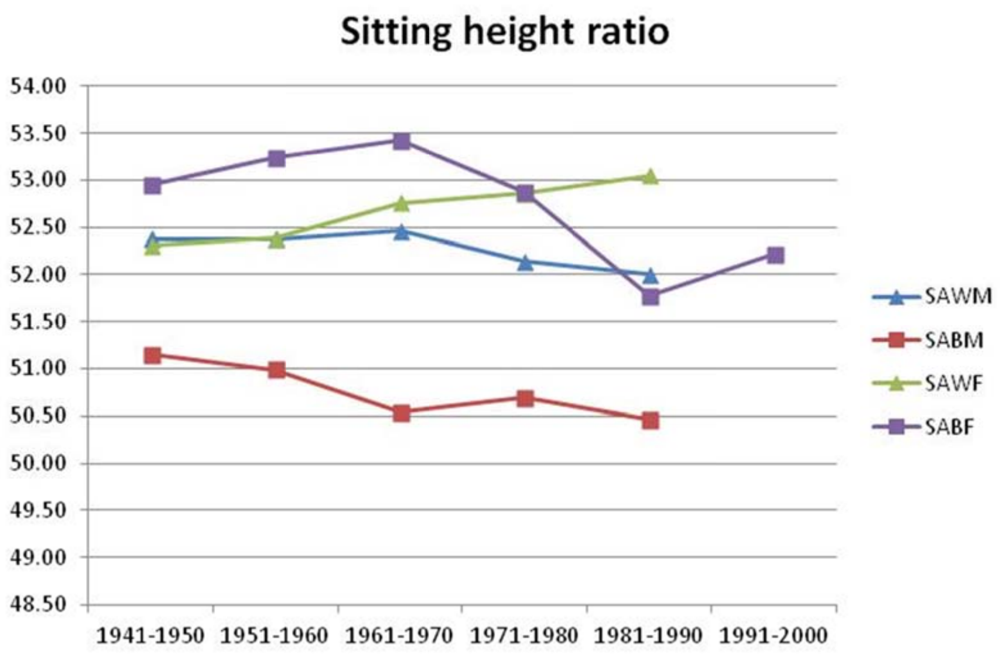


Figure 5.41 Comparisons of the differences in the secular trend of anthropometric sitting height ratio for South African population groups.

Chapter 6: Ancestry differences and secular trends in Total Skeletal Height (TSH)

In this section the ancestry differences and secular trends for osteometric stature (as represented by Total skeletal height [TSH]) were analysed in South African populations groups. This was done to supplement data on living individuals as outlined earlier. In addition, the South African groups were compared to data from North America in order to analyse the differences in TSH between these southern and northern hemisphere samples.

6.1 Ancestry differences and secular trends in TSH of South African population groups

The osteometric stature (as represented by TSH) of South African groups was analysed to observe whether differences exist between individuals of African and European descent. Also, the groups were compared over birth cohorts of 10 years to determine whether secular trends are taking place within each population group. The intra-observer and inter-observer correlations were high (intra-class correlations between 0.990 and 1) for all osteometric measurements (Appendix A4). This indicates that all measurements could be accurately repeated.

6.1.1 Ancestry differences and secular trends in the TSH of South African black and white males

Ancestry differences in TSH

The mean TSH and sample sizes of both the South African black males (SABM) and white males (SAWM) are shown in Table 6.1. The sample comprised of a total of 188 SABM and 51 SAWM with dates of birth (DOB) ranging from 1900 to 1980. Due to the possible inaccurate representation of TSH caused by small sample sizes, the results of SAWM in the 1900's (n = 1), 1950's (n = 3) and 1960's (n = 1) are not discussed.

The non-parametric Kruskal-Wallis test which is equivalent to the parametric analysis of variance for TSH, classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between the mean TSH of SABM and SAWM. In Figure 6.1 the difference in the average TSH between SABM and SAWM for all birth cohorts combined can be seen. SABM had an overall average TSH of 1520.6 mm while SAWM were significantly taller with an overall average TSH of 1576.7 mm (Kruskal-Wallis

Chi-Squared = 26.0494; p = <0.0001). Table 6.1 demonstrates that across all decades, except 1921-1930, the average TSH of SAWM is significantly higher than those of SABM.

Table 6.1 The sample sizes, mean TSH and Kruskal-Wallis results for TSH between South African black and white males per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-squared	p-value
1900 - 1910	SABM SAWM	23 1	1516.1 1485.4	58.28 -	-	-
1911 - 1920	SABM SAWM	21 10	1496.6 1572.5	74.95 49.96	8.5018	**0.0035**
1921 - 1930	SABM SAWM	19 10	1528.8 1574.3	68.49 57.32	3.0400	0.0812
1931 - 1940	SABM SAWM	30 13	1520.4 1577.2	57.34 57.75	6.4448	**0.0111**
1941 - 1950	SABM SAWM	33 13	1543.5 1600.9	63.21 68.59	7.6669	**0.0056**
1951 - 1960	SABM SAWM	32 3	1525.0 1582.0	65.90 27.49	-	-
1961 - 1970	SABM SAWM	23 1	1496.7 1396.0	101.59 -	-	-
1971 - 1980	SABM	7	1537.5	73.48	-	-
1900 - 1980	SABM SAWM	188 51	1520.6 1576.7	70.74 63.08	26.0494	**<0.0001**

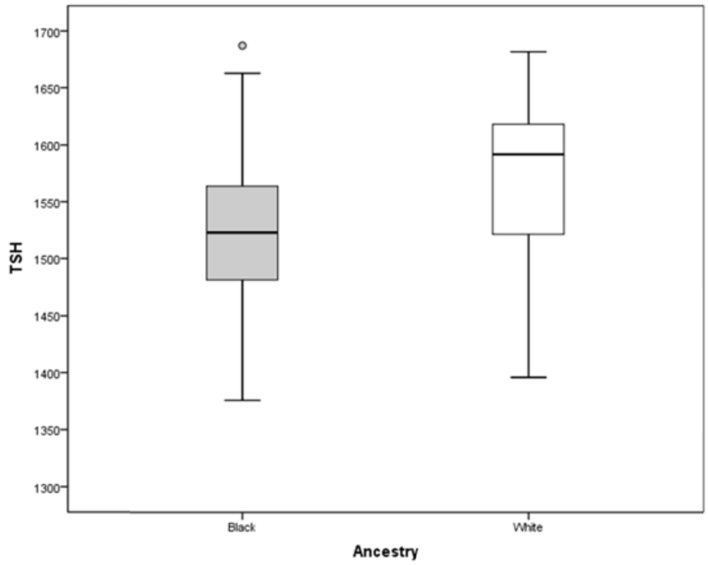


Figure 6.1 Differences in the mean TSH between South African black and white males for the overall period.

Secular trends in mean TSH

Comparison of the average TSH plotted against Date of Birth (DOB) cohort of a decade using the SAS NPAR1WAY procedure for SABM and SAWM indicated that the average TSH increased from 1572.5 mm in the 1910's to 1600.1 mm in the 1940's for SAWM and increased from 1516.1 mm in the 1900's to 1537.5 mm in the 1980's for SABM (Table 6.1). Figure 6.2 demonstrates the differences in the secular trend between SABM and SAWM. From 1900 to 1970 the TSH of SABM demonstrated no significant secular trend (Kruskal-Wallis Chi-squared = 6.4079; p-value = 0.4930). The TSH in SABM increased and decreased during the whole period, showing non-directional fluctuations. The stature initially decreased with 19.5 mm from the 1900's to the 1910's followed by an increase of 32.2 mm in the 1920's. The TSH then again decreased with 8 mm in the 1930's followed by an increase of 23.1 mm in the 1940's. From 1950, the TSH continued to gradually decrease with 18.5 mm and 28.4 mm in the 1950's and 1960's, respectively. A final increase of 40.8 mm is observed in the 1980's. Similarly, SAWM demonstrated no significant secular trend in TSH (Kruskal-Wallis Chi-Squared = 8.8408; p = 0.1827) with a gradual increase of 1.8 mm, 2.9 mm, and 23.7 mm from the 1910's to 1940's.

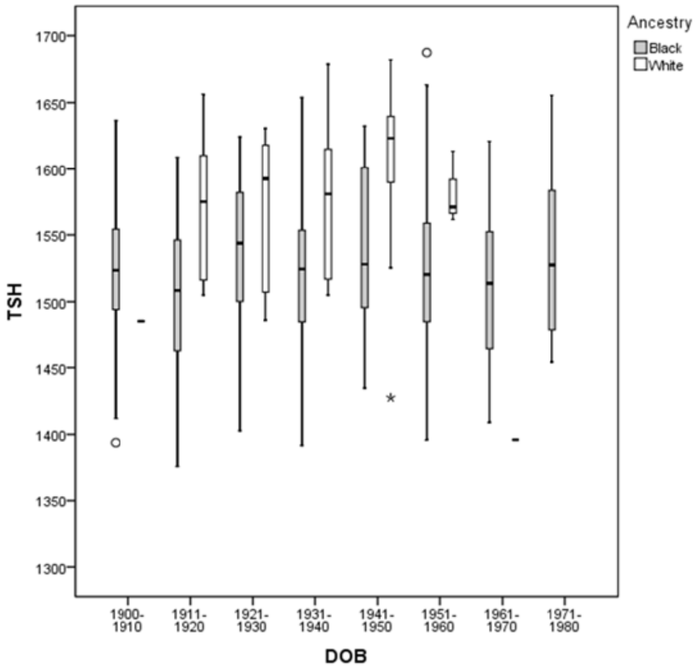


Figure 6.2 Secular trends in the mean TSH of South African black and white males. (*/° outliers)

6.1.2 Ancestry differences and secular changes in the TSH of South African black and white females

Ancestry differences between mean TSH

Table 6.2 demonstrates the mean TSH and sample sizes of both the South African black females (SABF) and white females (SAWF). The sample comprised of a total of 169 SABF and only 23 SAWF with dates of birth (DOB) ranging from 1900 to 1990. Due to the possible inaccurate representation of TSH caused by small sample sizes, the results of SAWF in the 1900's (n = 1), 1910's (n = 3), 1950's (n = 1) and 1990's (n = 1) are not discussed.

The non-parametric Kruskal-Wallis test which is equivalent to the parametric analysis of variance for TSH, classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between the mean TSH of SABF and SAWF. In Figure 6.3 the difference in the average TSH between SABF and SAWF for all birth cohorts combined can be seen. SABF had an overall average TSH of 1417.3 mm while SAWF were significantly taller with an overall average TSH of 1464.3 mm (Kruskal-Wallis Chi-Squared = 9.5704; p = 0.0020). Table 6.2 demonstrates that during the 1920's, the averages TSH of SAWF are significantly higher than those of SABF (p = 0.0247). During the

1930's and 1940's, no significant differences were observed (p = 0.1071 and p = 0.8875, respectively).

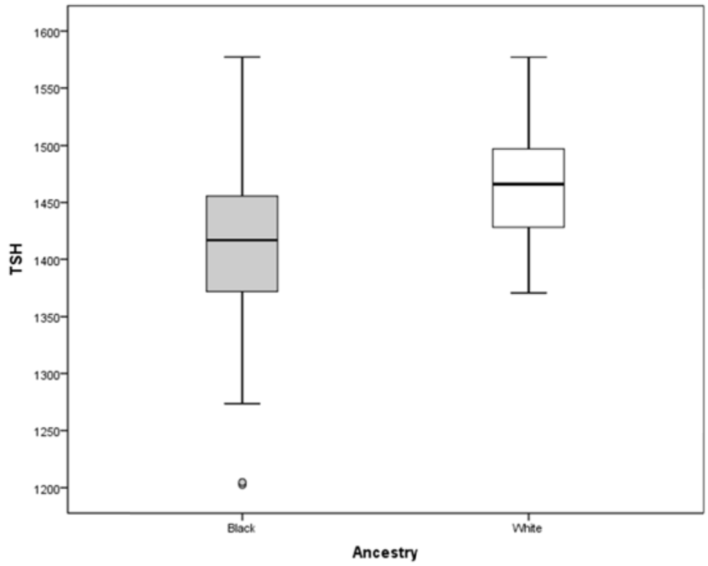


Figure 6.3 Differences in the mean TSH between South African black and white females for the overall period.

Table 6.2 The sample sizes, mean TSH and Kruskal-Wallis results for TSH between South African black and white females per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-squared	p-value
1900 - 1910	SABF SAWF	19 1	1411.4 1524.8	68.48 -	-	-
1911 - 1920	SABF SAWF	26 3	1383.3 1392.0	57.63 6.93	-	-
1921 - 1930	SABF SAWF	26 7	1418.2 1462.7	50.72 42.66	5.0440	**0.0247**
1931 - 1940	SABF SAWF	26 5	1427.6 1484.8	75.75 53.19	2.5962	0.1071
1941 - 1950	SABF SAWF	30 5	1438.9 1447.8	79.01 62.93	0.0200	0.8875
1951 - 1960	SABF SAWF	21 1	1415.7 1577.3	79.38 -	-	-
1961 - 1970	SABF	16	1420.8	44.01	-	-
1971 - 1980	SABF	5	1423.7	65.60	-	-
1981 - 1990	SAWF	1	1498.5	-	-	-
1900 - 1990	SABF SAWF	169 23	1417.3 1464.3	67.98 58.36	9.5704	**0.0020**

Secular trends in mean TSH

Comparison of the average TSH plotted against Date of Birth (DOB) cohort for a decade using the SAS NPAR1WAY procedure for SABF and SAWF indicated that the average TSH decreased from 1462.6 mm in the 1920's to 1447.8 mm in the 1940's for SAWF and increased from 1411.4 mm in the 1900's to 1423.7 in the 1970's for SABF (Table 6.2). In Figure 6.4, the differences in the secular trend between SABF and SAWF can be seen. From 1900 to 1960 the TSH of SABF demonstrated no significant secular trend (Kruskal-Wallis Chi-squared = 10.8873; p-value = 0.1436) with non-directional fluctuations. The stature initially decreased with 28.1 mm from the 1900's to the 1910's followed by an increase of 34.9 mm, 9.3 mm and 11.4 mm in the 1920's, 1930's and 1940's. The TSH then again decreased with 23.2 mm in the 1950's and increased slightly with 5.1 mm and 3.0 mm in the 1960's and 1970's, respectively. Similarly, SAWF demonstrated no significant secular trend in TSH (Kruskal-Wallis Chi-Squared = 10.6973; p = 0.0982) with an increase of 22.1 mm from the 1920's to 1930's, followed by a decrease of 37.0 mm in the 1940's.

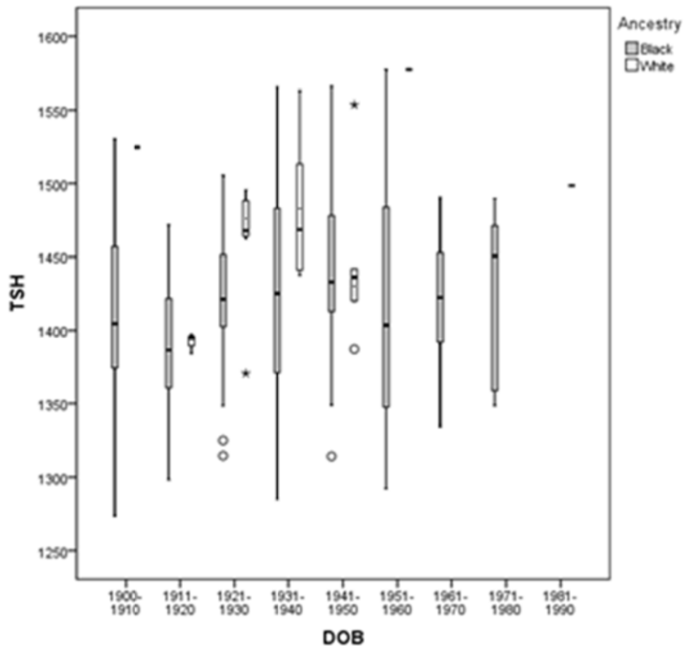


Figure 6.4 Secular trends in the mean TSH of South African black and white females. (*/° outliers)

6.2 Osteometric differences and secular trends in stature (TSH) of Southern and Northern hemisphere population groups

The statures (TSH) of white South African males (SAWM) and females (SAWF) were compared to white North American males (NAWM) and females (NAWF) in order to determine whether differences exist between groups from the southern and northern hemispheres. Also, the groups were compared by birth cohorts of 10 years to compare the secular trends that are taking place within each population group. Population groups of African descent could not be included since only North American cadaver heights (Chapter 4) were available for this group and no TSH data for black North American groups could be found.

6.2.1 Secular changes and differences in the TSH of South African and North American males

The sample sizes and mean TSH of SAWM and NAWM are shown in Table 6.3. The sample comprised of a total of 68 NAWM and 51 SAWM with dates of birth (DOB) ranging from 1900 to 1980.

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for TSH, classified by group using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between the mean TSH of NAWM and SAWM. Due to the possible inaccurate representation of TSH caused by small sample sizes, the results of SAWM in the 1990's (n = 1), 1950's (n = 3) and 1960's (n = 1) are not discussed.

Table 6.3 demonstrates that NAWM are significantly taller (Kruskal-Wallis Chi-squared = 7.0083; p = 0.0081) than SAWM. In Figure 6.5 the difference in the average TSH between SAWM and NAWM for all birth cohorts combined can be seen. Overall, NAWM had an average TSH of 1607.3 mm while SAWM had an average TSH of 1576.7 mm. NAWM were thus on average 30.7 mm taller than SAWM. Table 6.3 also demonstrates that when analysed by birth cohort, no significant differences could be observed ($p > 0.05$).

Comparison of the average TSH plotted against Date of Birth (DOB) cohort of a decade using the SAS NPAR1WAY procedure for SAWM and NAWM indicated non-directional fluctuations. In Figure 6.6 the secular changes in the mean TSH of NAWM and SAWM can be seen. No significant trends were observed in NAWM. Overall, the TSH of NAWM increased from 1615.0 mm in the 1930's to 1619.3 mm in the 1980's, while the TSH of SAWM increased from 1572.5 mm in the 1910's to 1601.0 mm in the 1940's.

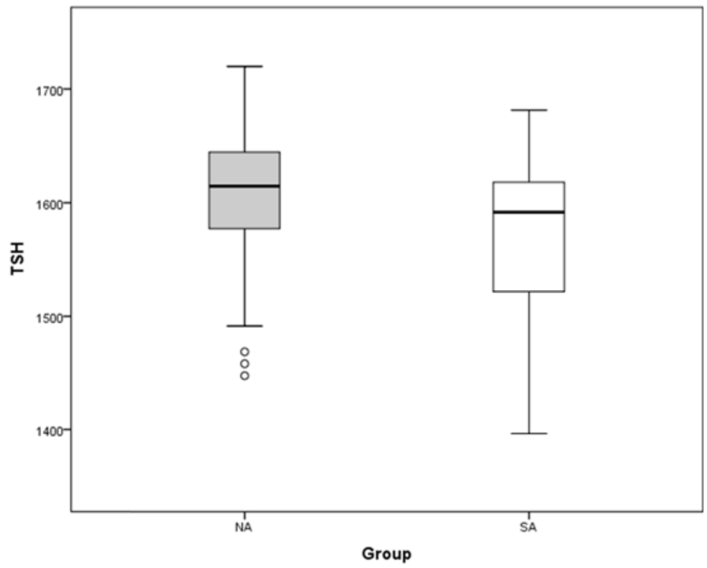


Figure 6.5 Differences in the mean TSH between South African and North American white males for the overall period.

Table 6.3 The sample sizes, mean TSH and Kruskal-Wallis results for TSH between white South African and North American males per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-squared	p-value
1900-1910	SAWM	1	1485.4	-	-	-
1911-1920	SAWM	10	1572.5	49.96	-	-
1921-1930	SAWM	10	1574.3	57.32	-	-
1931-1940	SAWM NAWM	13 9	1577.2 1615.0	57.75 74.87	2.8997	0.0886
1941-1950	SAWM NAWM	13 12	1600.9 1593.4	68.59 70.76	0.2959	0.5865
1951-1960	SAWM NAWM	3 22	1582.0 1612.9	27.49 46.07	-	-
1961-1970	SAWM NAWM	1 14	1396.0 1596.1	- 59.32	-	-
1971-1980	NAWM	11	1619.3	48.96	-	-
1900-1980	SAWM NAWM	51 68	1576.7 1607.3	63.08 57.44	7.0083	**0.0081**

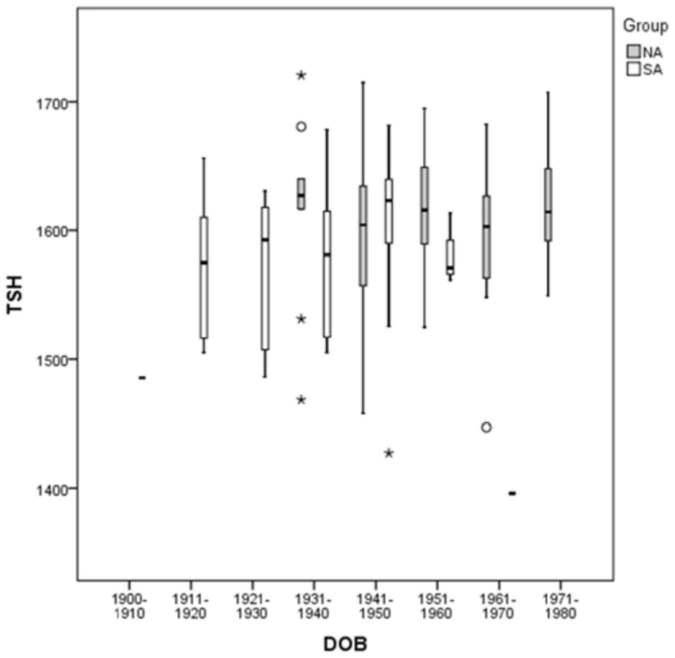


Figure 6.6 Secular trends the mean TSH of South African and North American white males per decade. (*/° outliers)

6.2.2 Secular changes and differences in the TSH of South African and North American females

The sample sizes and mean TSH of SAWF and NAWF are shown in Table 6.4. The sample was limited and comprised of a total of 43 NAWF and only 23 SAWF with dates of birth (DOB) ranging from 1941 to 1960. Due to the small sample sizes and possible inaccurate representation of TSH, the results of SAWF in the 1900's (n = 1), 1910's (n = 3); 1950's (n = 1) and 1980's (n = 1) are not discussed.

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for TSH, classified by group using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between the mean TSH of NAWF and SAWF. Table 6.4 demonstrates that NAWF are significantly taller (Kruskal-Wallis Chi-squared = 4.9006; p = 0.0268) than SAWF. On average, NAWF are 35.4 mm taller than SAWF. In Figure 6.7 the difference in the average TSH between NAWF and SAWF for all birth cohorts combined can be seen. Overall, NAWM had an average TSH of 1499.6 mm while SAWM had an average TSH of 1464.3 mm. Figure 6.8 demonstrates a lack of a secular trend with non-directional fluctuations in TSH for both NAWF and SAWF with a slight decrease across the whole period.

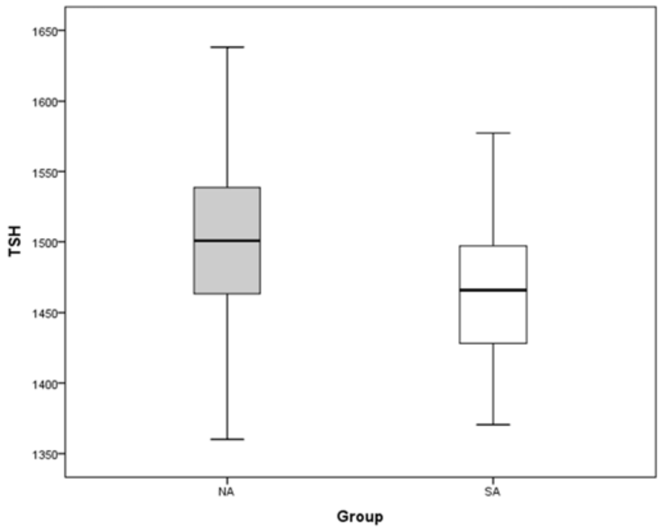


Figure 6.7 Differences in the mean TSH between South African and North American white females for the overall period.

Table 6.4 The sample sizes, mean TSH and Kruskal-Wallis results for TSH between white South African and North American females per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-squared	p-value
1900-1910	SAWF	1	1524.8	-	-	-
1911-1920	SAWF	3	1392.0	6.93	-	-
1921-1930	SAWF	7	1462.7	42.66	-	-
1931-1940	SAWF	5	1484.8	53.19	-	-
1941-1950	SAWF NAWF	5 7	1447.8 1538.4	62.93 57.01	4.1209	**0.0424**
1951-1960	SAWF NAWF	1 19	1577.3 1487.4	- 47.38	2.7143	0.0995
1961-1970	NAWF	9	1507.1	71.54	-	-
1971-1980	NAWF	8	1486.4	67.75	-	-
1981-1990	SAWF	1	1498.5	-	-	-
1900-1990	SABF NAWF	23 43	1464.3 1499.6	58.36 59.42	4.9006	**0.0268**

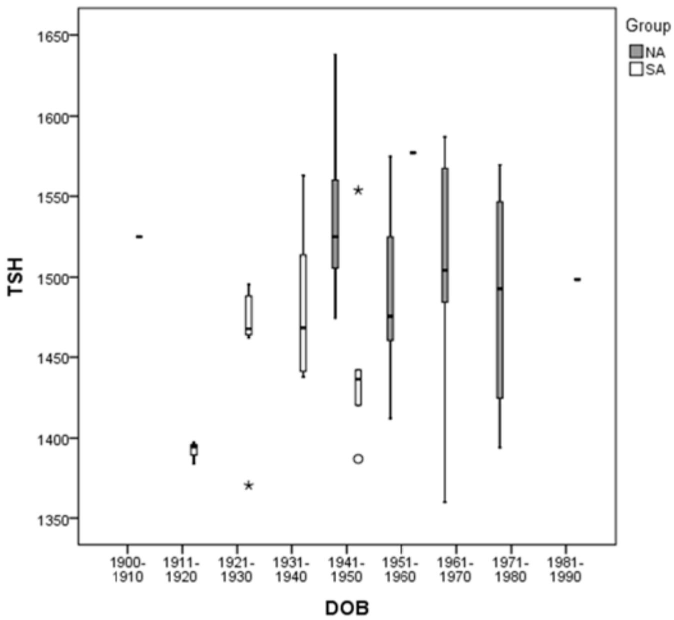


Figure 6.8 Secular trends in the mean TSH of South African and North American white females per decade.

6.2.3 Sex differences in the TSH of South African and North American groups

Figure 6.9 demonstrates the differences in the mean TSH between South African and North American males and females for the combined birth cohorts. Although SAWM are significantly shorter than NAWM they are still taller than NAWF. SAWF were the shortest of all the groups.

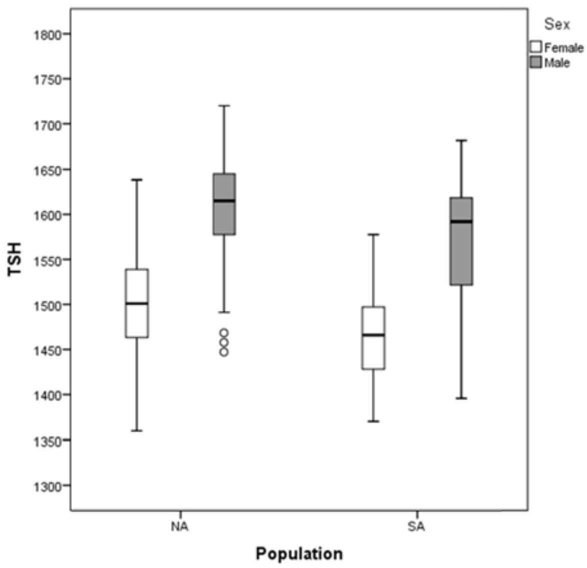


Figure 6.9 Mean TSH between South African (SA) and North American (NA) population groups.

Chapter 7: Differences and secular trends in the osteometric limb proportions of South African and North American population groups

In this chapter the osteometric limb proportions between the two major South African population groups were compared to determine whether differences exist between individuals of African and European descent. These individuals were born between 1900 and 1990. The osteometric limb proportions for each birth cohort were also compared to determine whether secular changes are taking place. Furthermore, the osteometric limb proportions of South African white groups were compared to North American white groups to determine whether differences exist between individuals of European descent in the southern and northern hemispheres. The same could unfortunately not been done for individuals of African descent, as no data from North America are available.

7.1. Ancestry differences and secular trends in the osteometric limb proportions of South African population groups

In this section the differences and similarities in osteometric limb proportions between South African population groups are discussed. The results for male and female groups are presented separately. The osteometric limb proportions are presented in four categories, namely the arm proportions (brachial index, upper limb ratio, arm ratio and forearm ratio), lower limb proportions (crural index, total lower limb ratio, lower limb ratio, thigh ratios 1 and 2 and leg ratios 1 and 2), intermembral indices and sitting height ratios.

7.1.1 Ancestry differences and secular trends in the osteometric limb proportions of South African black and white males

7.1.1.1 Ancestry differences and secular trends in the osteometric upper limb proportions of South African black and white males

Ancestry differences in upper limb proportions

In Table 7.1 the results of the non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for brachial index ([radius max length/humerus max length] x100), upper limb ratio (arm length/TSH), arm ratio (humerus max length/TSH) and forearm ratio 1 (radius max length/TSH) and forearm ratio 2 (ulna max length/TSH), classified by ancestry using the SAS NPAR1WAY procedure, can be seen. This test was used to determine whether significant differences exist between South African black males (SABM) and South African white males (SAWM).

Over the combined birth cohort, a significant difference ($p < 0.05$) was observed in the arm length (humerus max length + radius max length), humerus max length and radius max length. SAWM had larger arm and humeral max length measurements than SABM while the radius max length is larger in SABM (Appendix C1; Table C1.1 and Figures C1.1 and C1.2). Although the ulna max length in SABM is 3.77 mm greater than in SAWM, this difference was not significant ($p = 0.0560$).

In Figure 7.1 the differences in the arm proportions between SABM and SAWM for all birth cohorts combined can be seen. No comparisons were made in birth cohorts with small sample sizes due to the possible inaccurate representation of the proportions. Therefore, the results of SAWM in 1900-1910 (n = 2), 1951-1960 (n = 3) and 1961-1970 (n = 1) are not discussed. SABM had a brachial index, upper limb ratio, forearm ratio 1 and forearm ratio 2 which were significantly higher than those of SAWM ($p < 0.0001$) across all birth cohorts. This indicates that SABM have greater forearm lengths relative to arm lengths and greater upper limb lengths and forearm lengths (radius max lengths and ulna max lengths) relative to stature (as represented by TSH) than SAWM. However, the upper limb ratio was more variable with no significant differences observed during 1910's and 1930's with SABM still having slightly higher values. No significant difference was observed in the arm ratio ($p = 0.0684$) with SAWM having slightly higher values than SABM indicating greater arm lengths relative to stature in SAWM.

Table 7.1 The sample sizes, mean osteometric upper limb proportions and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Brachial index					Upper limb ratio					Arm ratio				
		N	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**
1900-1910	SABM	28	80.17	2.94	-	-	23	0.385	0.015	-	-	23	0.213	0.010	-	-
	SAWM	2	74.01	1.41			1	0.405	-			1	0.232	-		
1911-1920	SABM	31	79.65	2.86	17.0500	**<0.0001**	21	0.384	0.014	3.8095	0.0510	21	0.214	0.009	0.2161	0.6420
	SAWM	10	74.71	1.82			8	0.375	0.066			10	0.216	0.005		
1921-1930	SABM	33	79.52	2.42	24.6480	**<0.0001**	19	0.379	0.009	4.4547	**0.0348**	19	0.211	0.004	0.0084	0.9269
	SAWM	13	73.59	1.75			10	0.371	0.015			10	0.213	0.010		
1931-1940	SABM	48	79.21	2.57	23.2823	**<0.0001**	30	0.378	0.010	1.7483	0.1861	30	0.211	0.007	1.8909	0.1691
	SAWM	21	74.88	2.84			13	0.377	0.014			13	0.216	0.009		
1941-1950	SABM	58	79.81	3.68	19.1720	**<0.0001**	33	0.381	0.010	5.3148	**0.0211**	33	0.211	0.008	0.6679	0.4138
	SAWM	17	75.53	2.63			13	0.374	0.007			13	0.213	0.006		
1951-1960	SABM	45	79.62	2.06	-	-	32	0.380	0.009	-	-	32	0.211	0.006	-	-
	SAWM	3	75.53	3.92			3	0.366	0.003			3	0.208	0.005		
1961-1970	SABM	37	79.84	2.77	-	-	23	0.384	0.026	-	-	23	0.214	0.016	-	-
	SAWM	1	74.18	-			1	0.382	-			1	0.219	-		
1971-1980	SABM	11	79.14	3.62	-	-	7	0.377	0.010	-	-	7	0.211	0.006	-	-
1900-1980	SABM	291	79.64	2.86	107.0928	**<0.0001**	188	0.381	0.014	16.6664	**<0.0001**	188	0.212	0.009	3.3208	0.0684
	SAWM	67	74.76	2.47			49	0.375	0.033			51	0.214	0.008		

Table 7.1 (continued) The sample sizes, mean osteometric upper limb proportions and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Forearm ratio 1					Forearm ratio 2				
		N	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**
1900-1910	SABM	23	0.172	0.007	-	-	23	0.182	0.007	-	-
	SAWM	1	0.174	-			1	0.184	-		
1911-1920	SABM	21	0.170	0.006	11.0095	**0.0009**	21	0.182	0.007	12.0071	**0.0005**
	SAWM	8	0.160	0.003			10	0.173	0.004		
1921-1930	SABM	19	0.168	0.006	11.5284	**0.0007**	17	0.180	0.007	11.3168	**0.0008**
	SAWM	10	0.157	0.006			10	0.169	0.006		
1931-1940	SABM	30	0.167	0.005	8.7720	**0.0031**	28	0.179	0.005	9.1554	**0.0025**
	SAWM	13	0.162	0.006			13	0.173	0.007		
1941-1950	SABM	33	0.170	0.006	17.9153	**<0.0001**	32	0.182	0.005	17.2801	**<0.0001**
	SAWM	13	0.161	0.004			13	0.173	0.004		
1951-1960	SABM	32	0.168	0.004	-	-	32	0.180	0.005	-	-
	SAWM	3	0.157	0.005			3	0.170	0.007		
1961-1970	SABM	23	0.170	0.011	-	-	23	0.181	0.012	-	-
	SAWM	1	0.163	-			1	0.182	-		
1971-1980	SABM	7	0.166	0.008	-	-	7	0.178	0.010	-	-
1900-1980	SABM	188	0.169	0.007	61.2777	**<0.0001**	183	0.181	0.007	53.5849	**<0.0001**
	SAWM	49	0.160	0.005			51	0.172	0.006		

*Radius max length/TSH ** Ulna max length/TSH

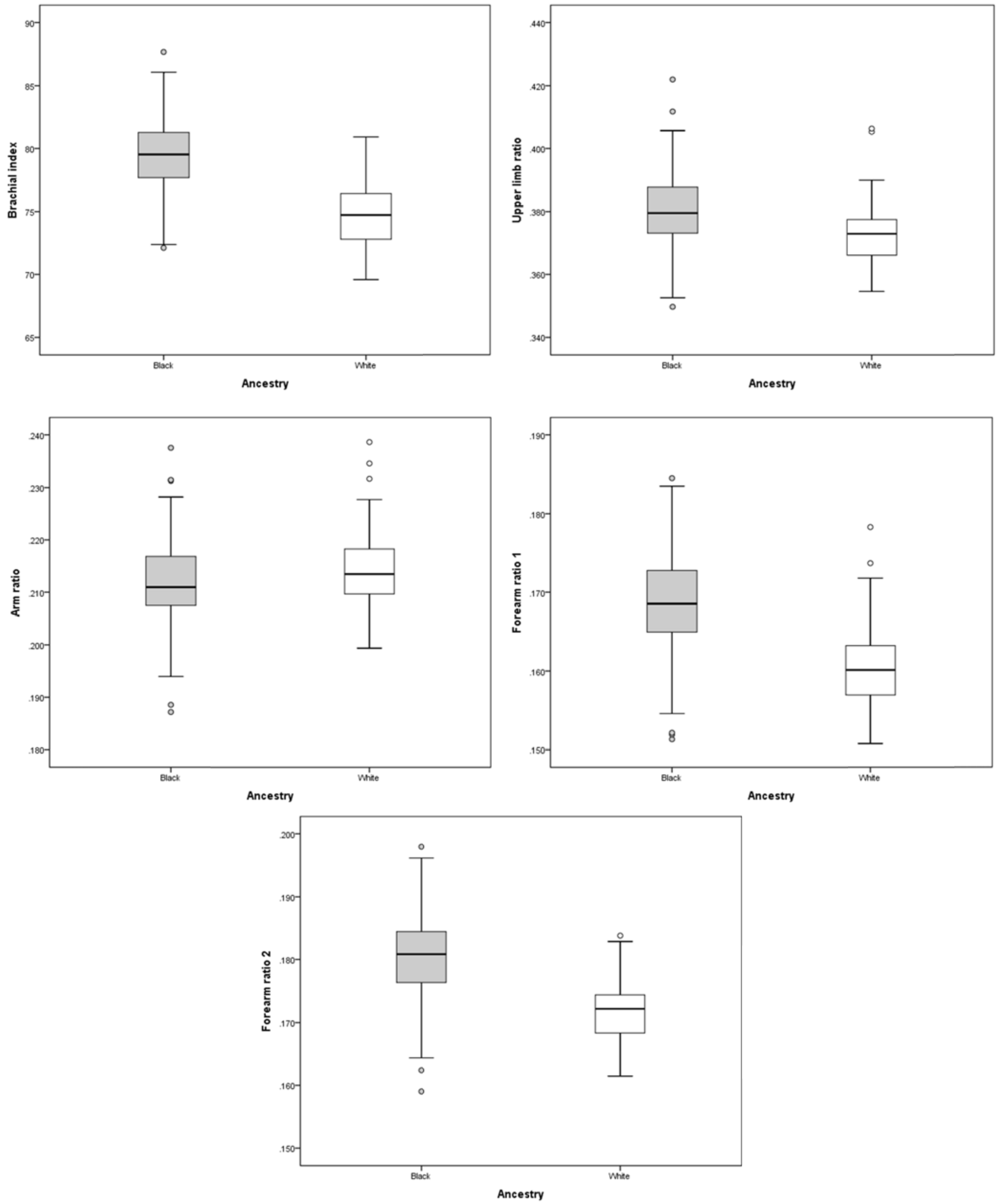


Figure 7.1 Ancestry differences in the osteometric upper limb ratios between South African black and white males over the total period.

Secular trends in arm proportions

Comparison of the brachial index, upper limb ratio, arm ratio, forearm ratio 1 and forearm ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM indicated that no secular trends occurred in the arm proportions from 1900 to 1980. The values for SAWM in 1900's, 1950's and 1960's are not discussed due to the small sample size of individuals born in these cohorts.

As seen in Table 7.1 and Figures 7.2 to 7.6, SABM and SAWM exhibited no significant secular changes in the brachial index (SABM: p-value = 0.9758; SAWM: p-value = 0.4360), upper limb ratio (SABM: p-value = 0.4193; SAWM: p-value = 0.1626), arm ratio (SABM: p-value = 0.8222; SAWM: p-value = 0.2807, forearm ratio 1 (SABM: p-value = 0.1317; SAWM: p-value = 0.0993) and forearm ratio 2 (SABM: p-value = 0.2557; SAWM: p-value = 0.1236). This indicates that no changes took place in any of the limb lengths relative to stature.

The brachial index of SABM decreased from 80.17 in the 1900's to 79.14 in the 1970's while an increase from 74.71 in the 1910's to 75.53 in the 1940's was observed for SAWM (Figure 4.2). A decrease from 0.385 to 0.377 and from 0.375 to 0.374 was observed in the upper limb ratio for SABM and SAWM, respectively (Figure 4.3). The arm ratio decreased from 0.213 to 0.211 for SABM from 1900's to 1970's and from 0.216 to 0.213 for SAWM from the 1910's to 1940's (Figure 4.4). A decrease from 0.172 to 0.166 was observed in forearm ratio 1 of SABM while an increase from 0.160 to 0.161 was observed in SAWM (Figure 4.5). The forearm ratio 2 decreased from 0.182 in the 1900's to 0.178 in the 1970's for SABM and remained unchanged at 0.173 from the 1910's to 1940's in SAWM (Figure 4.6). It should be emphasized that none of these trends were statistically significant.

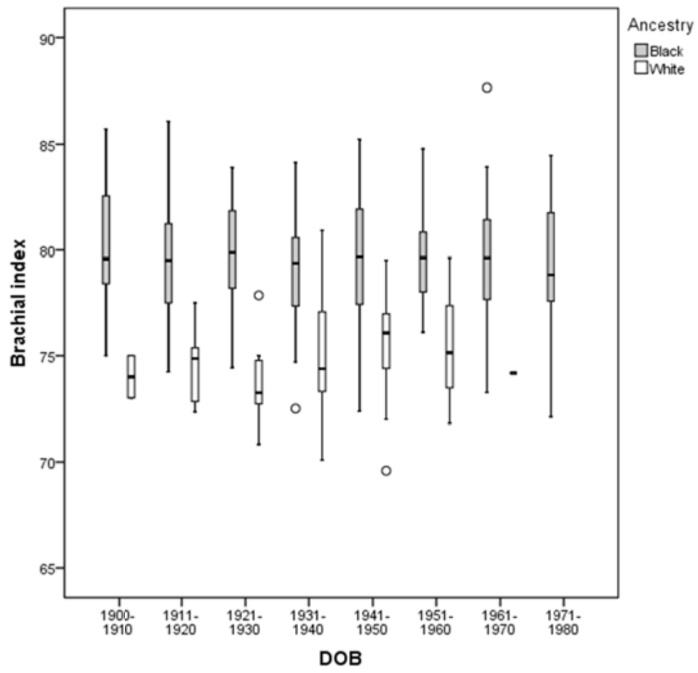


Figure 7.2 Secular trends in the osteometric brachial index of South African black and white males.

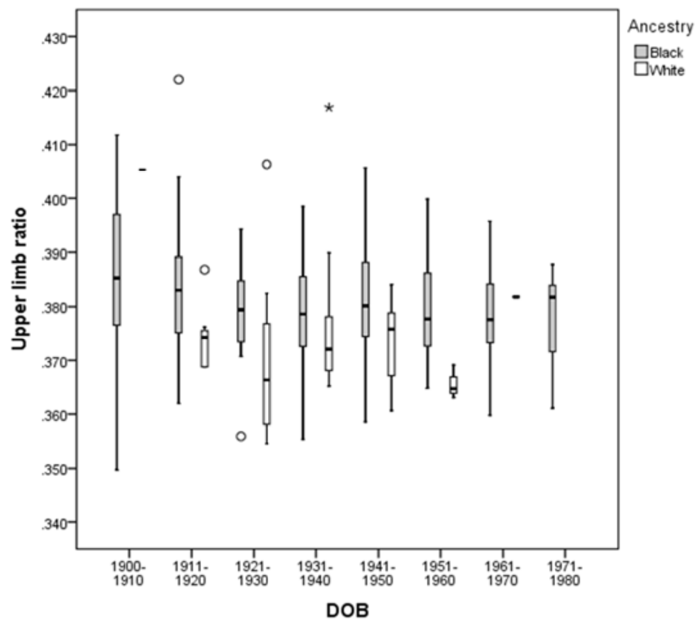


Figure 7.3 Secular trends in the osteometric upper limb ratio of South African black and white males.

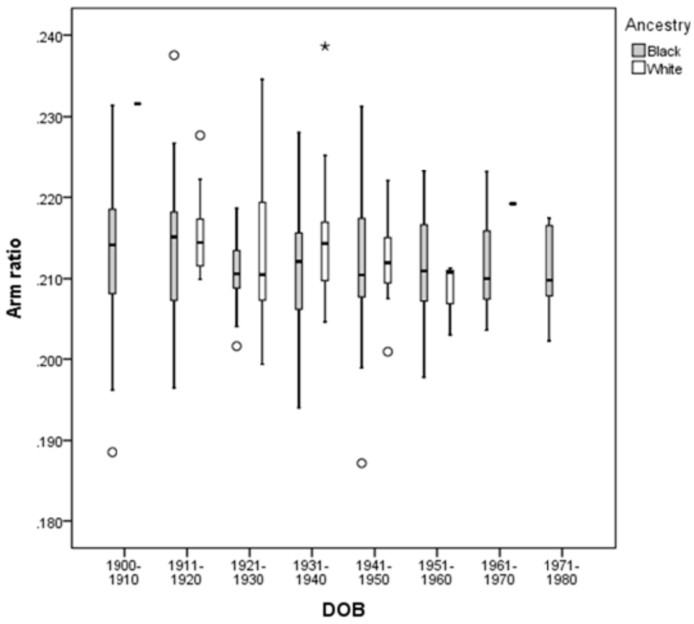


Figure 7.4 Secular trends in the osteometric arm ratio of South African black and white males.

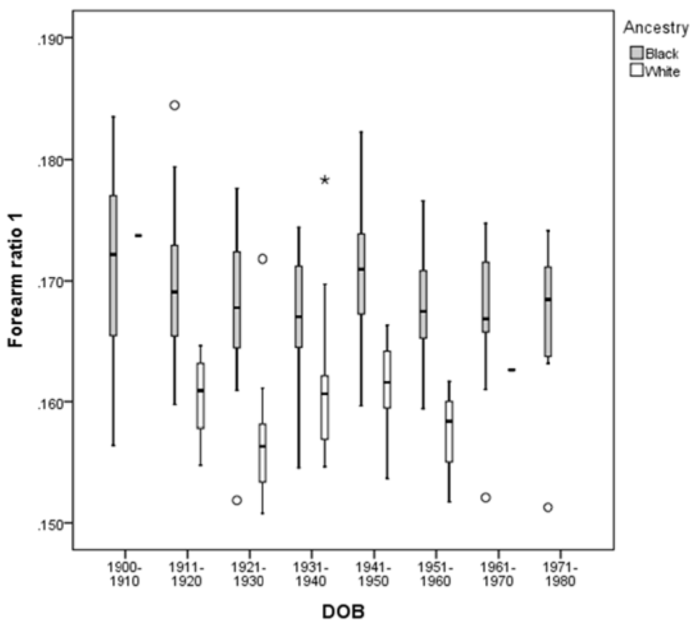


Figure 7.5 Secular trends in the osteometric forearm ratio 1 of South African black and white males.

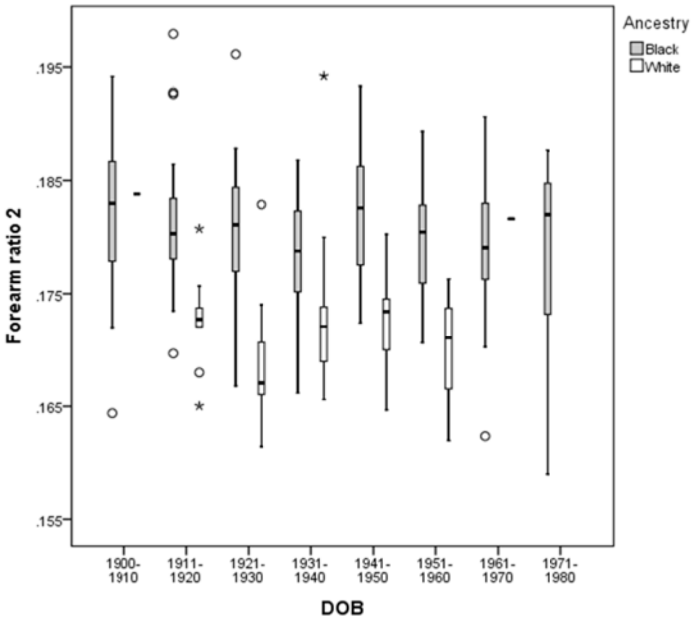


Figure 7.6 Secular trends in the osteometric forearm ratio 2 of South African black and white males.

7.1.1.2 Ancestry differences and secular trends in the osteometric lower limb proportions of South African black and white males

Ancestry differences in lower limb proportions

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for crural index ([tibia condylo-malleolar length/femur bicondylar length] x100), total lower limb ratio (femur bicondylar length + tibia condylo-malleolar length + talo-calcaneal height/TSH), lower limb ratio (femur bicondylar length + tibia condylo-malleolar length/TSH), thigh ratio 1 (femur max length/TSH) and thigh ratio 2 (femur bicondylar length/TSH), leg ratio 1 (tibia condylo-malleolar length/TSH) and leg ratio 2 (fibula max length/TSH), classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between SABM and SAWM (Table 7.1).

For the combined birth cohort, significant differences ($p < 0.05$) were observed in the total lower limb length, lower limb length, femur max length, and femur bicondylar length. No significant differences were observed in the tibia condylo-malleolar ($p = 0.8948$) and fibula max lengths ($p = 0.1443$). Overall, SAWM have larger/greater lower limb bone measurements than SABM except for the tibia condylo-malleolar length which is similar (Appendix C1; Table C1.2 and Figures C1.3 and C1.4).

The difference in the lower limb proportions between SABM and SAWM for all birth cohorts combined as well as per birth cohort can be seen in Table 7.2. The results of SAWM in 1900-1910 (n = 2), 1951-1960 (n = 3) and 1961-1970 (n = 1) are not discussed since no comparisons were made for birth cohorts with small sample sizes (n < 5). As seen in Figure 7.7, the crural index, total lower limb ratio, lower limb ratio, leg ratio 1 and leg ratio 2 for SABM were significantly higher than those of SAWM (p = <0.0001). This indicates that SABM have greater leg lengths (tibia condylo-malleolar lengths) to thigh lengths (femur bicondylar lengths) and total lower limb lengths, lower limb lengths and leg lengths (tibia condylo-malleolar lengths and fibula max lengths) relative to stature (as represented by TSH) than SAWM. Although SABM had slightly higher values for thigh ratio 1 and thigh ratio 2 than SAWM, no significant differences were observed (p = 0.1059 and p = 0.0650, respectively) indicating a slightly greater femur max length and femur bicondylar length relative to stature.

Table 7.2 The sample sizes, mean osteometric lower limb proportions and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Crural index					Total lower limb ratio					Lower limb ratio					Thigh ratio 1*				
		N	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**
1900-1910	SABM	28	83.90	2.34	-	-	20	0.596	0.013	-	-	23	0.559	0.019	-	-	23	0.303	0.012	-	-
	SAWM	2	83.15	2.66			1	0.644	-			1	0.597	-			1	0.331	-		
1911-1920	SABM	29	83.09	2.65	6.7989	**0.0091**	20	0.596	0.014	6.2884	**0.0122**	21	0.555	0.015	5.0161	**0.0251**	21	0.303	0.008	1.8286	0.1763
	SAWM	12	80.73	2.01			10	0.584	0.010			10	0.542	0.010			10	0.299	0.007		
1921-1930	SABM	33	83.12	2.36	7.5324	**0.0061**	19	0.594	0.011	5.4758	**0.0193**	19	0.554	0.011	8.6232	**0.0033**	19	0.301	0.006	1.4232	0.2329
	SAWM	13	80.62	2.79			10	0.582	0.014			10	0.539	0.013			10	0.298	0.009		
1931-1940	SABM	47	83.37	2.48	10.4561	**0.0012**	28	0.592	0.012	4.0279	**0.0448**	30	0.552	0.015	4.0392	**0.0445**	30	0.299	0.008	0.1573	0.6916
	SAWM	20	81.25	2.06			12	0.587	0.022			13	0.546	0.021			13	0.300	0.012		
1941-1950	SABM	57	83.94	3.00	8.6060	**0.0034**	32	0.595	0.013	7.6563	**0.0057**	33	0.555	0.015	5.8921	**0.0152**	33	0.300	0.008	0.9762	0.3231
	SAWM	16	81.73	1.82			12	0.583	0.008			13	0.543	0.011			13	0.299	0.006		
1951-1960	SABM	43	83.80	1.91	-	-	30	0.592	0.008	-	-	32	0.553	0.009	-	-	32	0.300	0.006	-	-
	SAWM	3	80.90	1.49			3	0.580	0.003			3	0.539	0.006			3	0.298	0.000		
1961-1970	SABM	34	83.79	2.52	-	-	22	0.590	0.008	-	-	23	0.557	0.034	-	-	23	0.302	0.018	-	-
	SAWM	1	81.38	-			1	0.590	-			1	0.548	-			1	0.305	-		
1971-1980	SABM	11	83.46	2.42	-	-	7	0.596	0.011	-	-	7	0.554	0.012	-	-	7	0.301	0.005	-	-
1900-1980	SABM	282	83.60	2.50	47.6254	**<0.0001**	178	0.593	0.011	28.0237	**<0.0001**	188	0.555	0.018	30.4898	**<0.0001**	188	0.301	0.010	2.6140	0.1059
	SAWM	67	81.19	2.13			49	0.585	0.016			51	0.544	0.016			51	0.300	0.009		

*Femur max length/TSH

Table 7.2 (continued) The sample sizes, mean osteometric lower limb proportions and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Thigh ratio 2*					Leg ratio 1**					Leg ratio 2***				
		N	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**
1900-1910	SABM	23	0.300	0.012	-	-	23	0.259	0.009	-	-	22	0.253	0.011	-	-
	SAWM	1	0.327	-			1	0.270	-			1	0.271	-		
1911-1920	SABM	21	0.301	0.008	2.1875	0.1391	21	0.255	0.009	6.4286	**0.0112**	18	0.249	0.008	3.5679	0.0589
	SAWM	10	0.297	0.007			10	0.246	0.006			8	0.242	0.006		
1921-1930	SABM	19	0.299	0.006	1.5347	0.2154	19	0.255	0.007	10.9137	**0.0010**	16	0.249	0.009	4.8750	**0.0272**
	SAWM	10	0.296	0.009			10	0.243	0.008			9	0.241	0.005		
1931-1940	SABM	30	0.298	0.008	0.1790	0.6722	30	0.255	0.008	6.7161	**0.0096**	30	0.250	0.008	6.1091	**0.0134**
	SAWM	13	0.299	0.012			13	0.248	0.010			11	0.243	0.006		
1941-1950	SABM	33	0.298	0.008	1.2869	0.2566	33	0.257	0.010	11.2520	**0.0008**	31	0.251	0.017	4.0676	**0.0437**
	SAWM	13	0.297	0.006			13	0.247	0.007			11	0.244	0.007		
1951-1960	SABM	32	0.298	0.006	-	-	32	0.255	0.005	-	-	31	0.236	0.055	-	-
	SAWM	3	0.296	0.001			3	0.243	0.005			3	0.239	0.004		
1961-1970	SABM	23	0.300	0.018	-	-	23	0.257	0.017	-	-	19	0.249	0.007	-	-
	SAWM	1	0.300	-			1	0.248	-			1	0.246	-		
1971-1980	SABM	7	0.299	0.005	-	-	7	0.255	0.009	-	-	7	0.251	0.009	-	-
1900-1980	SABM	188	0.299	0.010	3.4046	0.0650	188	0.256	0.010	48.4794	**<0.0001**	174	0.248	0.026	27.1868	**<0.0001**
	SAWM	51	0.298	0.009			51	0.246	0.008			44	0.243	0.007		

*Femur bicondylar length/TSH **Tibia condylo-malleolar length/TSH ***Fibula max length/TSH

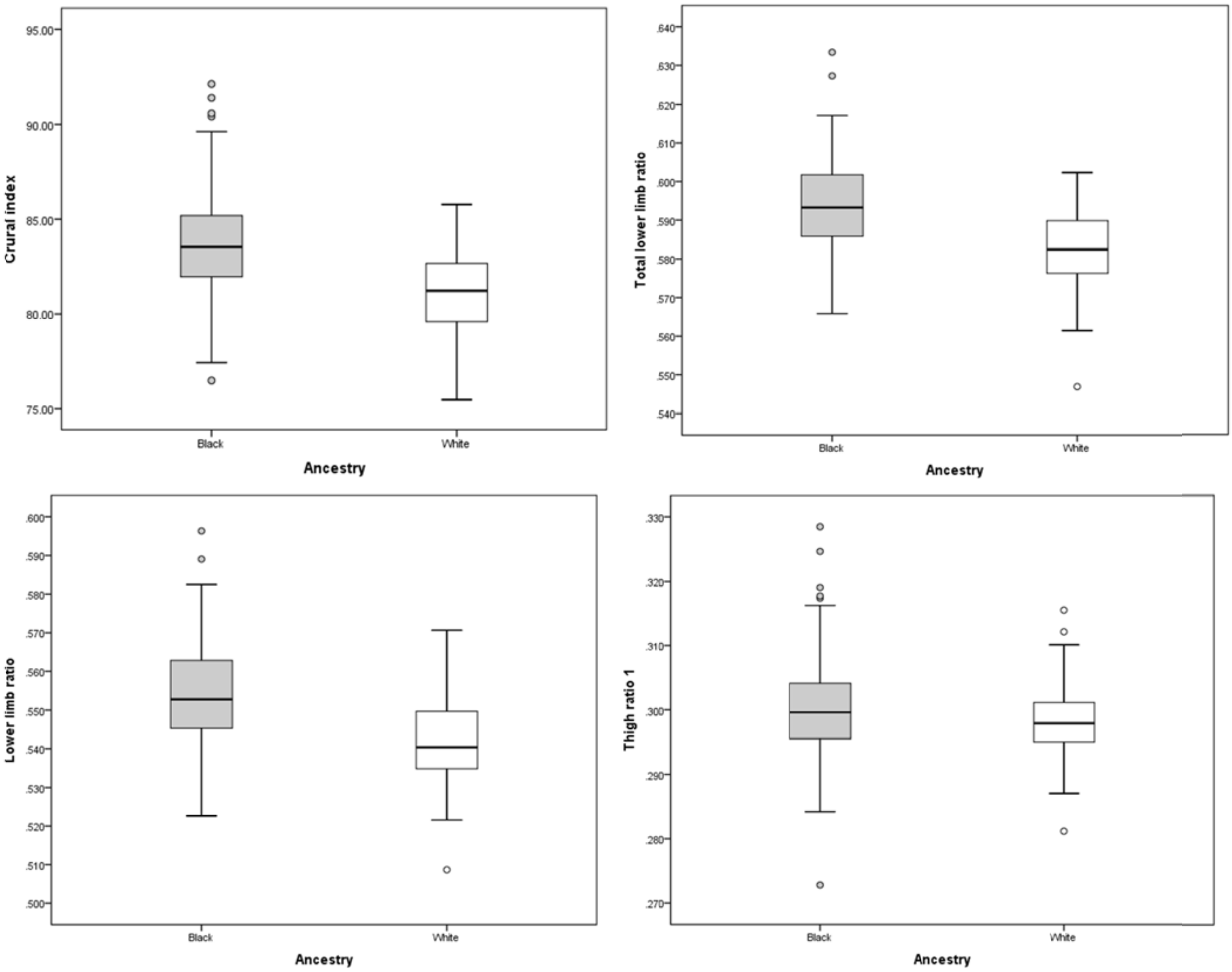


Figure 7.7 Ancestry differences in the osteometric lower limb proportions between South African black and white males over the total period.

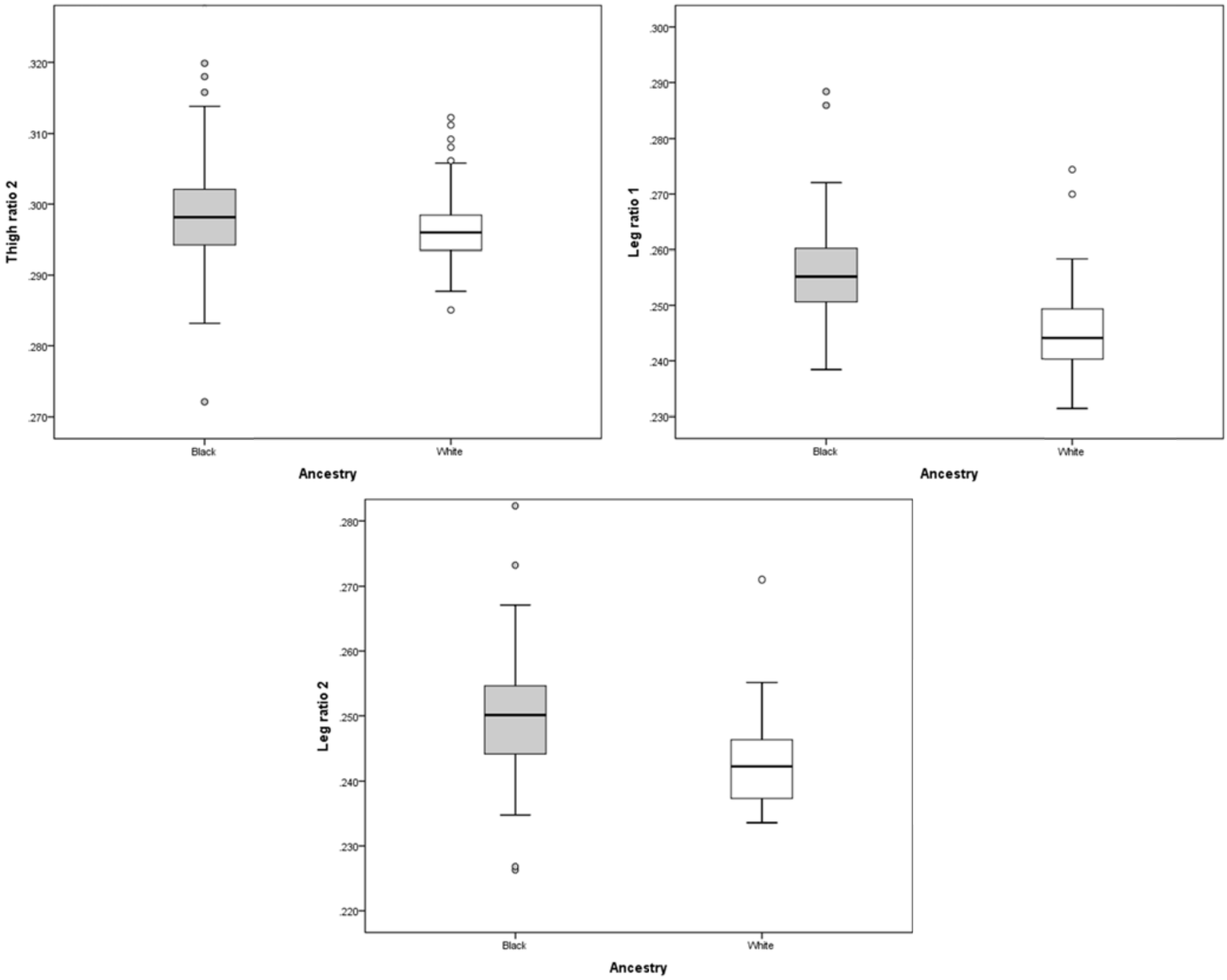


Figure 7.7 (continued) Ancestry differences in the osteometric lower limb proportions between South African black and white males over the total period.

Secular trends in lower limb proportions

The results for the comparison of the crural index, total lower limb ratio, lower limb ratio, thigh ratio 1, thigh ratio 2, leg ratio 1 and leg ratio 2 plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM can be seen in Table 7.2 The results indicated that no secular trends occurred in the lower limb proportions from 1900 to 1980. The values for SAWM in 1900's, 1950's and 1960's are not discussed due to the small sample size of individuals born in these cohorts.

Table 7.2 and Figures 7.2 to 7.6 illustrate that no significant secular changes occurred in the crural index (SABM: p-value = 0.8011; SAWM: p-value = 0.7818), total lower limb ratio (SABM: p-value = 0.7454; SAWM: p-value = 0.7171), lower limb ratio (SABM: p-value = 0.8594; SAWM: p-value = 0.7371), thigh ratio 1 (SABM: p-value = 0.7187; SAWM: p-value = 0.6540), thigh ratio 2 (SABM: p-value = 0.7839; SAWM: p-value = 0.6945), leg ratio 1 (SABM: p-value = 0.8091; SAWM: p-value = 0.5338) and leg ratio 2 (SABM: p-value = 0.7352; SAWM: p-value = 0.6126) of SABM and SAWM.

The crural index decreased from 83.90 in the 1900's to 83.46 in the 1970's for SABM and from 80.73 in the 1910's to 81.73 in the 1940's for SAWM indicating that the leg lengths became slightly shorter relative to the thigh length (Figure 7.8). The total lower limb ratio remained unchanged at 0.596 in SABM while it decreased from 0.584 to 0.583 in SAWM (Figure 7.9). The lower limb ratio decreased from 0.559 to 0.554 in SABM while an increase is observed from 0.542 to 0.543 in SAWM (Figure 7.10). This indicates that in SAWM the total lower limb lengths decreased slightly relative to stature and the lower limb lengths increased while only the lower limb lengths of SABM decreased relative to stature. A decrease was observed for SABM from 0.303 to 0.301 and 0.300 to 0.299 for the thigh ratios 1 and 2, respectively which indicates a slight increase in the thigh lengths relative to stature. No changes are observed in the thigh ratios 1 (0.299) and thigh ratio 2 (0.297) for SAWM (Figures 7.11 and 7.12). A decrease from 0.259 to 0.255 for leg ratio 1 and 0.253 to 0.251 for the leg ratio 2 was observed in SABM while increases from 0.246 to 0.247 and 0.242 to 0.244 were observed in SAWM (Figures 7.13 and 7.14). This indicates that while the leg lengths are decreasing slightly relative to stature in SABM, a slight increase is taking place in SAWM.

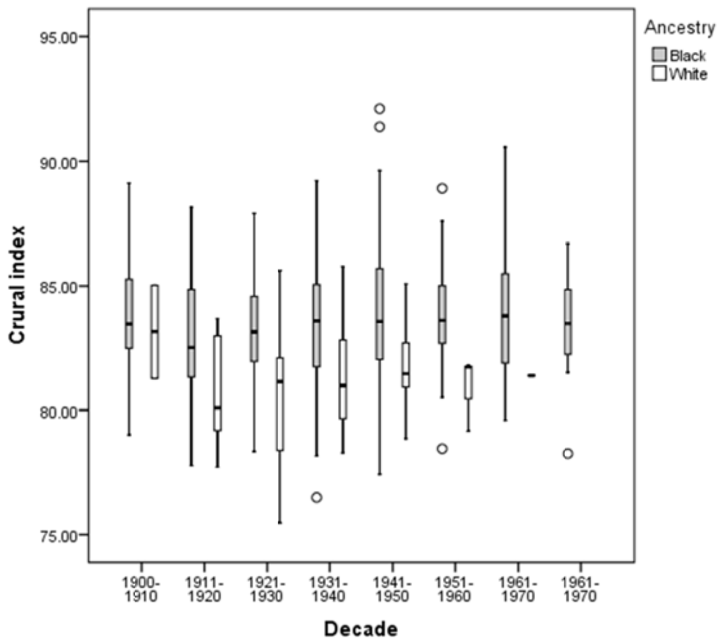


Figure 7.8 Secular trends in the osteometric crural index of South African black and white males.

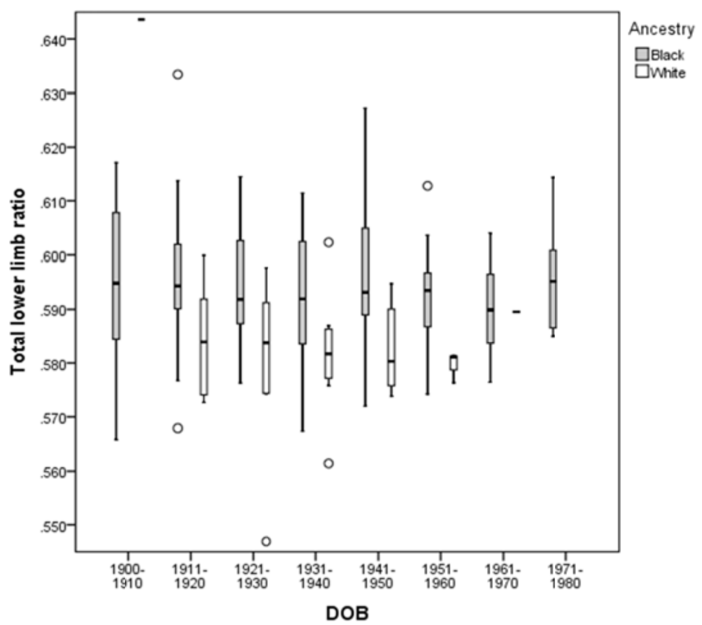


Figure 7.9 Secular trends in the osteometric total lower limb ratio of South African black and white males.

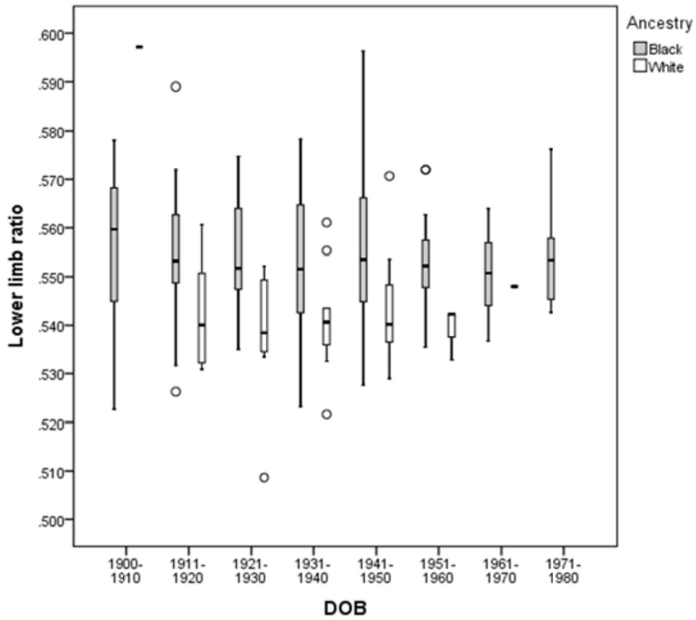


Figure 7.10 Secular trends in the osteometric lower limb ratio of South African black and white males.

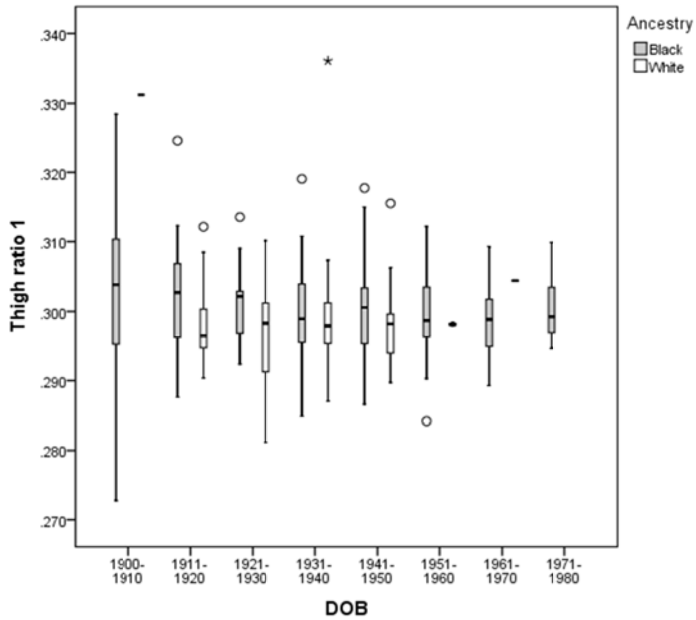


Figure 7.11 Secular trends in the osteometric thigh ratio 1 of South African black and white males.

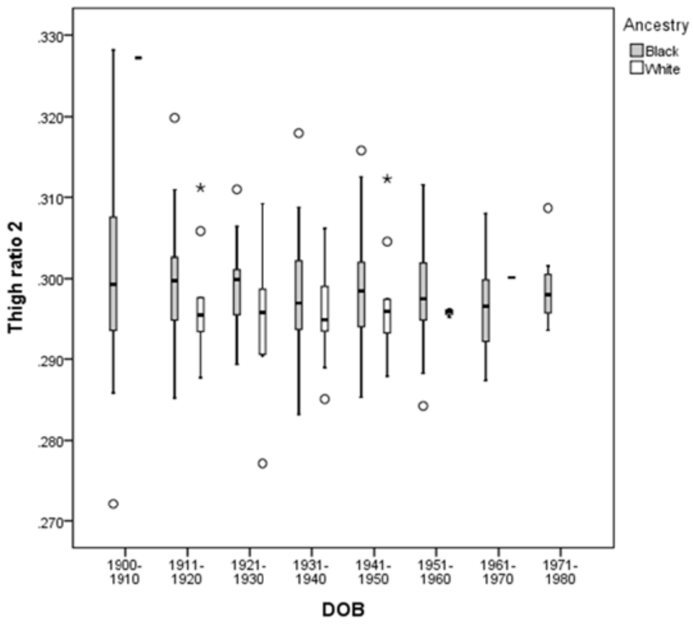


Figure 7.12 Secular trends in the osteometric thigh ratio 2 of South African black and white males.

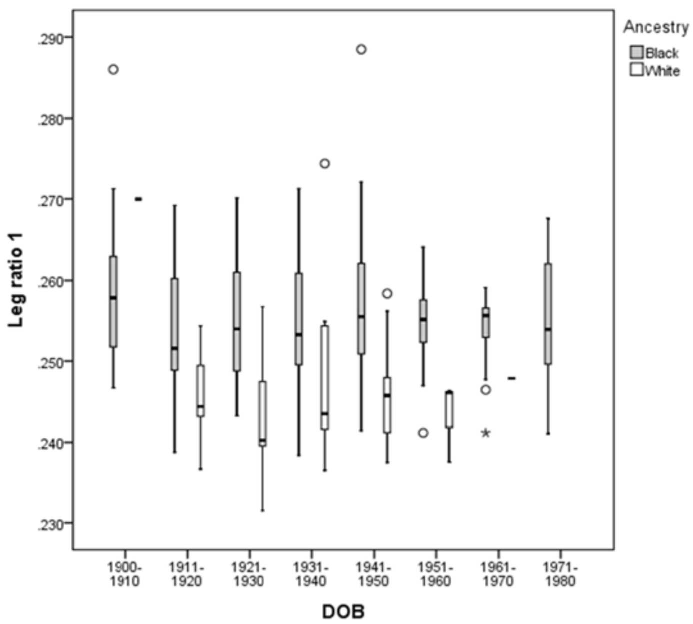


Figure 7.13 Secular trends in the osteometric leg ratio 1 of South African black and white males.

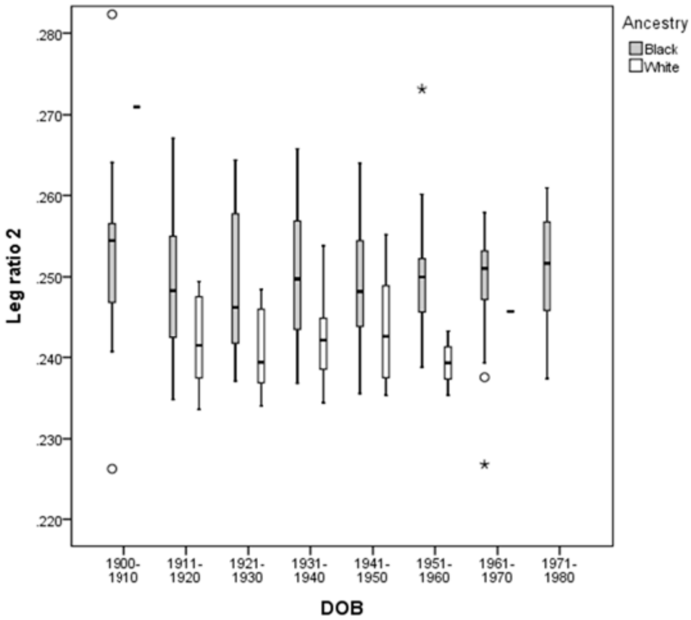


Figure 7.14 Secular trends in the osteometric leg ratio 2 of South African black and white males.

7.1.1.3 Secular changes and ancestry differences in the osteometric intermembral index of South African black and white males

Ancestry differences in the intermembral index

The mean intermembral indices of both SABM and SAWM are shown in Table 7.3 and Figure 7.15. The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the intermembral index ([Humerus max length + radius max length/Femur max length + tibia condylo-malleolar length] x100), classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant ancestry differences exist between SABM and SAWM.

No significant difference was observed in the intermembral index between SABM and SAWM (Kruskal-Wallis Chi-squared = 0.0639; p = 0.8004) for any birth cohort or the combined period. This indicates that the total arm lengths relative to lower limb lengths are similar in SAWM and SABM.

Table 7.3 The sample sizes, mean osteometric intermembral indices and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared	p-value
1900-1910	SABM SAWM	27 2	68.96 67.92	3.31 0.07	-	-
1911-1920	SABM SAWM	29 10	69.02 69.33	1.47 0.85	0.4138	0.5201
1921-1930	SABM SAWM	33 13	68.36 68.926	1.38 3.69	0.0430	0.8357
1931-1940	SABM SAWM	47 20	68.23 68.80	1.59 1.35	1.4538	0.2279
1941-1950	SABM SAWM	58 14	68.91 68.65	1.93 1.90	0.3239	0.5693
1951-1960	SABM SAWM	44 3	68.96 67.82	1.69 0.49	-	-
1961-1970	SABM SAWM	34 1	69.03 69.67	1.45 -	-	-
1971-1980	SABM	11	68.49	1.72	-	-
1900-1980	SABM SAWM	283 63	68.75 68.82	1.87 2.05	0.0639	0.8004

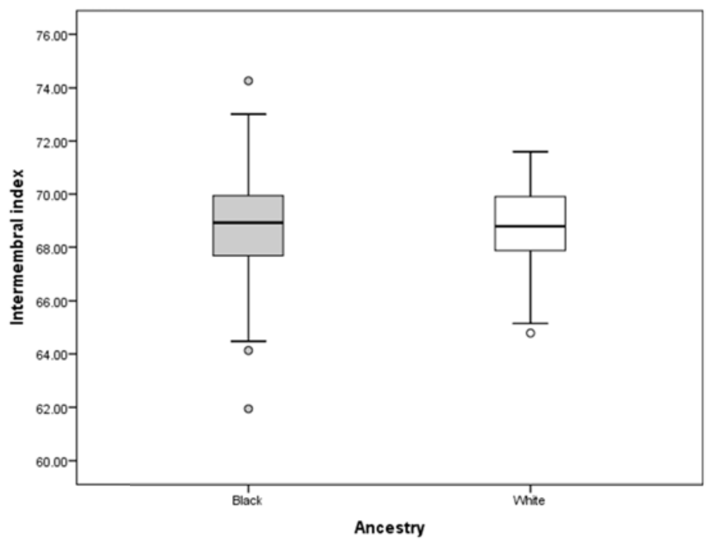


Figure 7.15 Ancestry difference in the osteometric intermembral index between South African black and white males over the total period.

Secular trends in the intermembral index

Comparison of the intermembral index plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM indicated no secular trend for SABM (Kruskal-Wallis Chi-squared = 10.2417; p-value = 0.1753) or SAWM (Kruskal-Wallis Chi-squared = 6.5911; p-value = 0.3603). Table 7.3 and Figure 7.16 demonstrate the decrease in the intermembral index for SABM from 68.96 in the 1900's to 68.49 in the 1970's and from 69.33 in the 1910's to 68.65 in the 1940's for SAWM, although this was not statistically significant. This indicates that there is a slight decrease in the arm lengths relative to lower limb lengths.

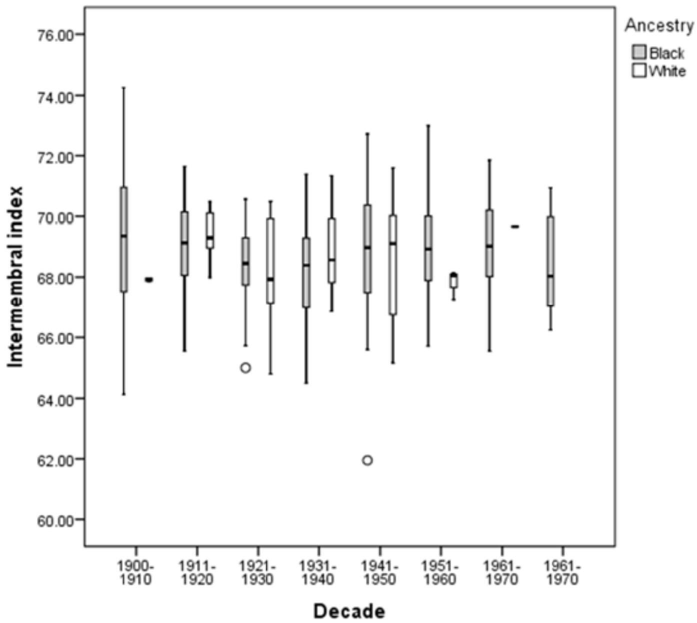


Figure 7.16 Secular trend and ancestry differences in the osteometric intermembral index for South African black and white males.

7.1.1.4 Secular changes and ancestry differences in the osteometric sitting height ratio of South African black and white males

Ancestry differences in the sitting height ratio

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the sitting height ratio (sitting height/TSH), classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between SABM and SAWM. Over the combined birth cohort, a significant difference was observed in the sitting heights with SAWM having overall larger measurements than SABM (Appendix C1; Table C1.3 and Figures C1.5 and C1.6).

Table 7.4 and Figure 7.17 demonstrate that a significant difference was observed in the sitting height ratio between SABM and SAWM (Kruskal-Wallis Chi-squared = 26.0028; p = <0.0001) for all birth cohorts and the combined period. This indicates that SAWM have higher sitting heights relative to stature than SABM.

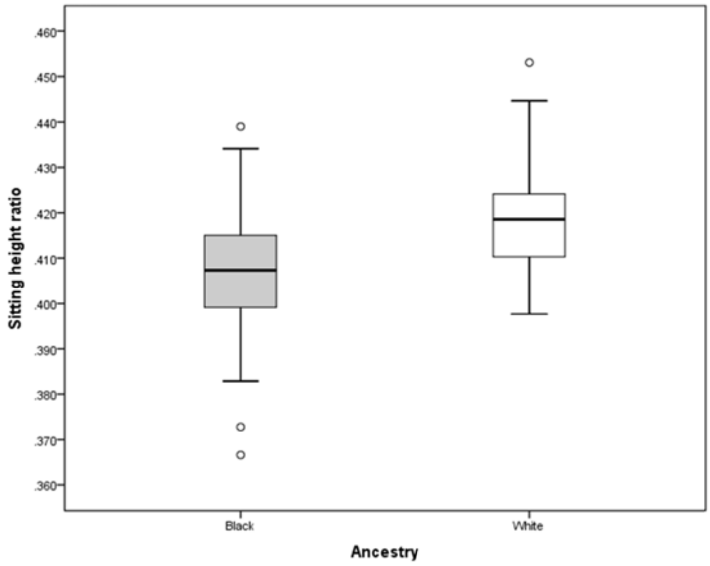


Figure 7.17 Ancestry differences in the osteometric sitting height ratio between South African black and white males over the total period.

Table 7.4 The sample sizes, osteometric sitting height ratios and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared	p-value
1900-1910	SABM SAWM	23 1	40.56 35.64	1.48 -	-	-
1911-1920	SABM SAWM	21 10	40.54 41.60	1.48 0.96	4.8286	**0.0280**
1921-1930	SABM SAWM	19 10	40.56 41.84	1.06 1.43	5.4758	**0.0193**
1931-1940	SABM SAWM	30 13	40.92 41.56	1.24 2.25	4.1462	**0.0417**
1941-1950	SABM SAWM	33 13	40.53 41.81	1.27 0.80	9.6749	**0.0019**
1951-1960	SABM SAWM	32 3	40.94 42.04	1.00 0.29	-	-
1961-1970	SABM SAWM	23 1	41.56 41.04	2.98 -	-	-
1971-1980	SABM	7	40.44	1.11	-	-
1900-1980	SABM SAWM	188 51	40.79 41.59	1.57 1.63	26.0028	**<0.0001**

Secular trends in the sitting height ratio

Comparison of the sitting height ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM indicated that no significant secular trend exists in the sitting height ratio for SABM (Kruskal-Wallis Chi-squared = 5.1040; p-value = 0.6473) and SAWM (Kruskal-Wallis Chi-squared = 3.9562; p-value = 0.6826) (Table 7.4 and Figure 7.18). The sitting height ratio decreased from 40.56 in the 1900's to 40.44 in the 1970's for SABM and increased from 41.60 in the 1910's to 41.81 in the 1940's for SAWM indicating a slight (non-significant) increase in sitting heights relative to stature in SAWM while SABM showed a decrease.

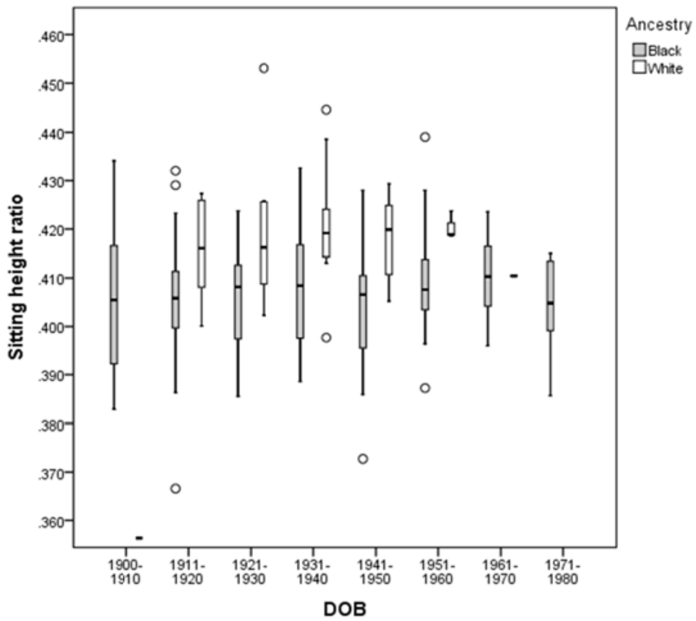


Figure 7.18 Secular trends in the osteometric sitting height of South African black and white males.

7.1.2 Secular trends and ancestry differences in the osteometric limb proportions of South African black and white females

7.1.2.1 Secular changes and ancestry differences in the osteometric upper limb proportions of South African black and white females

Ancestry differences in upper limb proportions

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for brachial index([radius max length/humerus max length] x100), upper limb ratio (arm length/TSH), arm ratio (humerus max length/TSH) and forearm ratio 1 (radius max length/TSH) and forearm ratio 2 (ulna max length/TSH), classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between South African black females (SABF) and South African white females (SAWF). The results for the comparisons in the arm proportions can be seen in Table 7.5.

A significant ancestry difference ($p < 0.05$) was observed in the humerus max length, radius max length and ulna max length for the combined birth cohort. Overall, SAWF have larger humeral max length measurements than SABF while the radius max length and ulna max length are 6.4 mm and 7.7 mm larger in SABF, respectively. The average arm length (humerus max length + radius max length) of SABF are slightly larger than that of SAWF, however the difference is not significant ($p = 0.4472$) (Appendix C2; Table C2.1 and Figures C2.1 and C2.2). Figure 7.19 illustrates the differences in the arm proportions between SABF and SAWF for all birth cohorts combined. Due to the possible effect of small sample sizes on an accurate representation of limb proportions, comparisons between specific birth cohorts are not presented. Therefore, the results of SAWF in 1900-1910 (n = 1), 1911-1920 (n = 4), 1951-1960 (n = 1) and 1981-1990 (n = 1) are not discussed.

SABF had a brachial index, upper limb ratio, forearm ratio 1 and forearm ratio which were significantly higher than those of SAWF ($p = <0.0001$). This indicates that SABF have greater forearm lengths relative to arm lengths and greater upper limb lengths and forearm lengths (radius max lengths and ulna max lengths) relative to stature (as represented by TSH) than SAWF. SAWF have a arm ratio which is slightly higher that of SABF, however the difference was not significant ($p = 0.2920$) indicating a slightly greater humerus max length relative to stature in SAWF.

Across all birth cohorts the brachial index and forearm ratio 2 of SABF were significantly higher from those of SAWF. The forearm ratio 1 of SABF was significantly higher across all birth cohorts except in the 1940's, while the upper limb ratio exhibited more variation with no significant differences observed in the 1930's ($p = 0.0857$) and the 1940's ($p = 0.2958$). The lack of a significant difference may possibly be due to the small number of SAWF in these birth cohorts. No significant differences were observed in any of the birth cohorts for the arm ratio (Figure 7.19).

Table 7.5 The sample sizes, mean osteometric upper limb proportions and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Brachial index					Upper limb ratio					Arm ratio				
		N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
1900-1910	SABF	24	77.75	2.18	-	-	19	0.378	0.012	-	-	19	0.213	0.007	-	-
	SAWF	1	70.13	-			1	0.354	-			1	0.209	-		
1911-1920	SABF	28	77.79	4.57	-	-	25	0.376	0.039	-	-	26	0.212	0.016	-	-
	SAWF	4	71.88	1.76			3	0.366	0.005			3	0.213	0.002		
1921-1930	SABF	31	79.00	2.02	14.8988	**0.0001**	26	0.375	0.014	7.4544	**0.0063**	26	0.210	0.009	0.0485	0.8257
	SAWF	7	72.10	2.82			7	0.360	0.007			7	0.209	0.003		
1931-1940	SABF	35	77.72	2.42	10.8391	**0.0010**	26	0.374	0.012	2.9538	0.0857	26	0.211	0.007	0.3490	0.5547
	SAWF	5	72.94	1.64			5	0.367	0.005			5	0.212	0.004		
1941-1950	SABF	38	78.11	3.26	11.0193	**0.0009**	29	0.376	0.033	1.0930	0.2958	30	0.211	0.008	0.8022	0.3704
	SAWF	7	73.44	2.69			5	0.374	0.022			5	0.215	0.013		
1951-1960	SABF	29	77.46	2.19	-	-	20	0.372	0.047	-	-	20	0.210	0.008	-	-
	SAWF	1	73.36	-			1	0.369	-			1	0.213	-		
1961-1970	SABF	19	77.78	3.10	-	-	16	0.367	0.013	-	-	16	0.207	0.008	-	-
1971-1980	SABF	7	79.33	3.84	-	-	5	0.369	0.007	-	-	5	0.206	0.006	-	-
1981-1990	SAWF	1	73.40	-	-	-	1	0.356	-	-	-	1	0.205	-	-	-
1900-1990	SABF	211	78.01	2.96	54.8529	**<0.0001**	166	0.374	0.028	13.6985	**0.0002**	168	0.210	0.009	1.1103	0.2920
	SAWF	26	72.62	2.27			23	0.365	0.012			23	0.212	0.006		

Table 7.5 (continued) The sample sizes, mean osteometric upper limb proportions and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Forearm ratio 1*					Forearm ratio 2**				
		N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
1900-1910	SABF	19	0.165	0.006	-	-	19	0.178	0.006	-	-
	SAWF	1	0.146	-			1	0.157	-		
1911-1920	SABF	25	0.163	0.008	-	-	25	0.177	0.008	-	-
	SAWF	3	0.153	0.005			3	0.164	0.003		
1921-1930	SABF	26	0.165	0.006	14.0110	**0.0002**	26	0.178	0.005	15.7078	**<0.0001**
	SAWF	7	0.151	0.006			7	0.162	0.006		
1931-1940	SABF	26	0.164	0.006	10.0413	**0.0015**	26	0.177	0.006	8.4115	**0.0037**
	SAWF	5	0.155	0.002			5	0.168	0.002		
1941-1950	SABF	29	0.165	0.009	2.8144	0.0934	29	0.179	0.009	4.4743	**0.0344**
	SAWF	5	0.159	0.010			5	0.169	0.009		
1951-1960	SABF	21	0.162	0.006	-	-	20	0.174	0.006	-	-
	SAWF	1	0.156	-			1	0.167	-		
1961-1970	SABF	16	0.160	0.006	-	-	16	0.173	0.007	-	-
1971-1980	SABF	5	0.163	0.006	-	-	5	0.178	0.008	-	-
1981-1990	SAWF	1	0.151		-	-	1	0.161		-	-
1900-1990	SABF	167	0.164	0.007	37.5182	**<0.0001**	166	0.177	0.007	42.1364	**<0.0001**
	SAWF	23	0.154	0.007			23	0.165	0.006		

*Radius max length/TSH ** Ulna max length/TSH

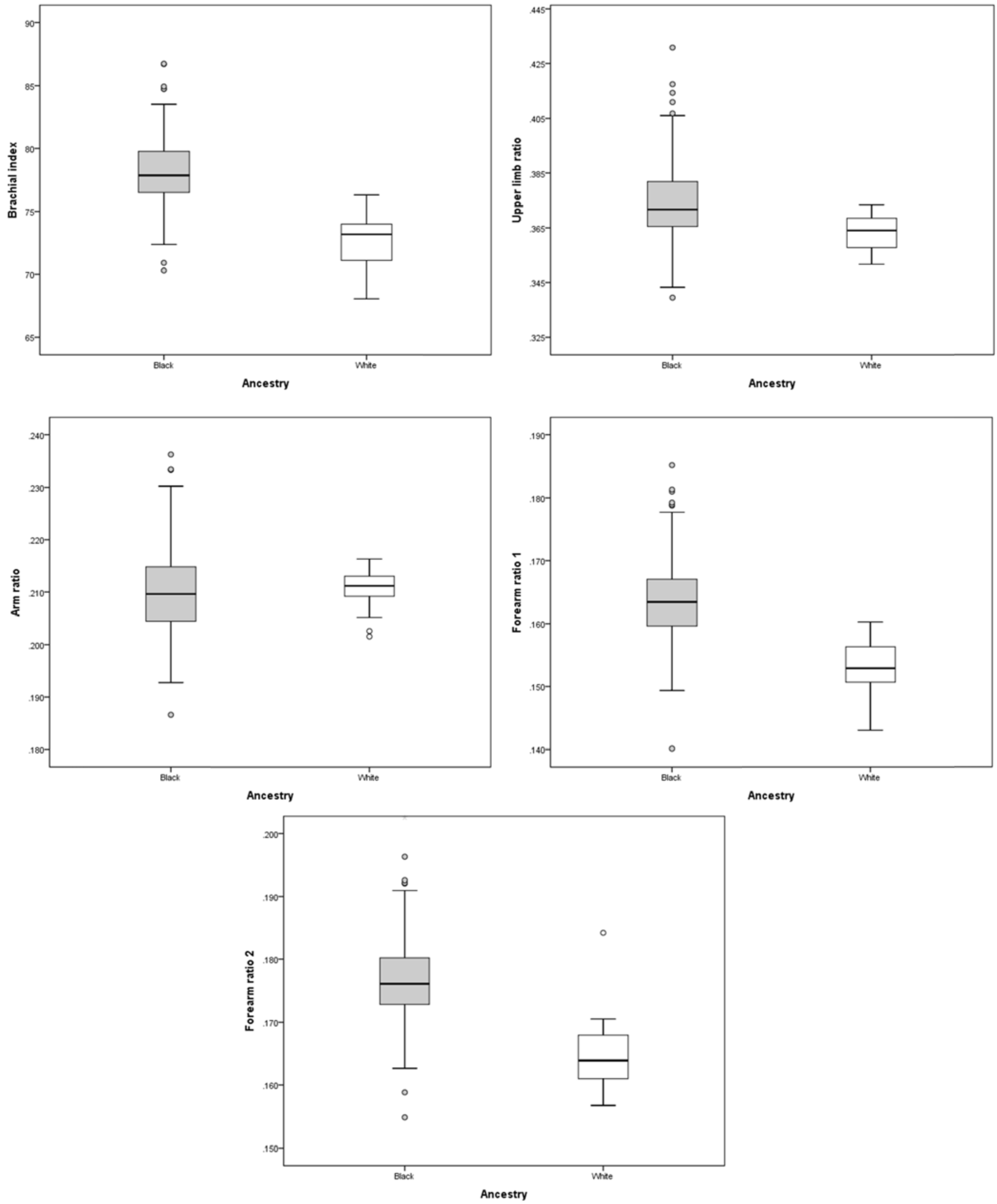


Figure 7.19 Ancestry differences in the osteometric upper limb ratios between South African black and white females over the total period.

Secular trends in upper limb proportions

The results for comparisons of the brachial index, upper limb ratio, arm ratio, forearm ratio 1 and forearm ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM can be seen in Table 7.5. No secular changes were observed in any of the arm proportions from 1900 to 1990. However, the values for SAWF in 1900's, 1910's, 1950's and 1990's are not discussed due to the small sample size of individuals born in these cohorts.

Figures 7.20 to 7.24 demonstrate that no significant secular changes were observed in the brachial index (SABF: p-value = 0.1679; SAWF: p-value = 0.6849), upper limb ratio (SABF: p-value = 0.3384; SAWF: p-value = 0.4014), arm ratio (SABF: p-value = 0.4116; SAWF: p-value = 0.2504, forearm ratio 1 (SABF: p-value = 0.1848; SAWF: p-value = 0.3429) and forearm ratio 2 (SABF: p-value = 0.0648; SAWF: p-value = 0.2038) of SAWF and SABF. The brachial index of SABF and SAWF increased from 77.75 in the 1900's to 79.33 in the 1970's and from 72.10 in the 1920's to 73.44 in the 1940's, respectively (Figure 7.20). A decrease from 0.378 to 0.369 was observed in the upper limb ratio for SABF while an increase was seen from 0.360 to 0.374 for SAWF (Figure 7.21). The arm ratio decreased from 0.213 in the 1900's to 0.206 in the 1970's for SABF and increased from 0.209 in the 1920's to 0.215 in the 1940's for SAWF (Figure 7.22). This indicates that there was a slight (but non-significant) decrease in the arm lengths relative to stature and arm lengths to stature in SABF while they increased in SAWF. The forearm ratio 1 decreased from 0.165 to 0.163 while the forearm ratio 2 remained unchanged at 0.178 for SABF. In SAWF, the forearm ratio 1 and 2 increased from 0.151 to 0.159 and 0.162 to 0.169, respectively (Figures 7.23 and 7.24) indicating a slight increase in the forearm lengths relative to stature in SAWF.

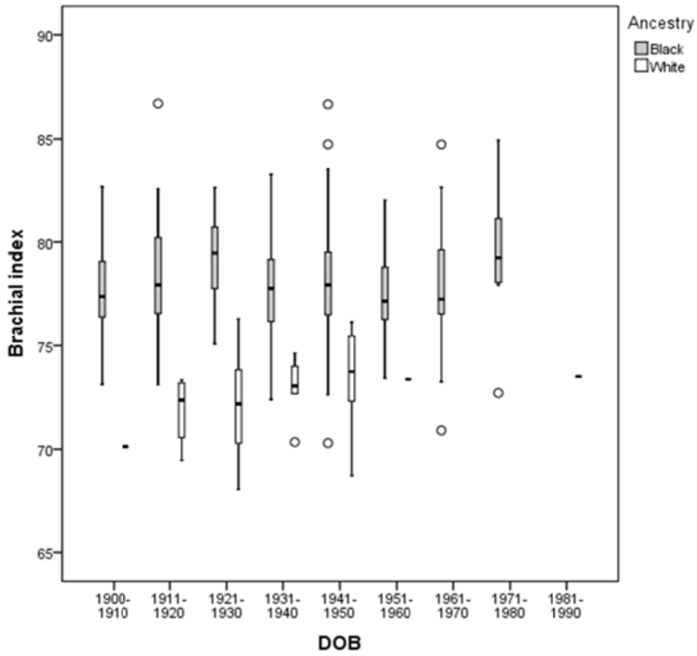


Figure 7.20 Secular trends in the osteometric brachial index of South African black and white females.

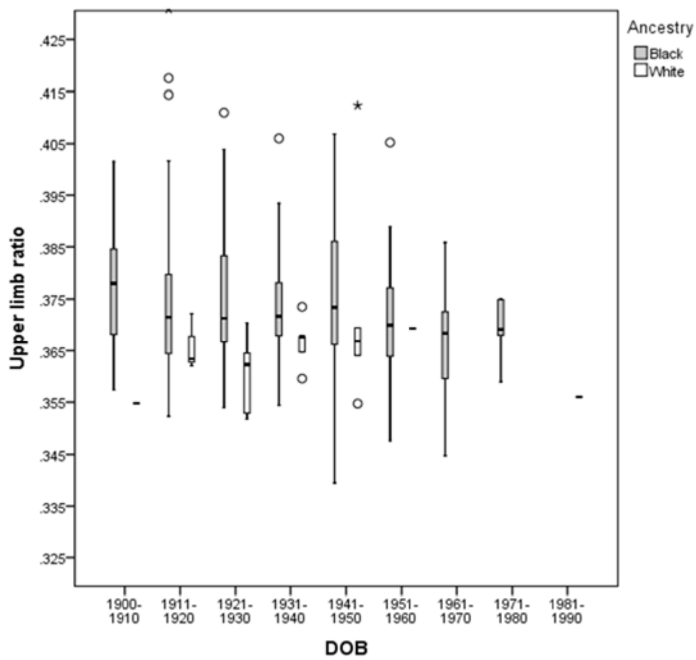


Figure 7.21 Secular trends in the osteometric upper limb ratio of South African black and white females.

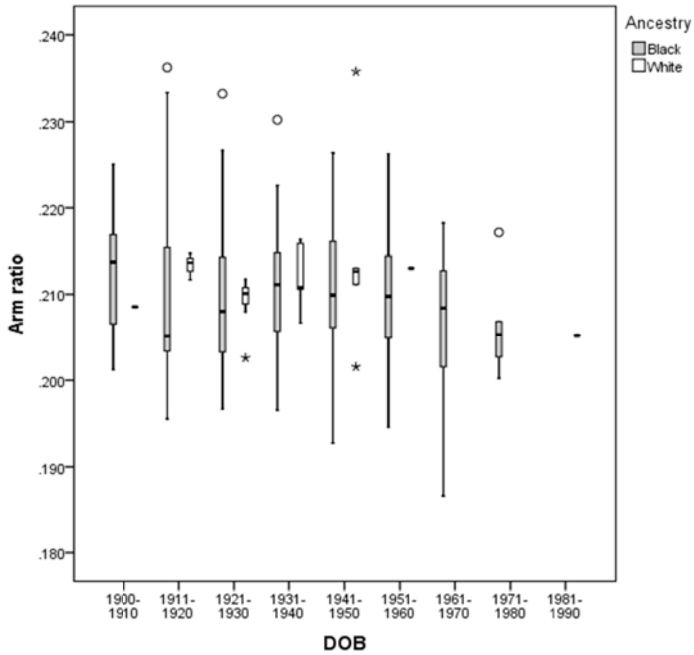


Figure 7.22 Secular trends in the osteometric arm ratio of South African black and white females.

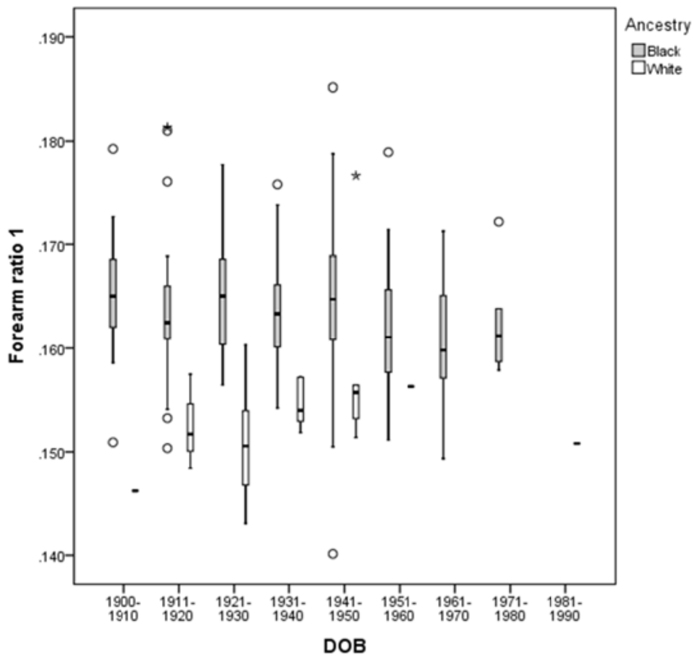


Figure 7.23 Secular trends in the osteometric forearm ratio 1 of South African black and white females.

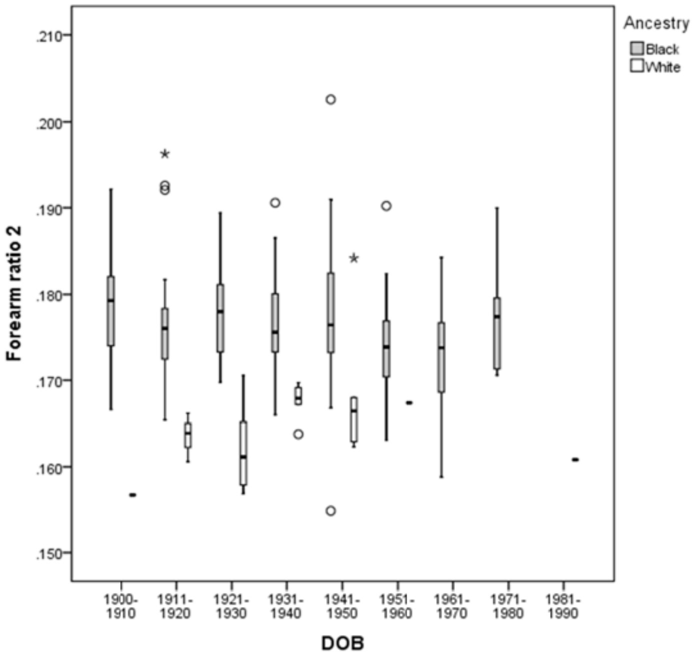


Figure 7.24 Secular trends in the osteometric forearm ratio 2 of South African black and white females.

7.1.2.2 Secular changes and ancestry differences in the osteometric lower limb proportions of South African black and white females

Ancestry differences in lower limb proportions

In Table 7.6 the results of the non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for crural index([tibia condylo-malleolar length/femur bicondylar length] x100), total lower limb ratio (femur bicondylar length + tibia condylo-malleolar length + talo-calcaneal height/TSH), lower limb ratio (femur bicondylar length+tibia condylo-malleolar length/TSH), thigh ratio 1 (femur max length/TSH) and thigh ratio 2 (femur bicondylar length/TSH), leg ratio 1 (tibia condylo-malleolar length/TSH) and leg ratio 2 (fibula max length/TSH), classified by ancestry using the SAS NPAR1WAY procedure can be seen. This test was performed in order to determine whether significant differences exist in the lower limb proportions between SABF and SAWF.

Over the combined birth cohort, no significant differences ($p > 0.05$) were observed in any of the lower limb measurements (total lower limb length, lower limb length, femur max length, femur bicondyalr length, tibia condylo-malleolar length and fibula max length) between SABF and SAWF. However, SAWF have slightly larger total lower limb length, lower limb length and thigh lengths (femur max and bicondylar lengths) while the leg measurements (tibia condylo-malleolar and fibula max lengths) are slightly larger in SABF (Appendix C2; Table C2.2 and Figures C2.3 and C2.4).

In Table 7.6 the difference in the lower limb proportions between SABF and SAWF for all birth cohorts combined as well as per birth cohort can be seen. Due to the small sample sizes, the results of SAWF in 1900's (n = 1), 1910's (n = 3), 1950's (n = 1) and 1980's (n = 1) are not discussed. All lower limb proportions were significantly higher in SABF ($p < 0.0001$). This indicates that SABF have greater leg lengths (tibia condylo-malleolar lengths) to thigh lengths (femur bicondylar lengths) and greater total lower limb lengths, lower limb lengths, thigh lengths (femur max lengths and femur bicondylar lengths) and leg lengths (tibia condylo-malleolar lengths and fibula max lengths) relative to stature (as represented by TSH) than SAWF.

Figure 7.25 demonstrates that, across all birth cohorts except the 1940's, the total lower limb ratio, lower limb ratio, thigh ratio 1 and 2 and leg ratios 1 and 2 differed significantly between SABF and SAWF. The crural index differs significantly between SABF and SAWF across all birth cohorts except the 1930's ($p = 0.1532$).

Table 7.6 The sample sizes, mean osteometric lower limb proportions and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Crural index					Total lower limb ratio					Lower limb ratio					Thigh ratio 1*				
		N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
1900-1910	SABF	24	82.45	2.54	-	-	16	0.591	0.016	-	-	19	0.554	0.016	-	-	19	0.303	0.009	-	-
	SAWF	1	81.53	-			1	0.577	-			1	0.537	-			1	0.294	-		
1911-1920	SABF	28	82.58	2.24	-	-	24	0.588	0.020	-	-	26	0.549	0.018	-	-	26	0.300	0.010	-	-
	SAWF	3	81.23	1.36			3	0.571	0.011			3	0.530	0.012			3	0.292	0.007		
1921-1930	SABF	29	83.03	1.95	12.7976	**0.0003**	24	0.595	0.017	11.8951	**0.0006**	26	0.556	0.017	14.0110	**0.0002**	26	0.304	0.010	4.4680	**0.0345**
	SAWF	7	79.54	1.51			7	0.573	0.008			7	0.532	0.006			7	0.296	0.004		
1931-1940	SABF	34	82.61	2.42	2.0400	0.1532	24	0.592	0.017	6.4533	**0.0111**	26	0.553	0.015	7.5029	**0.0062**	26	0.303	0.008	6.9260	**0.0085**
	SAWF	5	81.16	0.98			5	0.572	0.011			5	0.531	0.011			5	0.293	0.006		
1941-1950	SABF	39	83.84	2.71	7.3850	**0.0066**	29	0.594	0.017	3.1501	0.0759	30	0.556	0.017	3.9200	**0.0477**	30	0.303	0.009	2.2756	0.1314
	SAWF	8	80.86	1.89			5	0.585	0.034			5	0.543	0.033			5	0.300	0.018		
1951-1960	SABF	29	82.72	1.91	-	-	20	0.586	0.016	-	-	21	0.547	0.016	-	-	21	0.299	0.009	-	-
	SAWF	1	83.70	-			1	0.579	-			1	0.540	-			1	0.294	-		
1961-1970	SABF	19	83.07	2.17	-	-	16	0.588	0.017	-	-	16	0.550	0.018	-	-	16	0.301	0.009	-	-
1971-1980	SABF	7	83.04	1.00	-	-	5	0.589	0.009	-	-	5	0.551	0.008	-	-	5	0.300	0.005	-	-
1981-1990	SAWF	1	82.1	-	-	-	1	0.577	-	-	-	1	0.539	-	-	-	1	0.295	-	-	-
1900-1990	SABF	209	82.95	2.30	21.8473	**<0.0001**	158	0.591	0.017	27.2268	**<0.0001**	169	0.552	0.017	30.4406	**<0.0001**	169	0.302	0.009	16.0119	**<0.0001**
	SAWF	26	80.79	1.66			23	0.576	0.017			23	0.535	0.017			23	0.295	0.009		

*Femur max length/TSH

Table 7.6 (continued) The sample sizes, mean osteometric lower limb proportions and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Thigh ratio 2*					Leg ratio 1**					Leg ratio 2***				
		N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Square	p-value
1900-1910	SABF	19	0.300	0.009	-	-	19	0.254	0.009	-	-	18	0.250	0.009	-	-
	SAWF	1	0.291	-			1	0.245	-			-	-	-		
1911-1920	SABF	26	0.297	0.010	-	-	26	0.252	0.009	-	-	26	0.246	0.009	-	-
	SAWF	3	0.289	0.008			3	0.240	0.004			2	0.234	0.004		
1921-1930	SABF	26	0.301	0.009	5.0440	**0.0247**	26	0.256	0.009	14.3426	**0.0002**	25	0.251	0.008	13.8021	**0.0002**
	SAWF	7	0.293	0.004			7	0.239	0.004			7	0.236	0.004		
1931-1940	SABF	26	0.299	0.008	6.1038	**0.0135**	26	0.254	0.009	7.2115	**0.0072**	24	0.248	0.010	4.6940	**0.0303**
	SAWF	5	0.291	0.006			5	0.241	0.006			4	0.238	0.004		
1941-1950	SABF	30	0.300	0.009	1.8689	0.1716	30	0.256	0.011	3.3800	0.0660	30	0.247	0.017	1.3829	0.2396
	SAWF	5	0.297	0.019			5	0.246	0.015			4	0.243	0.015		
1951-1960	SABF	21	0.296	0.009	-	-	21	0.251	0.009	-	-	20	0.243	0.017	-	-
	SAWF	1	0.292	-			1	0.248	-			1	0.244	-		
1961-1970	SABF	16	0.298	0.009	-	-	16	0.252	0.011	-	-	16	0.247	0.010	-	-
1971-1980	SABF	5	0.298	0.005	-	-	5	0.253	0.004	-	-	4	0.250	0.006	-	-
1981-1990	SAWF	1	0.293	-	-	-	1	0.246	-	-	-	1	0.241	-	-	-
1900-1990	SABF	169	0.299	0.009	14.5429	**0.0001**	169	0.254	0.010	31.7790	**<0.0001**	163	0.248	0.012	22.1368	**<0.0001**
	SAWF	23	0.293	0.009			23	0.242	0.008			19	0.238	0.008		

*Femur bicondylar length/TSH **Tibia condylo-malleolar length/TSH ***Fibula max length/TSH

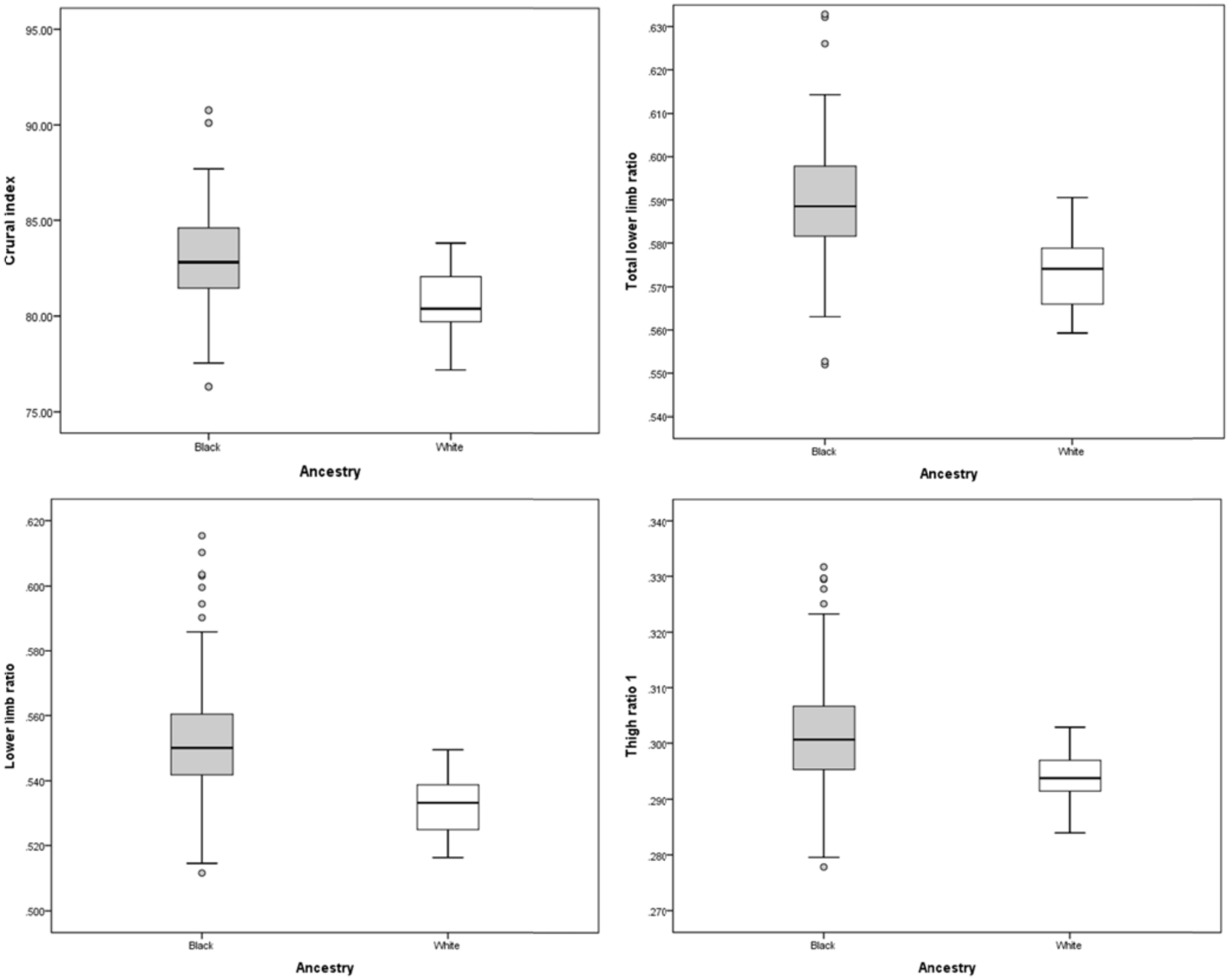


Figure 7.25 Ancestry differences in the osteometric lower limb proportions between South African black and white females over the total period.

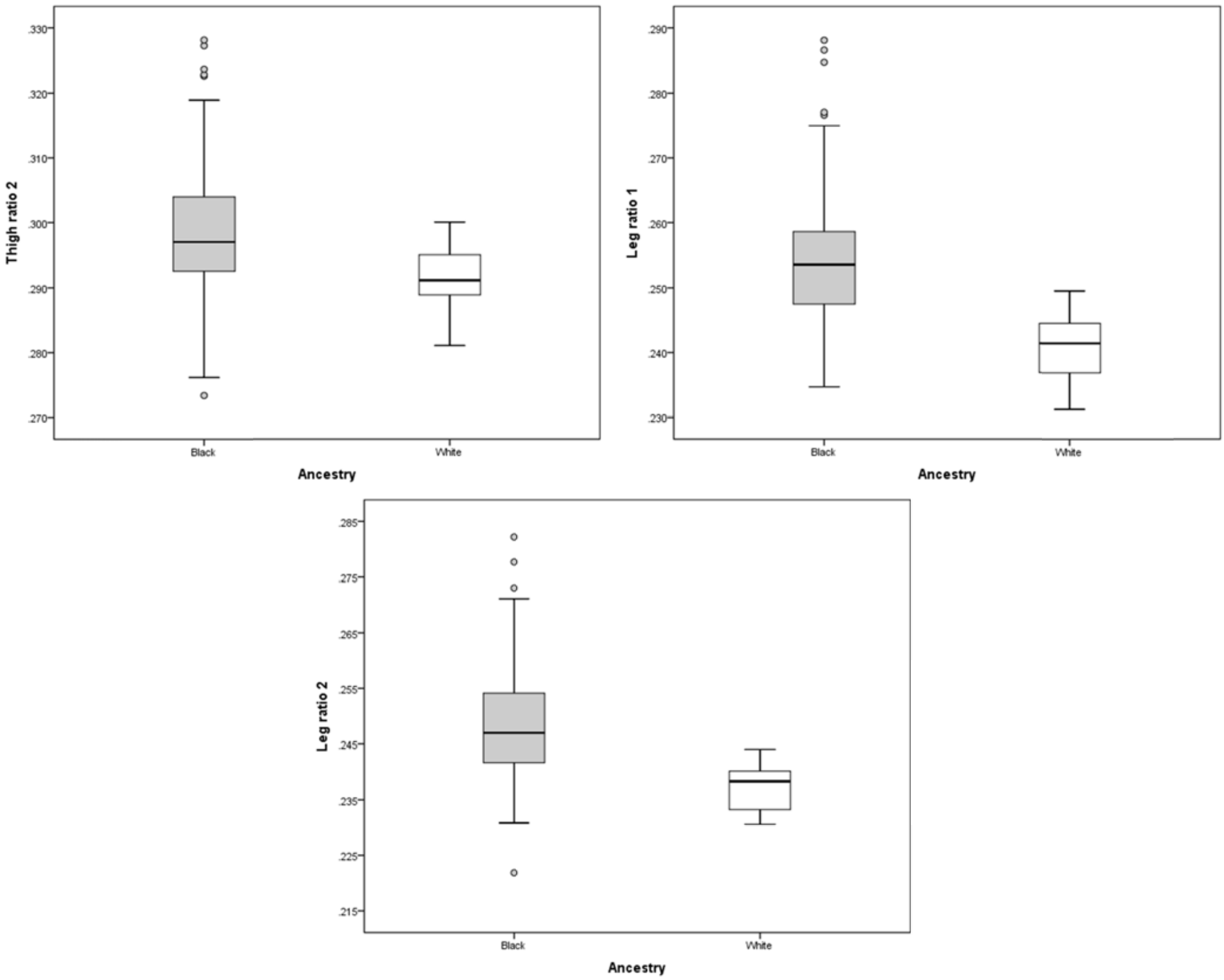


Figure 7.25 (continued) Ancestry differences in the osteometric lower limb proportions between South African black and white females over the total period.

Secular trends in lower limb proportions

Comparison of the crural index, total lower limb ratio, lower limb ratio, thigh ratio 1, thigh ratio 2, leg ratio 1 and leg ratio 2 plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABF and SAWF indicated that no secular trends occurred in the lower limb proportions from 1900 to 1990 (Table 7.6). The values for SAWF in 1900's, 1910's, 1950's and 1980's are not discussed due to the small sample size of individuals born in these cohorts.

As seen in Table 7.6 and Figures 7.26 to 7.32, no significant secular changes occurred in the crural index (SABF: p-value = 0.6100; SAWF: p-value = 0.2808), total lower limb ratio (SABF: p-value = 0.2466; SAWF: p-value = 0.9359), lower limb ratio (SABF: p-value = 0.1332; SAWF: p-value = 0.8520), thigh ratio 1 (SABF: p-value = 0.3181; SAWF: p-value =

0.9213), thigh ratio 2 (SABF: p-value = 0.3039; SAWF: p-value = 0.9318), leg ratio 1 (SABF: p-value = 0.3848; SAWF: p-value = 0.4268) and leg ratio 2 (SABF: p-value = 0.2197; SAWF: p-value = 0.4722) of SABF and SAWF.

Increases from 82.45 in the 1900's to 83.04 in the 1970's for SABM and from 79.54 in the 1920's to 80.86 in the 1940's for SAWM were observed in the crural index (Figure 7.26), indicating a slight increase in the leg lengths relative to stature. The total lower limb and lower limb ratio of SABF decreased from 0.591 to 0.589 and 0.554 to 0.551, respectively. In SAWF the total lower limb ratio increased from 0.573 to 0.585 while the lower limb ratio increased from 0.532 to 0.543 (Figures 7.27 and 28). The thigh ratios 1 and 2 decreased from 0.303 to 0.300 and 0.300 to 0.298, respectively, in SABF. The thigh ratio 1 of SAWF increased from 0.296 to 0.300 while the thigh ratio 2 increased from 0.293 to 0.297 (Figures 7.29 and 7.30). This indicates a slight decrease in the lower limb lengths and thigh lengths relative to stature in SABF while they increased in SAWF. A decrease was observed in the leg ratio 1 of SABF from 0.254 to 0.253 while an increase was observed in SAWF from 0.239 to 0.246 (Figure 7.31). The leg ratio 2 of SABF and SAWF increased from 0.246 to 0.247 and 0.236 to 0.243, respectively (Figure 7.32). This indicates an increase in the tibia condylo-malleolar lengths relative to stature while the fibula max lengths increased in SABF and both increased in SAWF. However, all trends were non-significant.

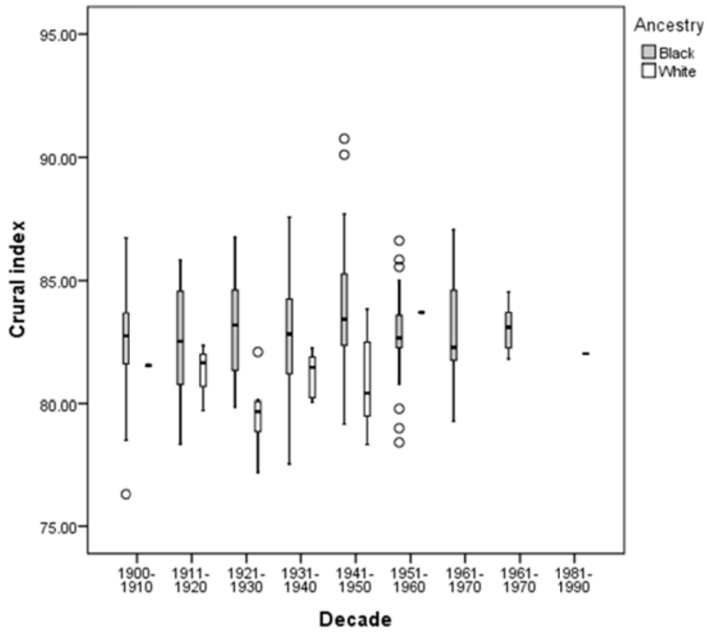


Figure 7.26 Secular trends in the osteometric crural index of South African black and white females.

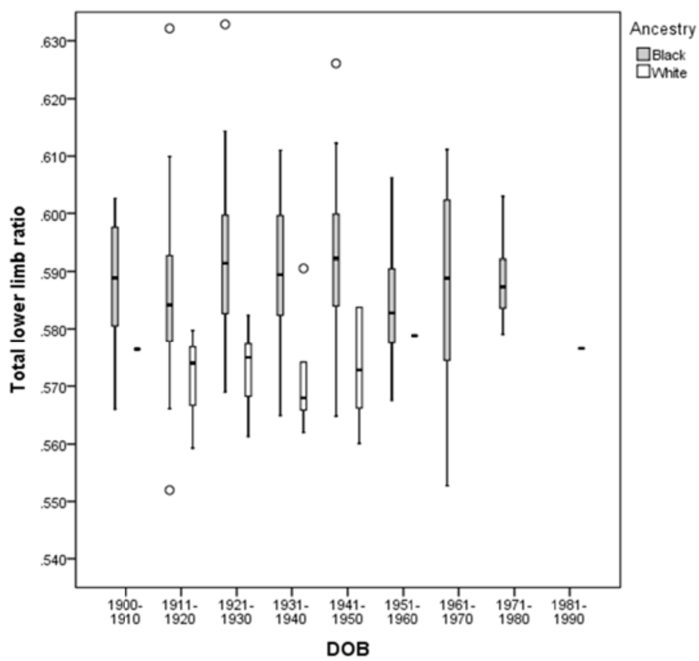


Figure 7.27 Secular trends in the osteometric total lower limb ratio of South African black and white females.

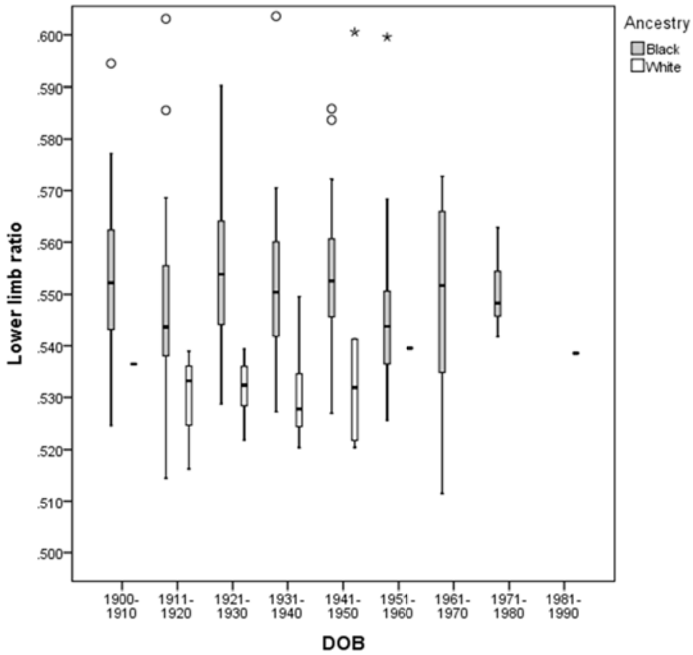


Figure 7.28 Secular trends in the osteometric lower limb ratio of South African black and white females.

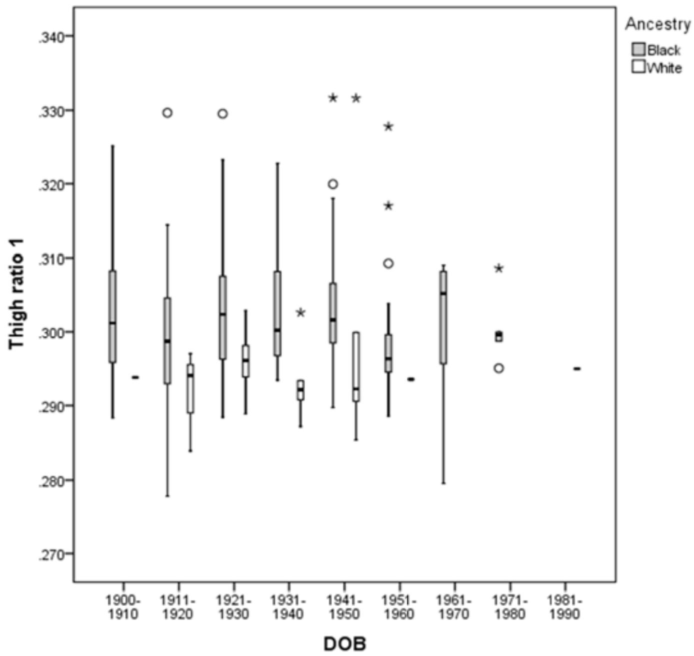


Figure 7.29 Secular trends in the osteometric thigh ratio 1 of South African black and white females.

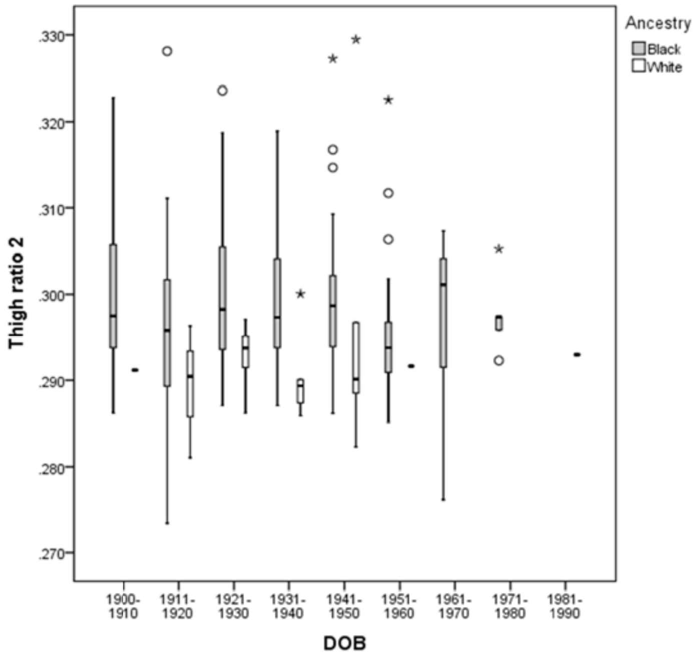


Figure 7.30 Secular trends in the osteometric thigh ratio 2 of South African black and white females.

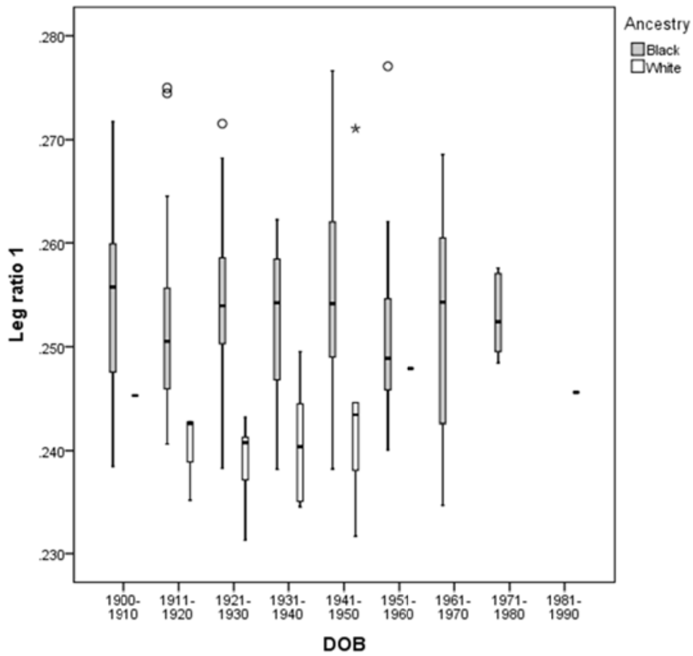


Figure 7.31 Secular trends in the osteometric leg ratio 1 of South African black and white females.

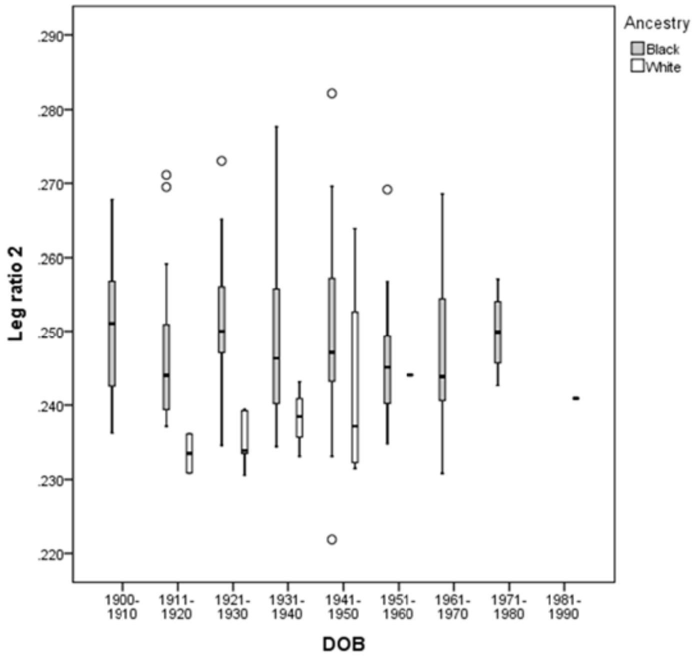


Figure 7.32 Secular trends in the osteometric leg ratio 2 of South African black and white females.

7.1.2.3 Secular changes and ancestry differences in the osteometric intermembral index of South African black and white females

Ancestry differences in the intermembral index

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the intermembral index ([Humerus max length + radius max length/Femur max length + tibia condylo-malleolar length] x100), classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant ancestry differences exist between SABF and SAWF (Table 7.7).

As demonstrated by Figure 7.33, no significant difference was observed in the intermembral index between SABF and SAWF (Kruskal-Wallis Chi-squared = 2.4163; p = 0.1201) for the combined period, with only a slightly higher ratio observed in SAWF. This indicates greater arm lengths relative to lower limb lengths in SAWF.

Table 7.7 The sample sizes, mean osteometric intermembral indices and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared	p-value
1900-1910	SABF SAWF	24 1	68.06 66.14	1.62 -	-	-
1911-1920	SABF SAWF	26 3	68.39 69.12	3.16 0.99	-	-
1921-1930	SABF SAWF	29 7	67.55 67.68	1.88 1.14	0.2496	0.6173
1931-1940	SABF SAWF	33 5	67.49 69.04	1.62 2.32	2.6224	0.1054
1941-1950	SABF SAWF	38 7	67.58 68.25	2.17 1.03	0.6630	0.4155
1951-1960	SABF SAWF	28 1	67.89 68.45	1.60 -	-	-
1961-1970	SABF	19	66.56	1.74	-	-
1971-1980	SABF	7	67.91	2.04	-	-
1981-1990	SAWF	1	66.11	-	-	-
1900-1990	SABF SAWF	204 25	67.68 68.19	2.06 1.51	2.4163	0.1201

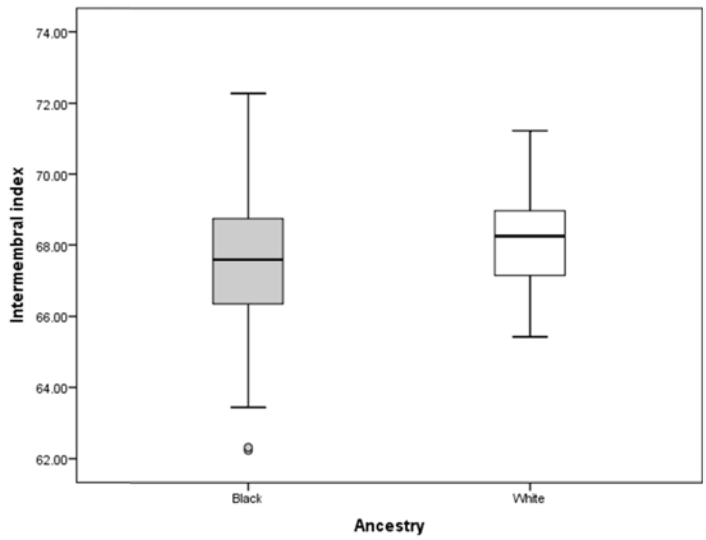


Figure 7.33 Ancestry difference in the osteometric intermembral index between South African black and white females over the total period.

Secular trends in the intermembral index

As seen in Table 7.7, comparison of the intermembral index plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure indicated no secular trend for SABF (Kruskal-Wallis Chi-squared = 9.8542; p-value = 0.1970) or SAWF (Kruskal-Wallis Chi-squared = 6.6961; p-value = 0.3499). Figure 7.34 demonstrates non-directional fluctuations with an overall decrease in the intermembral index for SABF from 68.06 in the 1900's to 67.91 in the 1970's while the intermembral index increased from 67.68 in the 1920's to 68.25 in the 1940's for SAWF.

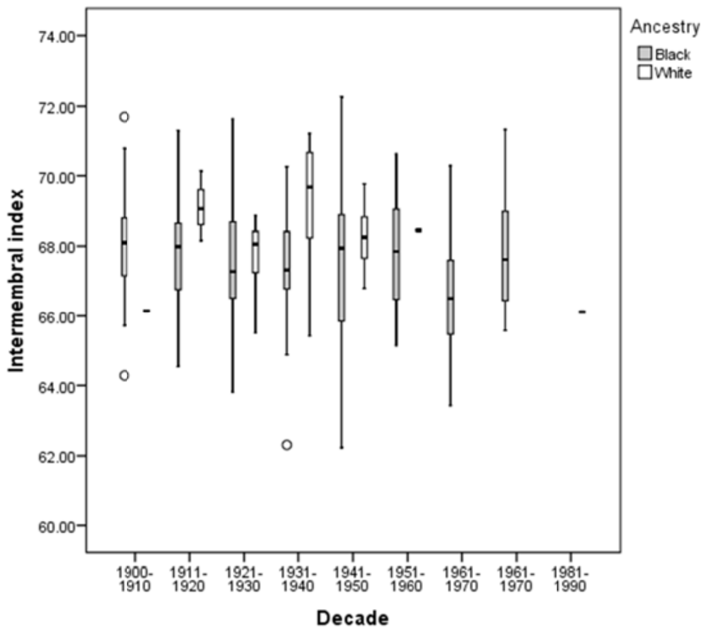


Figure 7.34 Secular trends in the osteometric intermembral index of South African black and white females.

7.1.2.4 Secular changes and ancestry differences in the osteometric sitting height ratio of South African black and white females

Ancestry differences in the sitting height ratio

The non-parametric Kruskal-Wallis test, which is equivalent to the parametric analysis of variance for the sitting height ratio (sitting height/TSH), classified by ancestry using the SAS NPAR1WAY procedure, was used to determine whether significant differences exist between SABF and SAWF. Over the combined birth cohort, a significant difference was observed in the sitting heights with SAWF having overall larger measurements than SABF (Appendix C2; Table C2.3 and Figures C2.5).

As seen in Table 7.8 and Figure 7.35, for the combined birth cohort, a significant difference was observed in the sitting height ratio between SABF and SAWF (Kruskal-Wallis Chi-squared = 21.9530; p = <0.0001). Overall, SAWF had higher sitting heights relative to stature than SABF. However, no significant differences were observed in the 1930's and 1940's possibly due to the small sample sizes of SAWF.

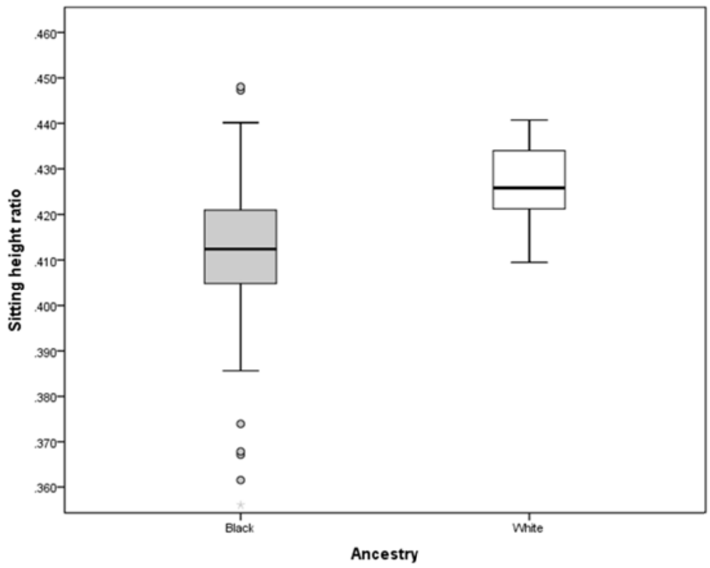


Figure 7.35 Ancestry difference in the osteometric sitting height ratio between South African black and white females over the total period.

Table 7.8 The sample sizes, osteometric sitting height ratios and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared	p-value
1900-1910	SABF	19	41.19	1.63	-	-
	SAWF	1	42.36	-		
1911-1920	SABF	26	41.35	1.99	-	-
	SAWF	3	42.90	1.05		
1921-1930	SABF	26	40.72	1.83	9.5023	**0.0021**
	SAWF	7	42.72	0.78		
1931-1940	SABF	26	41.19	1.83	3.5337	0.0601
	SAWF	5	42.79	1.12		
1941-1950	SABF	30	40.60	1.68	3.2089	0.0732
	SAWF	5	41.48	3.35		
1951-1960	SABF	21	41.45	1.63	-	-
	SAWF	1	42.12	-		
1961-1970	SABF	16	41.25	1.70	-	-
1971-1980	SABF	5	41.10	0.92	-	-
1981-1990	SAWF	1	42.34	-	-	-
1900-1990	SABF	169	41.07	1.75	21.9530	**<0.0001**
	SAWF	23	42.43	1.68		

Secular trends in the sitting height ratio

Comparison of the sitting height ratio plotted against Date of Birth (DOB) cohorts of 10 years using the SAS NPAR1WAY procedure for SABM and SAWM indicated no significant secular trend in the sitting height ratio for SABF (Kruskal-Wallis Chi-squared = 8.8774; p-value = 0.2616) and SAWF (Kruskal-Wallis Chi-squared = 1.8153; p-value = 0.9359). The sitting height ratio decreased from 41.19 in the 1900's to 41.10 in the 1970's for SABF and from 42.72 in the 1920's to 41.48 in the 1940's for SAWF (Figure 7.36) indicating a slight (but statistically non-significant) decrease in the sitting heights relative to stature.

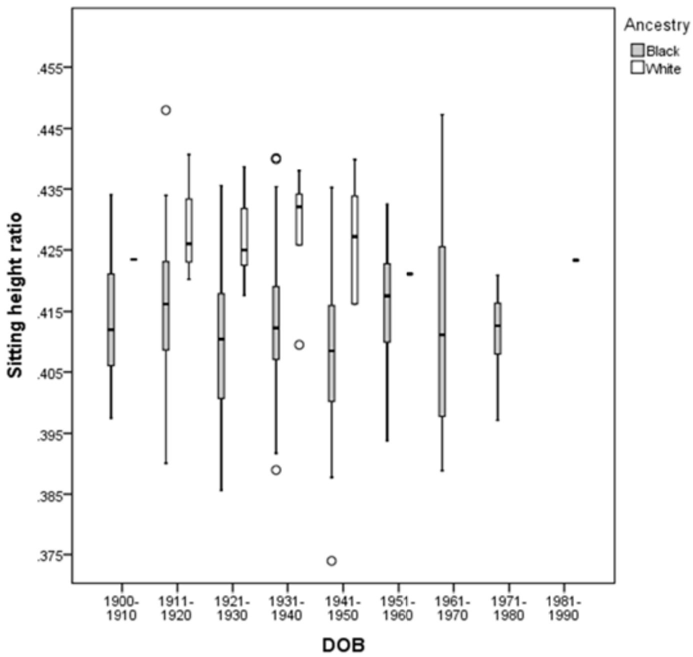


Figure 7.36 Secular trends in the osteometric sitting height of South African black and white females.

7.1.3 Sex differences in secular changes in the osteometric limb proportions of South African population groups

In this section all the limb proportions are provided for the four groups combined. In addition to using the NPAR1WAY procedure, preliminary discriminant analysis was applied to the various limb proportions. The results of the accuracies of the quadratic stepwise discriminant analysis on all 16 variables, the arm indices and the lower limb indices can be seen in Appendix C3. The results from this analysis indicate that some ratios discussed below exhibit distinct differences which may be used in future for sex and ancestry estimation.

Overall, the posterior probabilities ranged from 53.19% to 69.75%. The highest classification was obtained when using the intermembral index, brachial index, arm ratio, forearm ratio, total lower limb ratio and thigh ratios 1 and 2. Cross-validation results indicated correct classification percentages of 81.4% in SABM, 78% in SABF, 67% in SAWM and 69% in SAWF using these variables while lower classification percentages were obtained when grouping upper limb proportions or lower limb proportions separately (59% to 77% and 44% to 71.87%, respectively). The selected upper limb and lower limb proportions also indicated that individuals most often misclassified within the same ancestry group followed by sex (i.e., SABM more often misclassified as SABF followed by SAWM and almost never as SAWF). However, further analysis with larger sample sizes will be required.

Figure 7.37 illustrates the differences in the mean brachial index between males and females. Individuals of African descent have a significantly higher brachial index than their counterparts of European descent. This indicates that individuals of African descent have greater forearm lengths (radius lengths) relative to arm lengths (humerus max lengths) than individuals of European descent. In all groups, no significant secular trend was observed, however, the brachial index of SAWM and SAWF exhibits a slight increase from the 1920's while it remains relatively unchanged in SABM and SABF. In both population groups, males have a slightly higher brachial index than the corresponding females with an overlap seen in the indices of SABM and SABF in the 1970's.

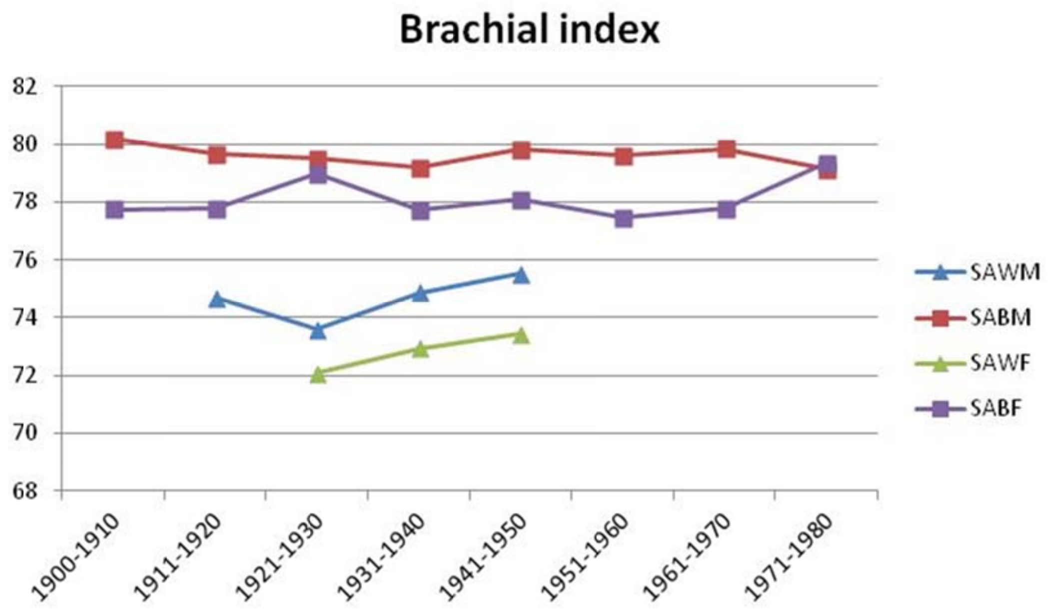


Figure 7.37 Comparisons of the differences in the secular trend of osteometric brachial index for South African population groups combined.

The differences in the upper limb index between males and females can be seen in Figure 7.38. Individuals of African descent have significantly higher upper limb indexes than their counterparts of European descent. This indicates greater arm lengths (humerus max length + radius max lengths) relative to stature in individuals of African descent. The upper limb ratio of SABM and SABF overlap with SAWM having a slightly lower upper limb ratio except in the 1930's when the ratio was lower in SABF and similar to SABM. In both groups, male groups have higher upper limb ratios than their corresponding female groups except in the 1940's when SAWM and SAWF have similar upper limb ratios. No significant secular trends are observed in any of the population groups. However, SABM and SABF exhibit a gradual decrease in the upper limb ratio while the ratio increased in SAWF indicating slightly shorter arm lengths to stature in SABM and SABF from 1900 to 1980. Non-directional fluctuations are observed in the upper limb ratio of SAWM.

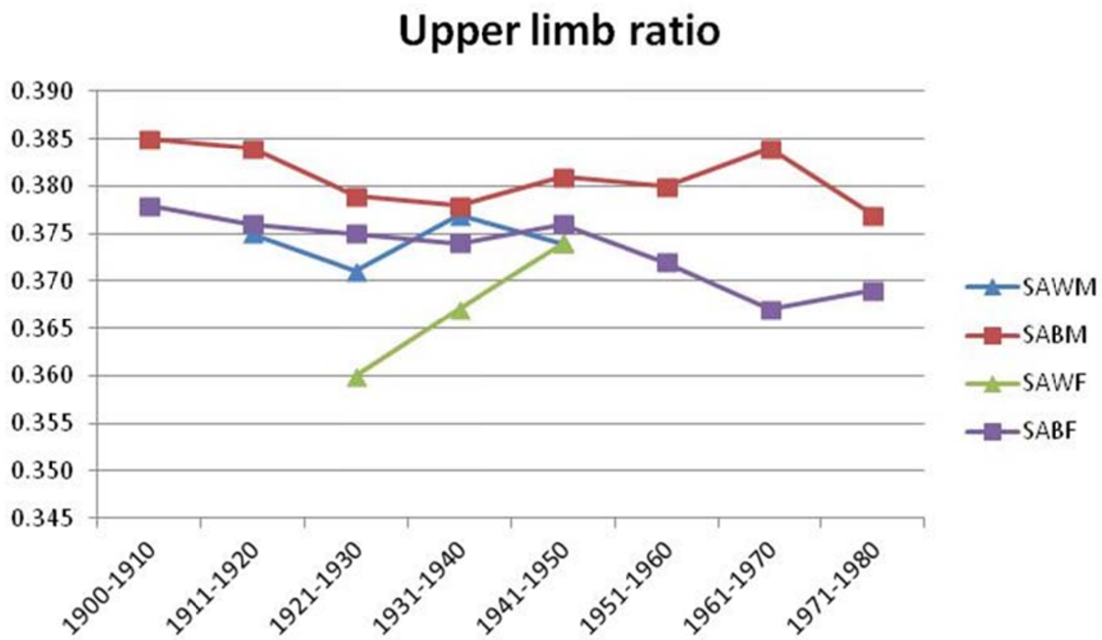


Figure 7.38 Comparisons of the differences in the secular trend of osteometric upper limb ratio for South African population groups combined.

In Figure 7.39 the differences in the arm ratio between males and females can be seen. No significant differences are observed between individuals of African or European decent; however, individuals of European decent have slightly (non-significant) higher arm ratios.

This indicates that there were no distinct differences in the arm lengths (humerus max lengths) relative to stature between black and white South African groups. Overall, no significant secular trends were observed with a minor increase observed in SAWF while a slight gradual decrease was observed in individuals of African descent. SAWM exhibited both increases and decreases from the 1910's to 1940's. Males have a slightly higher arm ratio than females except in the 1900's, 1930's and 1940's when SABM and SABF had similar ratios. In the 1940's, SAWF have higher arm ratios than SAWM.

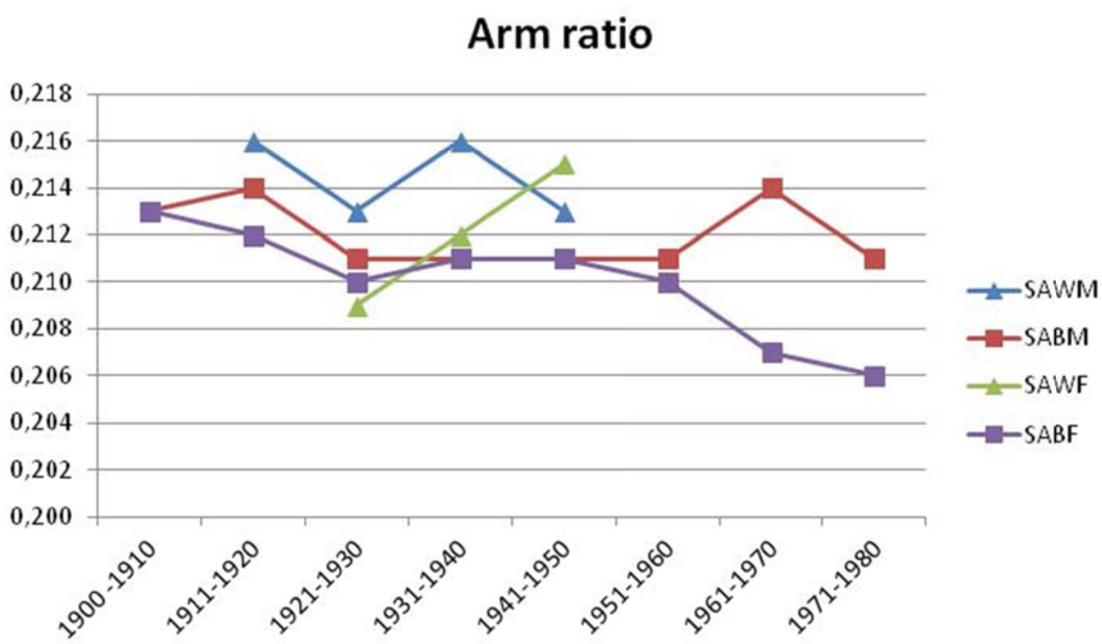


Figure 7.39 Comparisons of the differences in the secular trend of osteometric arm ratio for South African population groups combined.

The differences in the forearm ratios 1 and 2 between males and females are clearly illustrated in Figures 7.40 and 7.41, respectively. Individuals of African descent have significantly higher forearm ratios than their counterparts of European descent. This indicates that SABM and SAWF have greater forearm lengths (radius max lengths and ulna max lengths) relative to stature than SAWM and SAWF, respectively. In both groups, males have larger forearm ratios than females, except in the 1970's when the forearm ratio 2 of SABM and SABF were similar. No significant secular trends are observed in either population group. SABM and SABF exhibit a minor gradual decrease in the forearm ratios while SAWF exhibit a slight increase. SAWM remained relatively unchanged except in the 1920;'s when the forearm ratios decreased.

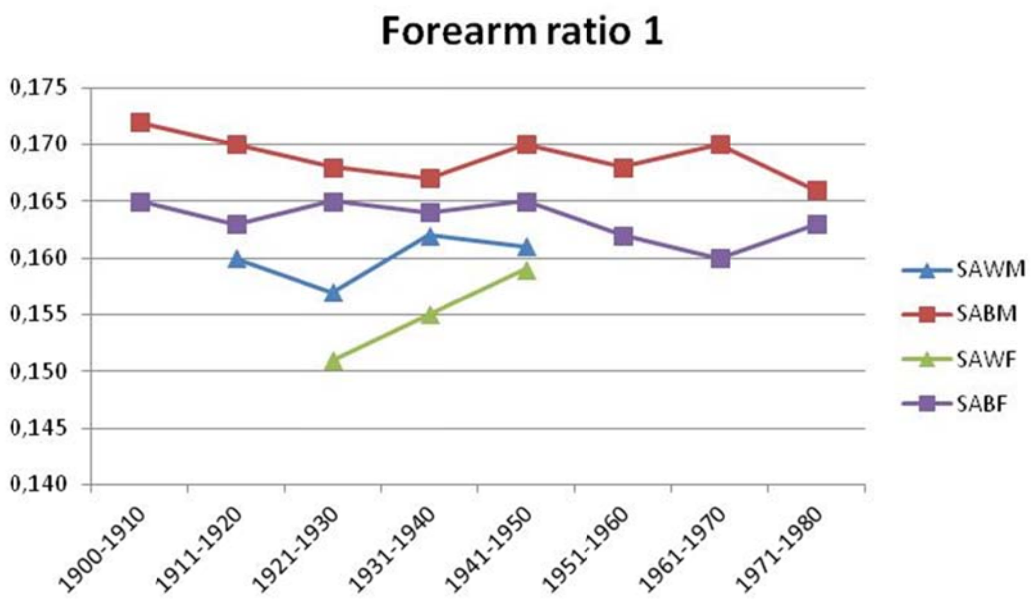


Figure 7.40 Comparisons of the differences in the secular trend of osteometric forearm ratio 1 for South African population groups combined.

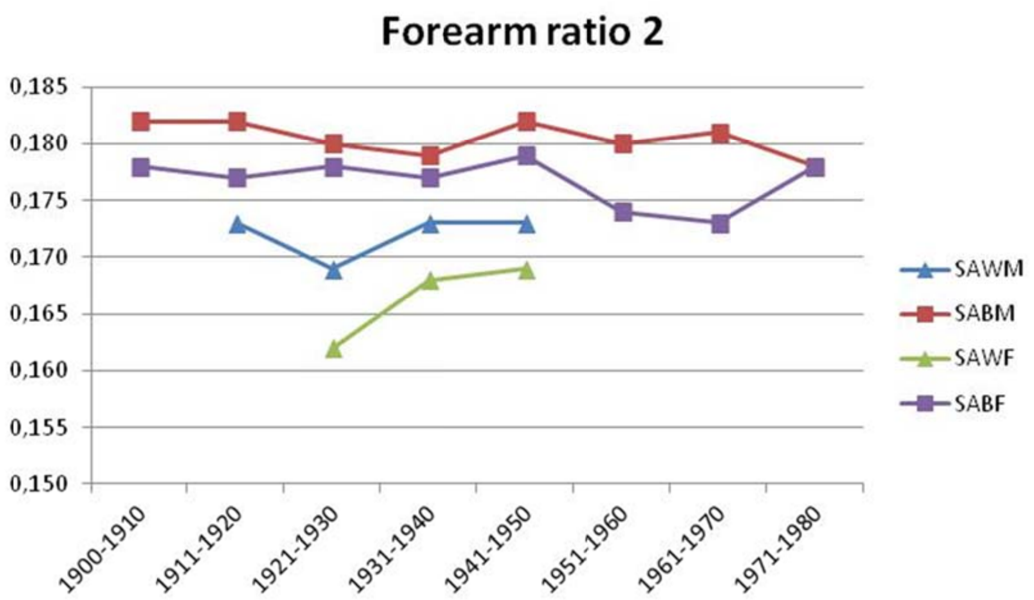


Figure 7.41 Comparisons of the differences in the secular trend of osteometric forearm ratio 2 for South African population groups combined.

Figure 7.42 illustrates the differences in the crural index between males and females. The crural index is significantly higher in individuals of African descent indicating higher leg lengths (tibia condylo-malleolar lengths) relative to thigh lengths (femur bicondylar lengths). Also, males had slightly higher crural indices than their female counterparts. However, in the 1920's and 1940's SABM and SABF have similar crural indices and in the 1930's SAWM and SAWF have similar values. No significant secular trends are observed with SABF, SAWM and SAWF exhibiting a slight increase in the crural index while SABM remain relatively unchanged.

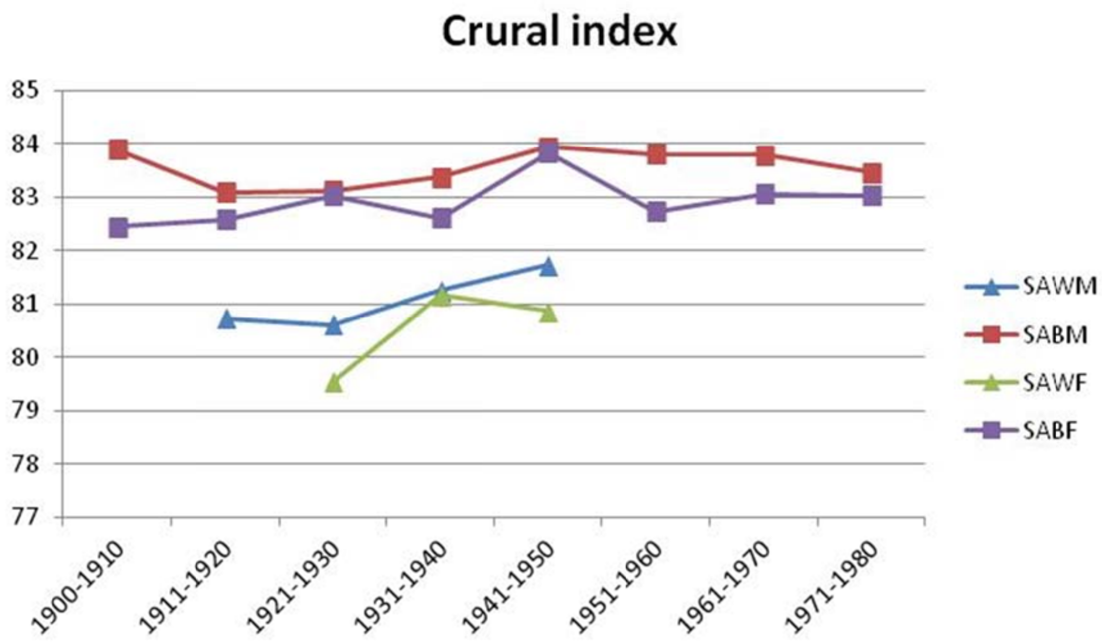


Figure 7.42 Comparisons of the differences in the secular trend of osteometric crural index for South African population groups combined.

The differences in the total lower limb ratio and lower limb ratio between males and females are seen in Figures 7.43 and 7.44, respectively. Individuals of African descent have higher total lower limb and lower limb ratios than their counterparts of European descent. This indicates that individuals of African descent have greater lower limb lengths (total lower limb lengths and lower limb lengths) relative to stature. SABM have slightly higher ratios than SABF except from the 1920's to the 1940's when the ratios overlap. SAWM have higher ratios than SAWF except in the 1940's when SAWF have higher values indicating that males have slightly greater lower limb lengths relative to stature. No significant secular trends are observed with SABM, SABF and SAWM exhibiting non-directional fluctuations while SAWF exhibit a large increase from the 1930's to 1940's indicating a rapid increase in lower limb lengths to stature.

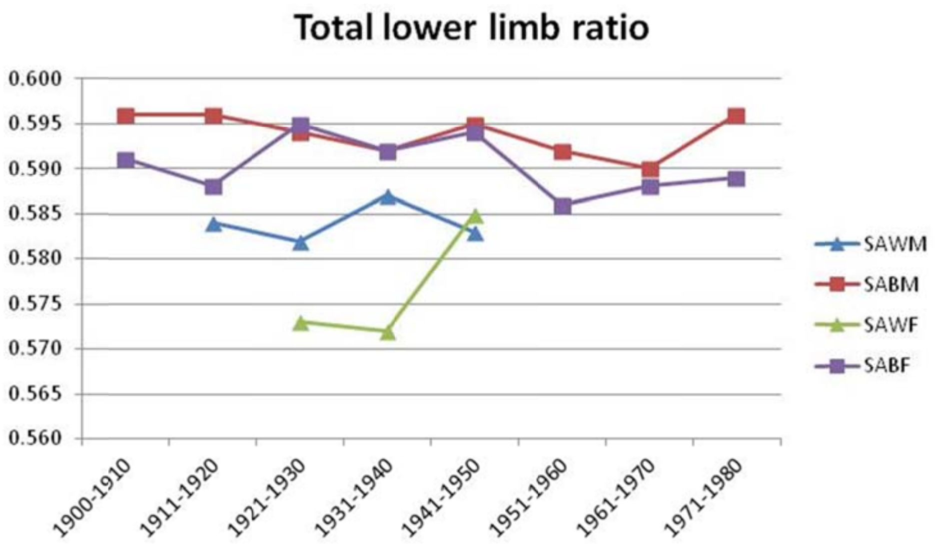


Figure 7.43 Comparisons of the differences in the secular trend of osteometric total lower limb ratio for South African population groups combined.

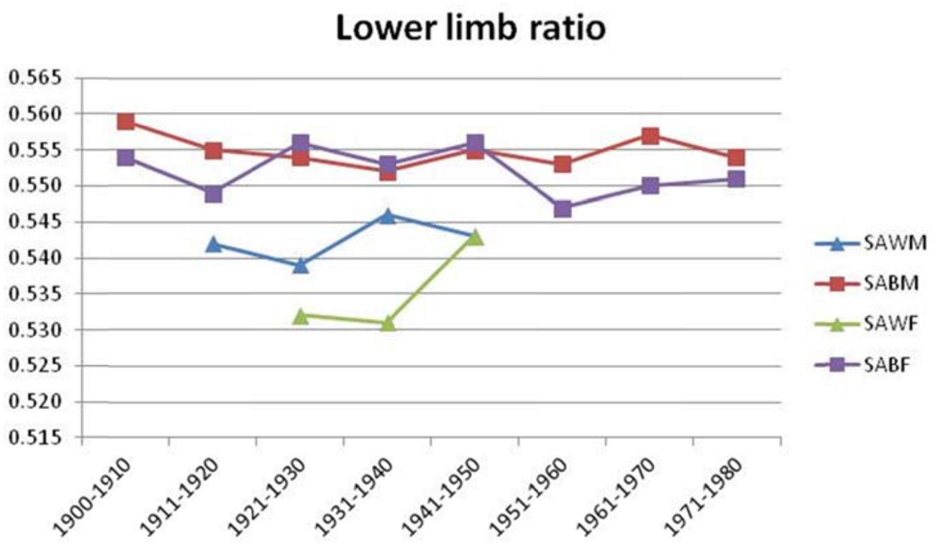


Figure 7.44 Comparisons of the differences in the secular trend of osteometric lower limb ratio for South African population groups combined.

In Figures 7.45 and 7.46 the differences in the thigh ratio 1 and 2 between males and females are clearly illustrated. No significant differences are observed in the thigh ratios between SABM and SAWM with SABM having slightly greater thigh lengths (femur max lengths and femur bicondylar lengths) than SAWM. However, a significant difference is observed between SABF and SAWF indicating that SAWF have distinctly shorter thigh lengths relative to stature. No significant secular trends are observed and the thigh ratios of SABM, SAWM and SABF exhibit distinct overlap with non-directional fluctuations. A non-significant increase is observed in the thigh ratios of SAWF with no significant differences between SABM, SAWM and SAWF in the 1940's.

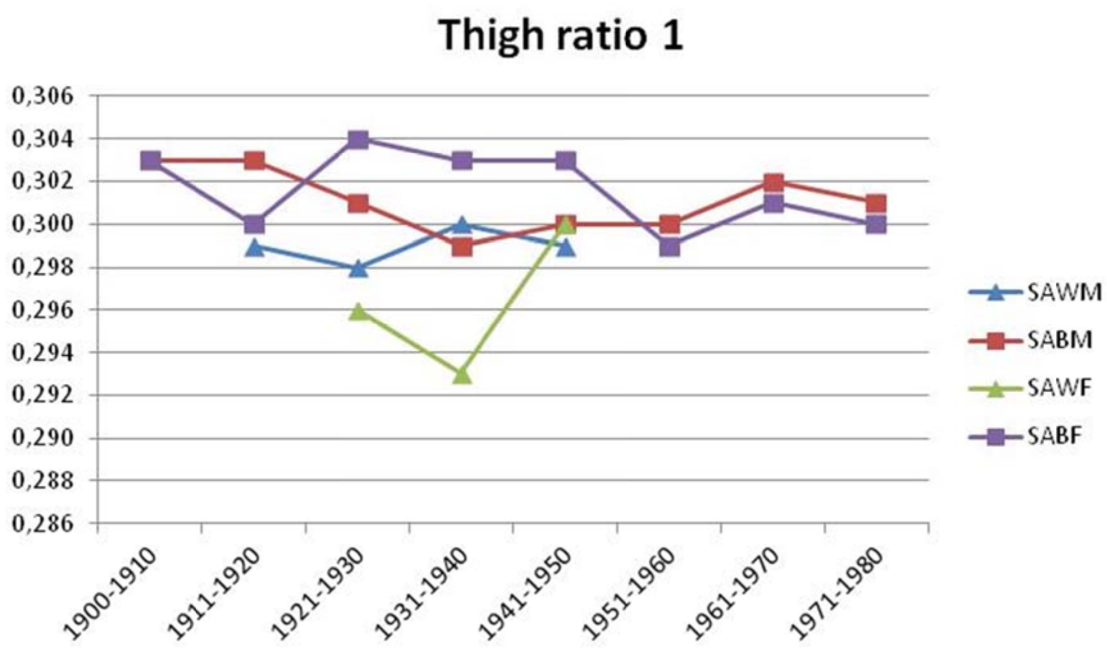


Figure 7.45 Comparisons of the differences in the secular trend of osteometric thigh ratio 1 for South African population groups combined.

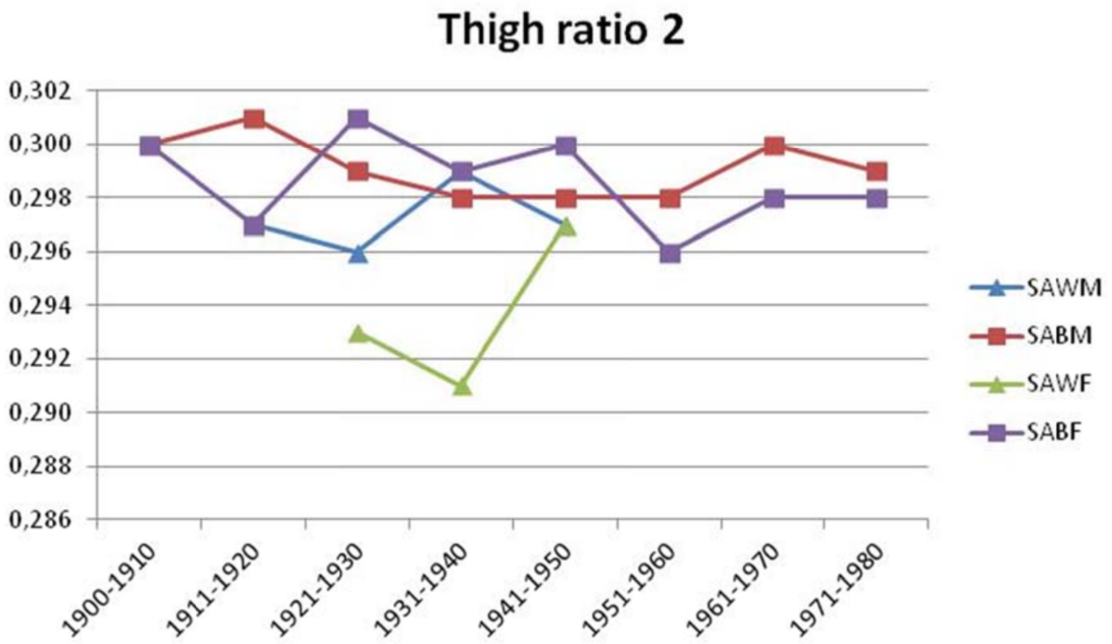


Figure 7.46 Comparisons of the differences in the secular trend of osteometric thigh ratio 2 for South African population groups combined.

In Figures 7.47 and 7.48 the differences in the leg ratios 1 and 2 between males and females are clearly illustrated. Individuals of African descent have higher leg ratios than their counterparts of European descent. This indicates that SABM and SABF have leg lengths (tibia condylo-malleolar lengths and fibula max lengths) which are greater relative to stature than SAWM and SAWF, respectively. No significant difference is observed in the leg ratios of SABM and SABF while SAWM have slightly higher values than SAWF. No significant secular trend is observed in any of the groups. The leg ratios of SABM and SABF remained relatively constant except in the 1950's when the leg ratio 2 exhibits distinctly lower values. The leg ratios of SAWM and SAWF gradually increased until no difference is observed in the 1940's.

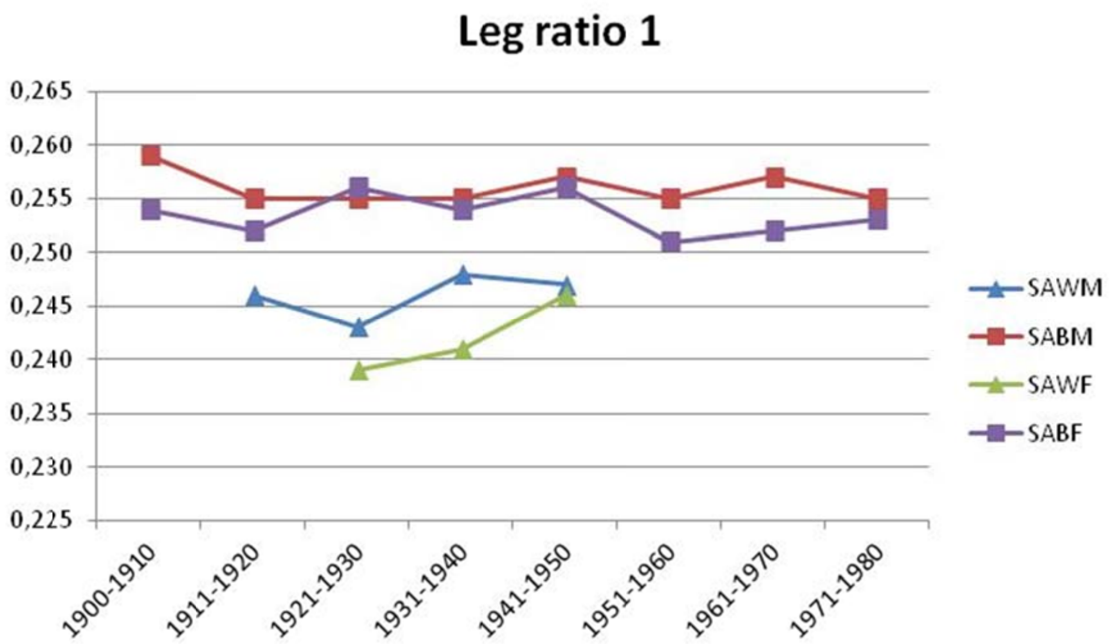


Figure 7.47 Comparisons of the differences in the secular trend of osteometric leg ratio 1 for South African population groups combined.

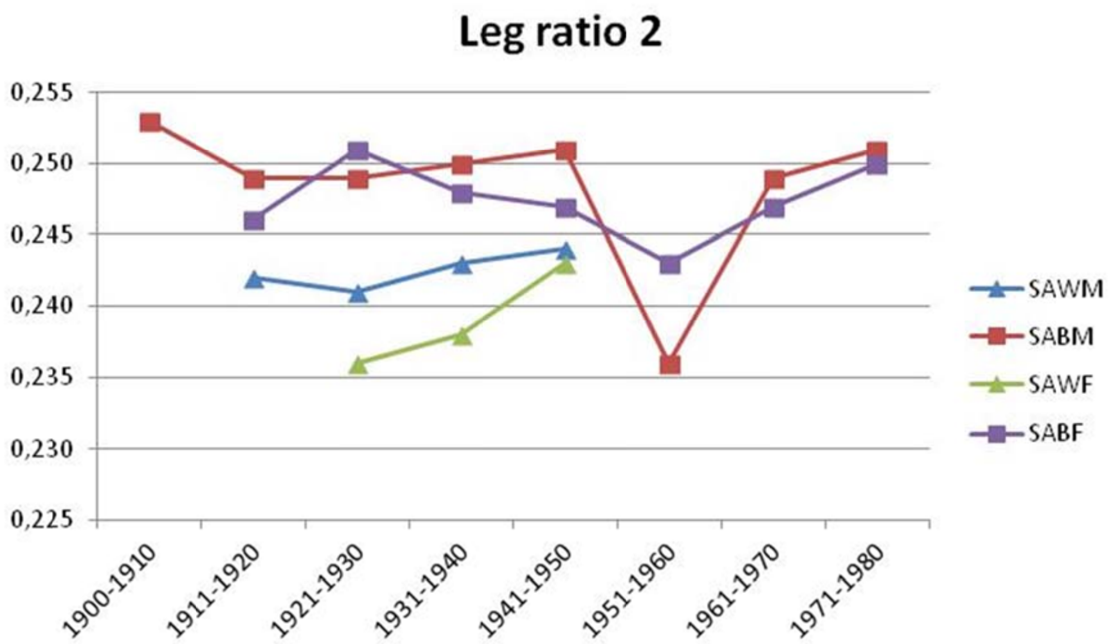


Figure 7.48 Comparisons of the differences in the secular trend of osteometric leg ratio 2 for South African population groups combined.

The differences in the intermembral index between males and females are illustrated in Figure 7.49. Individuals of European descent have slightly higher intermembral indexes than their counterparts of African descent; however the difference is not significant. This indicates that SAWF and SAWM have slightly greater arm lengths (humerus max length + radius max lengths) to lower limb lengths (femur max length + tibia condyle-malleolar length) than SABF and SABM, respectively. In both ancestry groups, males have higher intermembral indices than the female except in the 1930's when SAWF have a higher ratio than SAWM. No significant secular trends are observed in the intermembral index. The intermembral index of SAWF overlaps with the indices of SABM and SAWM.

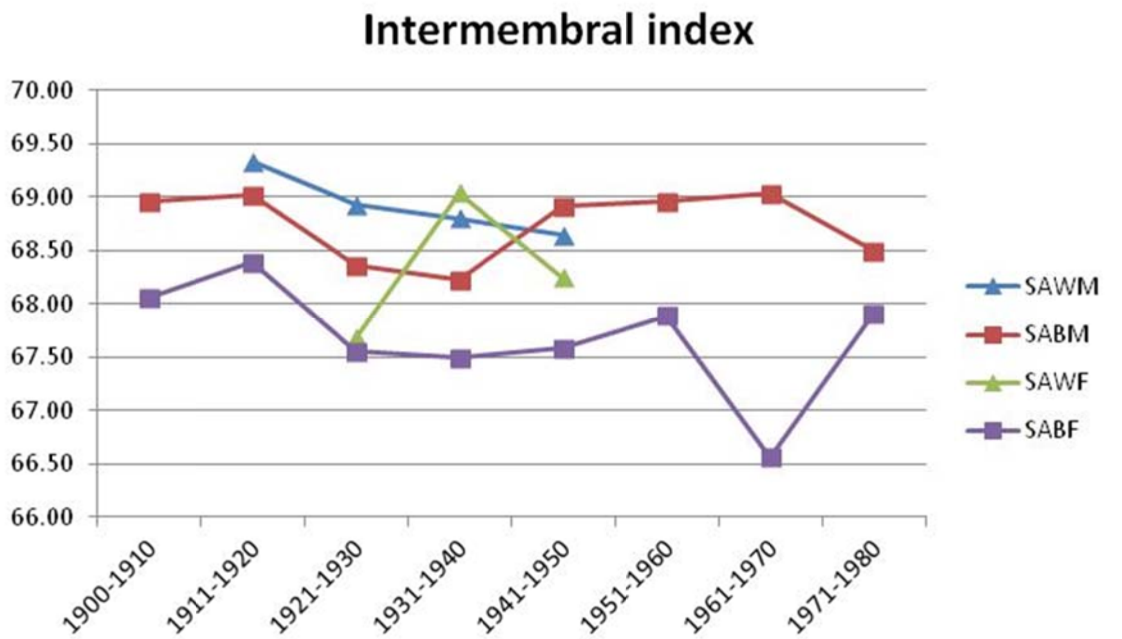


Figure 7.49 Comparisons of the differences in the secular trend of osteometric intermembral index for South African population groups combined.

Figure 7.50 demonstrates the differences in the sitting height ratio between black and white males and females. Individuals of European descent have significantly higher sitting height ratios than their counterparts of African descent indicating higher sitting heights relative to stature in SAWM and SAWF. No secular trends are observed in the sitting height ratios with SAWF exhibiting a gradual decrease while SAWM, SABM and SABF remain relatively constant. Overall, females have a slightly higher sitting height ratio than their corresponding male group with some overlap in the 1940's and a higher ratio for SABM than SABF in the 1960's.

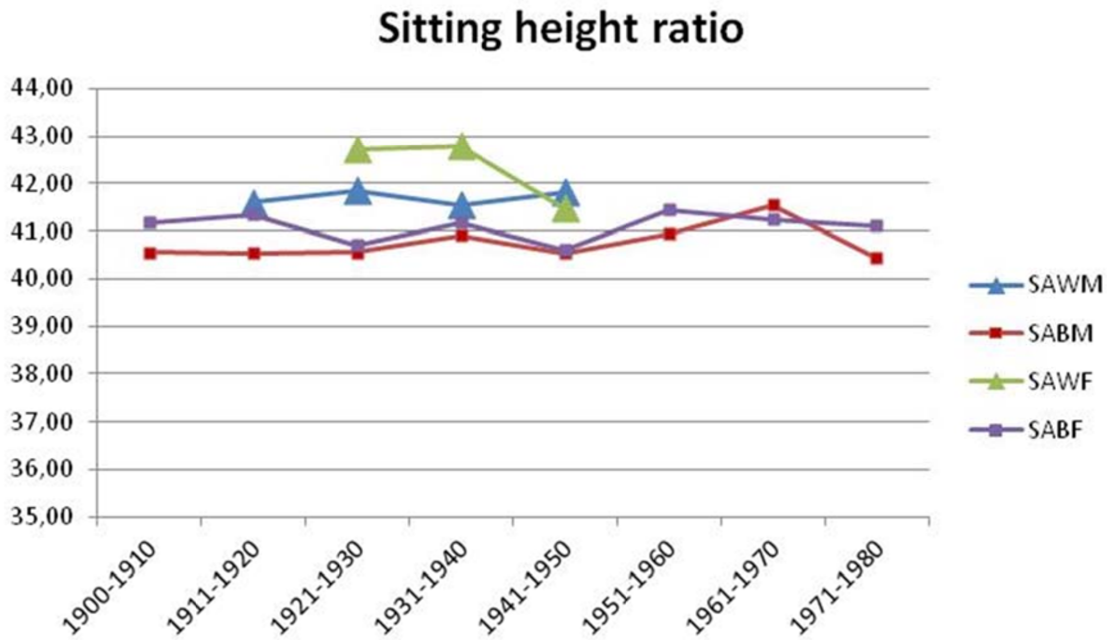


Figure 7.50 Comparisons of the differences in the secular trend of osteometric sitting height ratio for South African population groups combined.

7.2 Differences in the osteometric limb proportions between white South African and North American population groups

In this section the osteometric limb proportions of the white South African (SA) males and females were compared to those of white North American (NA) males and females over the total birth period in order to determine whether differences exist between Northern and Southern hemisphere groups. Unfortunately no data were available for the black North American group, so no assessment could be made with regard to similarities or differences between black SA and NA groups.

7.2.1 Differences and secular changes in the osteometric arm proportions of white South African and North American males and females

The sample sizes and mean osteometric arm proportions of SA and NA groups are shown in Table 7.9. The non-parametric Kruskal-Wallis test which is equivalent to the parametric analysis of variance for brachial index, upper limb ratio, arm ratio and forearm ratios 1 and 2, classified by population groups using the SAS NPAR1WAY procedure was used to determine whether significant differences exist between South African white males (SAWM) and North American white males (NAWM) and between South African white females (SAWF) and North American white females (NAWF).

No significant differences ($p > 0.05$) were observed in the arm length (humerus max length + radius max length) and max ulna length while significant differences were observed in the humerus max length and radius max length between NAWM and SAWM. NAWM had slightly greater ulna max lengths than SAWM but greater arm lengths, humerus max lengths and radius max lengths were observed in SAWM. No significant differences were observed in any of the upper limb lengths between NAWF and SAWF with NAWF having slightly greater arm lengths, radius max lengths and ulna max lengths than SAWF (Appendix D: Table D1 and Figure D1).

Table 7.9 and Figures 7.51 - 7.53 demonstrate that a significant difference exists in brachial index, upper limb ratio and arm ratio of SAWM and NABM ($p = <0.0001$) and SAWF and NAWF ($p = 0.0002$, $p = 0.0234$ and $p = <0.0001$, respectively). On average, NAWM and NAWF have higher brachial indices than their SA counterparts while the upper limb ratio and arm ratios are higher in SAWM and SAWF. This indicates that NA groups have greater forearm lengths (radius max lengths) relative to arm lengths (humerus max lengths) while SA groups have greater upper limb lengths (humerus max length + radius max length) and arm lengths (humerus max length) relative to stature (as represented by TSH). Overall, the brachial indices of males were higher than their female counterparts with NAWM having the higher values than NAWF and SAWM having higher values than SAWF. However, NAWF have brachial indices that are similar to those of SAWM (Figure 7.51) indicating similar forearm lengths relative to arm lengths. The upper limb ratios of males were also higher than their female counterparts with the SAWM having the highest value and NAWF having the lowest value. The upper limb ratios of NAWM and SAWF were similar (Figure 7.52). As seen in Figure 7.53, the arm ratio does not exhibit distinct sex differences with SAWM and SAWF having higher values than both NAWM and NAWF. This indicates a distinct difference in population groups between the northern and southern hemisphere without the influence of sexual dimorphism.

Table 7.9 and Figures 7.54 and 7.55 also demonstrate that no significant difference existed in forearm ratios 1 and 2 between SAWM and NAWM ($p = 0.2838$ and $p = 0.0918$, respectively) and SAWF and NAWF ($p = 0.7723$ and $p = 0.7113$, respectively). However, SA groups have slightly greater forearm lengths (radius max length and ulna max length) relative to stature than NA groups while the forearm ratios are higher in males than in females. The brachial indices of males were higher than those of their female counterparts with NAWM having higher values than NAWF and SAWM having higher values than SAWF. However, NAWF have brachial indices that are similar to those of SAWM (Figure 7.51). The upper limb ratios of males were also higher than their female counterparts with the SAWM having the highest value and NAWF having the lowest value. The upper limb ratios of NAWM and SAWF were similar (Figure 7.52). As seen in Figure 7.53, the arm ratio does not exhibit significant sex differences with both SAWM and SAWF having higher values than NAWM and NAWF.

Table 7.9 The sample sizes, mean osteometric arm proportions and Kruskal-Wallis test results between white South African and North American males and females for the overall period.

Ancestry	Brachial index					Upper limb ratio					Arm ratio				
	N	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**
SAWM	67	74.76	2.47	25.5445	**<0.0001**	49	0.375	0.012	16.3537	**<0.0001**	51	0.214	0.008	29.4146	**<0.0001**
NAWM	72	76.94	2.08			68	0.365	0.008			68	0.207	0.006		
SAWF	26	72.62	2.27	13.5138	**0.0002**	23	0.365	0.012	5.1417	**0.0234**	23	0.212	0.006	16.0282	**<0.0001**
NAWF	45	74.67	2.23			43	0.359	0.008			43	0.206	0.005		

Ancestry	Forearm ratio 1					Forearm ratio 2				
	N	**Mean**	**SD**	**Chi-Squared**	**p-value**	N	Mean	SD	**Chi-Squared**	**p-value**
SAWM	49	0.160	0.005	1.1487	0.2838	51	0.172	0.006	2.8430	0.0918
NAWM	68	0.159	0.004			68	0.170	0.004		
SAWF	23	0.154	0.007	0.0837	0.7723	23	0.165	0.006	0.1370	0.7113
NAWF	43	0.153	0.004			43	0.164	0.004		

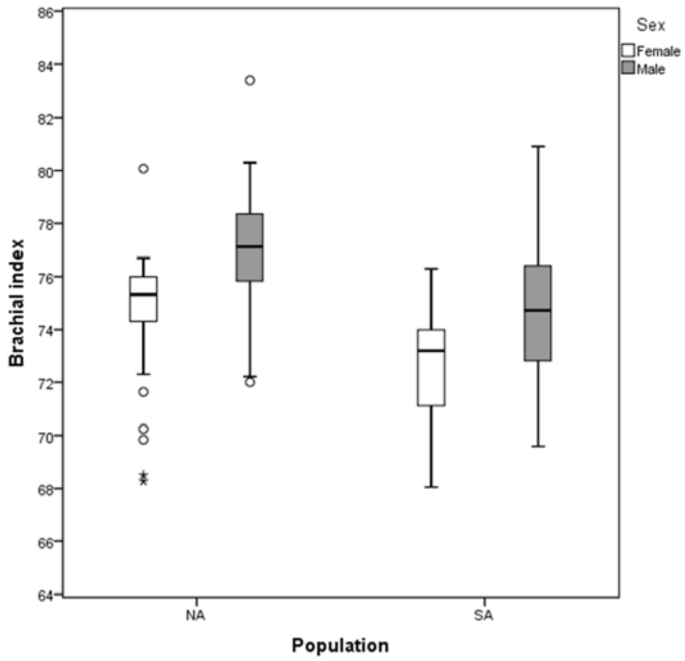


Figure 7.51 Differences in the osteometric brachial index between white South African and North American males and females over the total period.

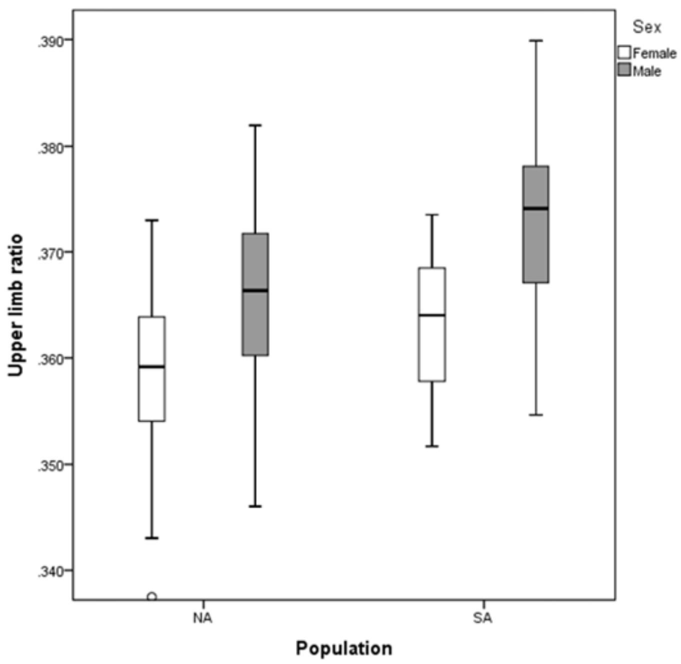


Figure 7.52 Differences in the osteometric upper limb ratio between white South African and North American males and females over the total period.

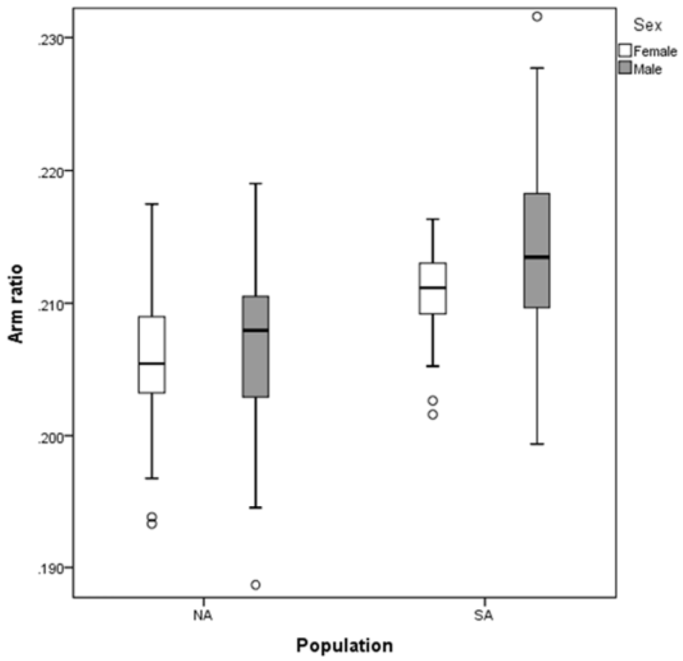


Figure 7.53 Differences in the osteometric arm ratio between white South African and North American males and females over the total period.

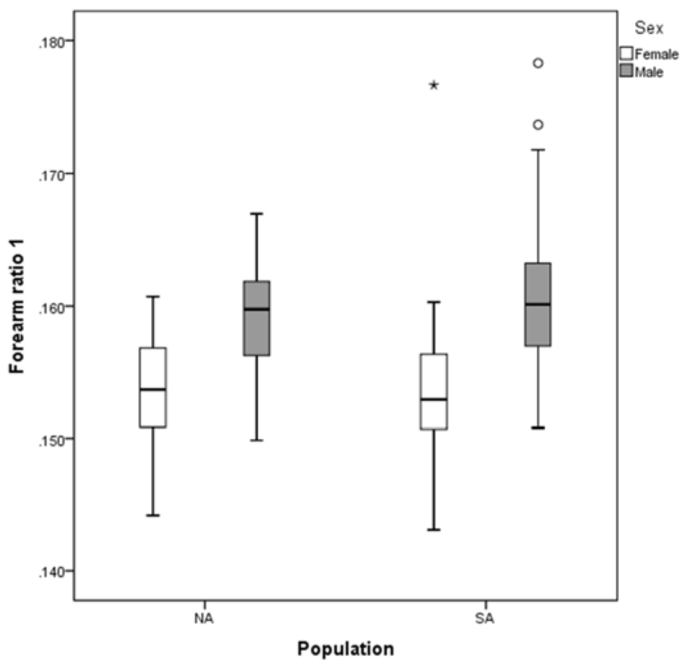


Figure 7.54 Differences in the osteometric forearm ratio 1 between white South African and North American males and females over the total period.

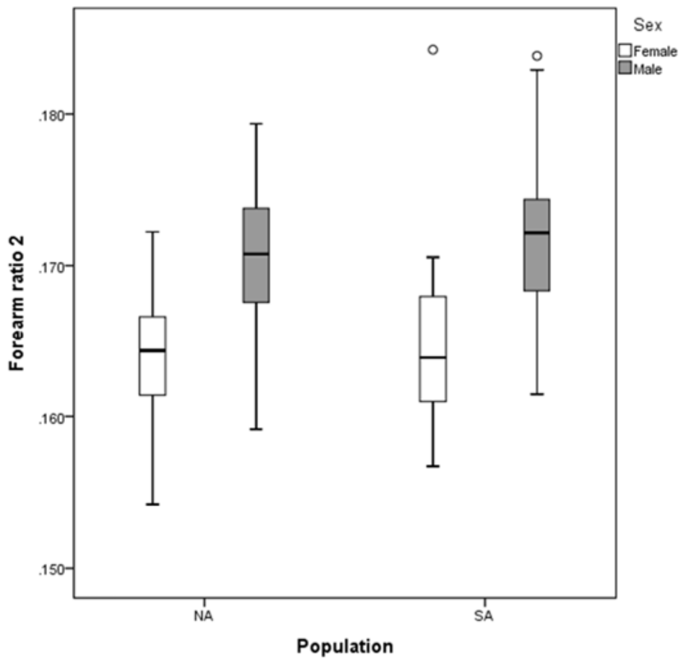


Figure 7.55 Differences in the osteometric forearm ratio 2 between white South African and North American males and females over the total period.

7.2.2 Differences in the osteometric lower limb proportions of white South African and North American males and females

In Table 7.10 the sample sizes and mean osteometric lower limb proportions and results of the non-parametric Kruskal-Wallis test which is equivalent to the parametric analysis of variance for crural index, total lower limb ratio, lower limb ratio, thigh ratios 1 and 2 and leg ratios 1 and 2, classified by population groups using the SAS NPAR1WAY procedure is shown. This procedure was used to determine whether significant differences exist between South African white males (SAWM) and North American white males (NAWM) and between South African white females (SAWF) and North American white females (NAWF).

No significant differences ($p > 0.05$) were observed in the any of the lower limb lengths between NAWM and SAWM and between NAWF and SAWF. NAWF had slightly greater total lower limb lengths (femur bicondylar length + tibia condylo-malleolar length + talo-calcaneal height), lower limb lengths (femur bicondylar length + tibia condylo-malleolar length), femur max lengths, tibia condylo-malleolar lengths and fibula max lengths than SAWM while SAWM had slightly greater femur bicondylar lengths. All the lower limb lengths were greater in NAWF compared to SAWF (Appendix D: Table D2 and Figure D2).

Table 7.10 and Figures 7.56 - 7.60 demonstrate significant differences in the crural index (p = 0.0137), total lower limb ratio (p = <0.0001), lower limb ratio (p = <0.0001), thigh ratio 1 (p = <0.0001) and thigh ratio 2 (p = <0.0001) of SAWM and NABM (p = <0.0001). Overall, NA groups had larger leg lengths (tibia condylo-malleolar lengths) relative to proximal lengths (femur bicondylar length) than corresponding SA groups. SAWM had greater total lower limb lengths, lower limb lengths and thigh lengths (femur max length and femur bicondylar length) relative to stature than NAWM. No significant differences were observed in the leg ratio 1 (p = 0.0764) and leg ratio 2 (p = 0.1615) of SAWM and NAWM (Figures 7.61 and 7.62, respectively). However, SAWM had slightly greater leg lengths (tibia condylo-malleolar and fibula max length) relative to stature. No significant differences (p >0.05) were observed in any of the limb proportions of SAWF and NAWF with NAWF having slightly greater leg lengths relative to stature. SAWF had greater lower limb lengths and thigh lengths and slightly greater leg lengths relative to stature than NAWF.

On average, NAWM have the highest crural index while SAWM, SAWF and NAWF had similar indices (Figure 7.56). The total lower limb and lower limb ratios of SAWM were significantly higher than those of NAWM, SAWF and NAWF. The ratios were similar between NAWM and SAWF with NAWF having a slightly lower ratio (Figures 7.57 and 7.58). Figure 7.59 and 7.60 illustrate the differences in the thigh ratios 1 and 2, respectively. SAWM exhibit the highest ratios followed by SAWF. The ratios were only slightly higher in SAWF compared to NA groups while no difference was observed in the ratios between NAWM and NAWF. This indicates a distinct difference in population groups without the influence of sexual dimorphism. Figures 7.61 and 7.62 illustrate the similarity in the leg ratios 1 and 2 between SAWM and NABM and SAWF and NAWF. Overall, the leg ratios are slightly higher in males than in females.

Table 7.10 The sample sizes, mean osteometric lower limb proportions and Kruskal-Wallis test results between white South African and North American males and females for the overall period.

Ancestry	Crural index					Total lower limb ratio					Lower limb ratio				
	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
SAWM	67	81.19	2.25	6.0808	0.0137	49	0.585	0.016	19.6310	<0.0001	51	0.544	0.016	20.5890	<0.0001
NAWM	72	82.25	2.75			68	0.575	0.010			68	0.533	0.010		
SAWF	26	80.79	1.73	0.2732	0.6012	23	0.576	0.017	1.9026	0.1678	23	0.535	0.017	1.0323	0.3096
NAWF	44	81.18	2.25			43	0.571	0.009			43	0.530	0.009		

Ancestry	Thigh ratio 1					Thigh ratio 2				
	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
SAWM	51	0.300	0.009	20.2976	<0.0001	51	0.298	0.009	24.5122	<0.0001
NAWM	68	0.293	0.008			68	0.290	0.007		
SAWF	23	0.295	0.009	1.4506	0.2284	23	0.293	0.009	2.0540	0.1518
NAWF	43	0.293	0.005			43	0.290	0.006		

Ancestry	Leg ratio 1					Leg ratio 2				
	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
SAWM	51	0.246	0.008	3.1401	0.0764	44	0.243	0.007	1.9601	0.1615
NAWM	68	0.243	0.007			68	0.241	0.007		
SAWF	23	0.242	0.008	0.4437	0.5053	19	0.238	0.008	0.1763	0.6746
NAWF	43	0.241	0.006			43	0.237	0.006		

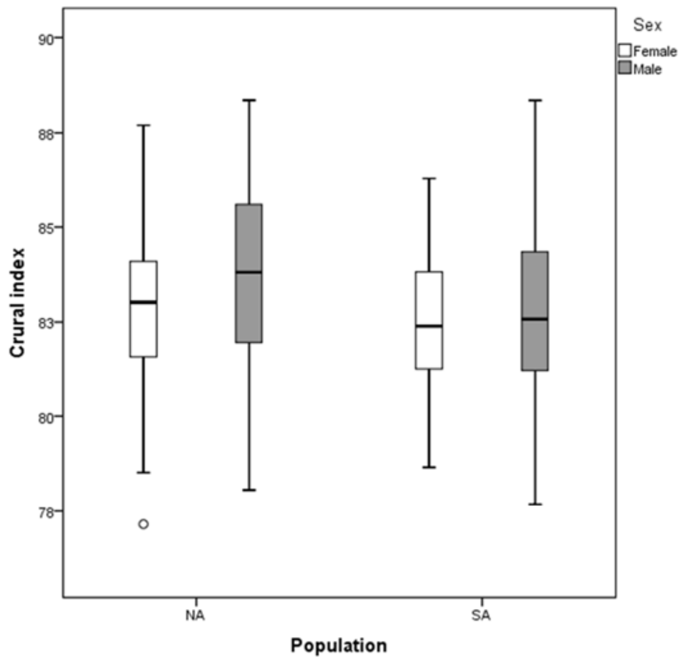


Figure 7.56 Differences in the osteometric crural index between white South African and North American males and females over the total period.

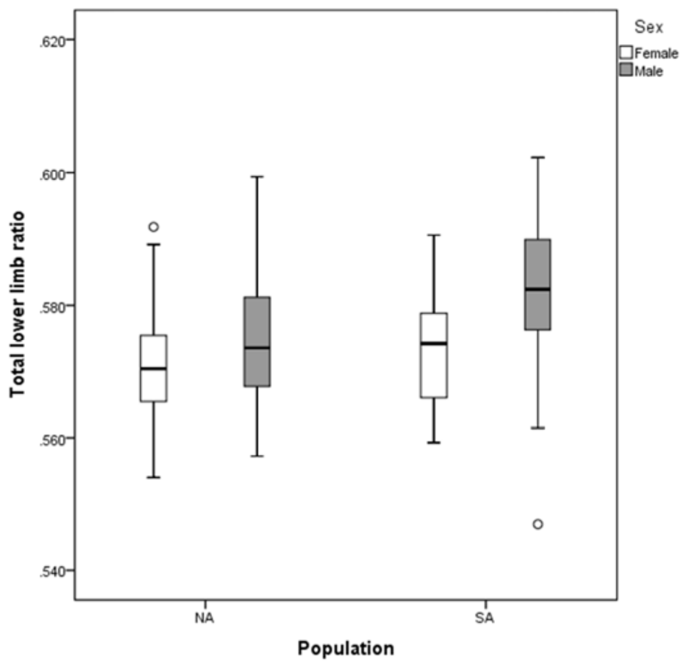


Figure 7.57 Differences in the osteometric total lower limb ratio between white South African and North American males and females over the total period.

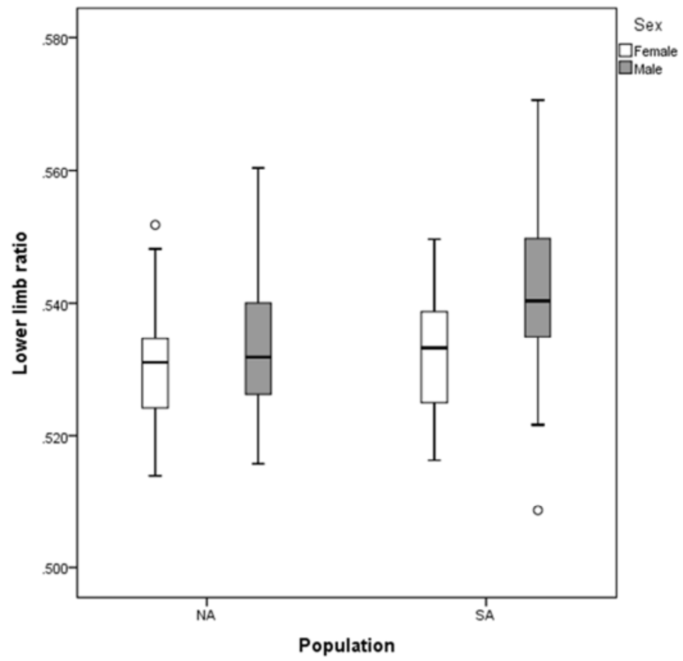


Figure 7.58 Differences in the osteometric lower limb ratio between white South African and North American males and females over the total period.

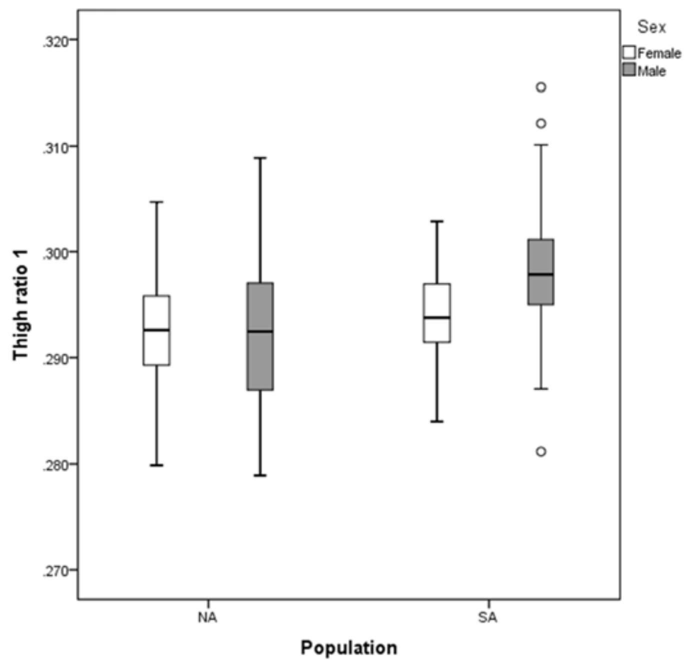


Figure 7.59 Differences in the osteometric thigh ratio 1 between white South African and North American males and females over the total period.

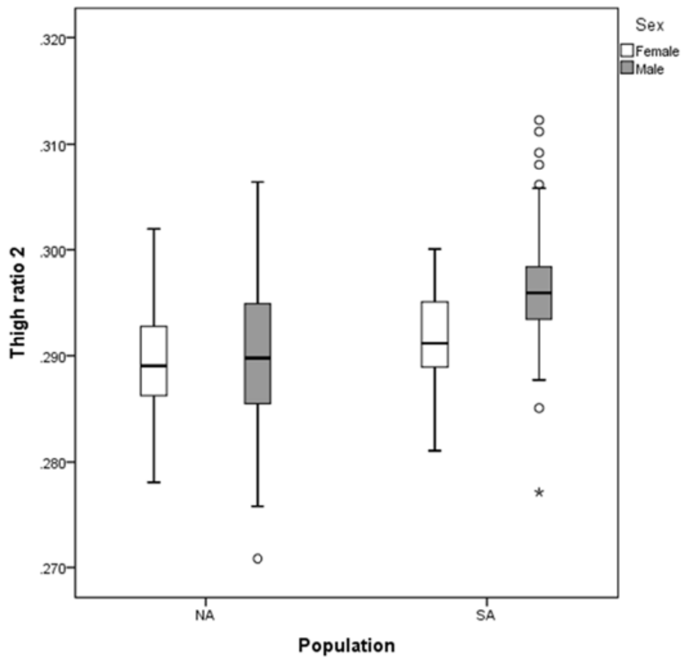


Figure 7.60 Differences in the osteometric thigh ratio 2 between white South African and North American males and females over the total period.

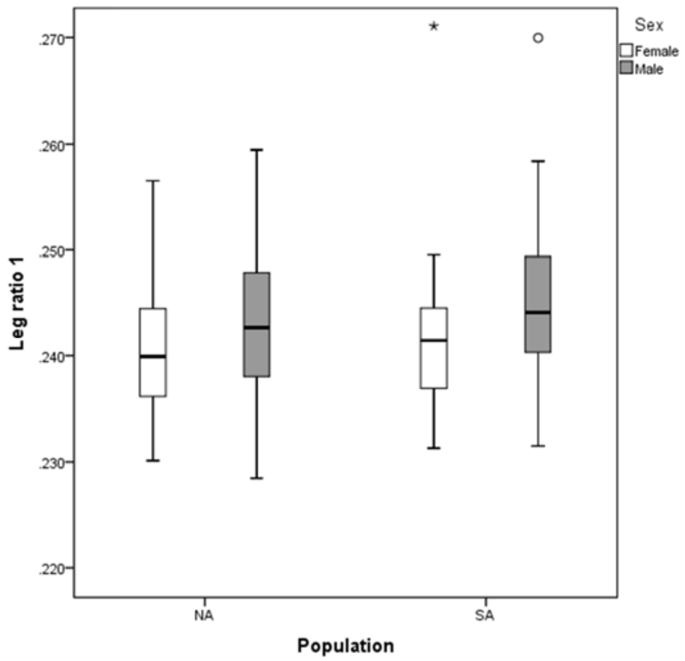


Figure 7.61 Differences in the osteometric leg ratio 1 between white South African and North American males and females over the total period.

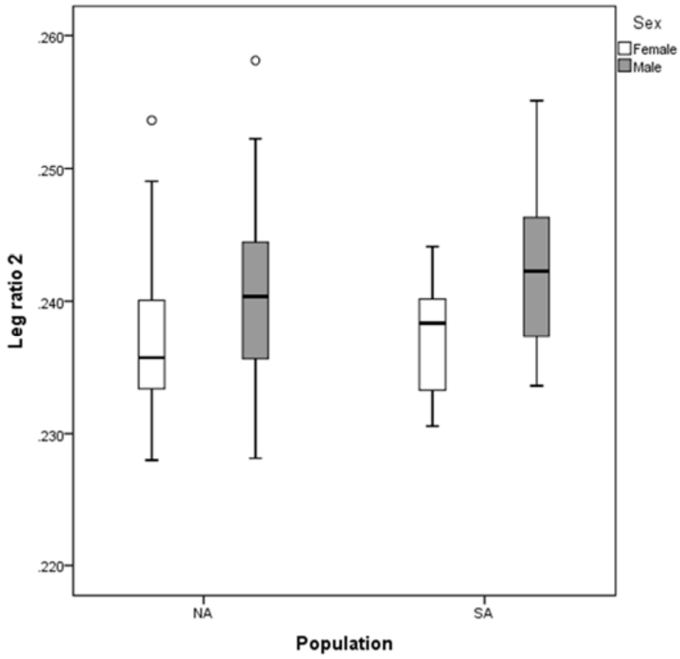


Figure 7.62 Differences in the osteometric leg ratio 2 between white South African and North American males and females over the total period.

7.2.3 Differences in the osteometric intermembral index of white South African and North American males and females

The sample sizes and mean intermembral index of SA and NA groups are shown in Table 7.12. The non-parametric Kruskal-Wallis test which is equivalent to the parametric analysis of variance for intermembral index, classified by population groups using the SAS NPAR1WAY procedure was used to determine whether significant differences exist between South African white males (SAWM) and North American white males (NAWM) and between South African white females (SAWF) and North American white females (NAWF).

No significant difference exists between the intermembral index of SAWM and NABM (p = 0.8015) and SAWF and NAWF (p = 0.3977). However, the SA groups have slightly (non-significant) greater arm lengths (humerus max length + radius max length) relative to lower limb lengths (femur max length + tibia condylo-malleolar length) than corresponding NA groups. Also, the intermembral indices of male groups are slightly higher than those of the corresponding female groups (Figure 7.63).

Table 7.11 The sample sizes, mean osteometric intermembral index and Kruskal-Wallis test results between white South African and North American males and females for the overall period.

Ancestry	Intermembral index				
	N	Mean	SD	Chi-Squared	p-value
SAWM NAWM	63 72	68.82 68.58	2.05 1.63	0.0632	0.8015
SAWF NAWF	25 44	68.19 67.71	1.51 1.57	0.7153	0.3977

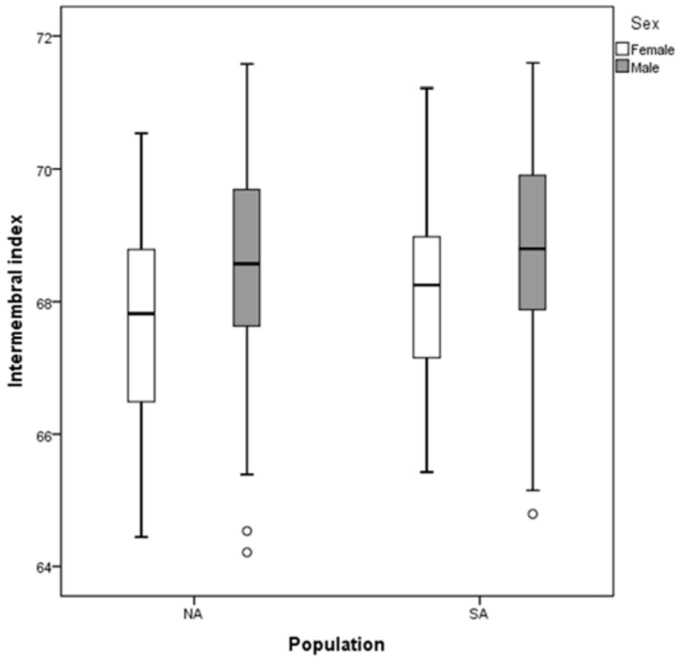


Figure 7.63 Differences in the osteometric intermembral index between white South African and North American males and females over the total period.

7.2.4 Differences and secular changes in the osteometric sitting height ratio of white South African and North American males and females

The sample sizes and mean osteometric sitting height ratio of SA and NA groups are shown in Table 7.12. The non-parametric Kruskal-Wallis test which is equivalent to the parametric analysis of variance for sitting height ratio, classified by population groups using the SAS NPAR1WAY procedure was used to determine whether significant differences exist between South African white males (SAWM) and North American white males (NAWM) and between South African white females (SAWF) and North American white females (NAWF).

Table 7.12 and Figures 7.64 demonstrate that a significant difference exists between the sitting height ratios of SAWM and NABM (p = <0.0001) with NAWM having higher sitting heights relative to stature. No difference is observed between SAWF and NAWF (p = 0.1678) with NAWF having slightly higher sitting heights relative to stature. The sitting height ratio of NAWF is slightly higher than those of NAWM and SAWF. However, SAWM have significantly lower sitting height ratios compared to the other groups.

Table 7.12 The sample sizes, mean osteometric sitting height ratios and Kruskal-Wallis test results between white South African and North American males and females for the overall period.

Ancestry	Sitting height ratio				
	N	**Mean**	**SD**	**Chi-Squared**	**p-value**
SAWM NAWM	51 68	41.59 42.49	0.016 0.010	16.3932	**<0.0001**
SAWF NAWF	23 43	42.43 42.95	0.017 0.009	1.9026	0.1678

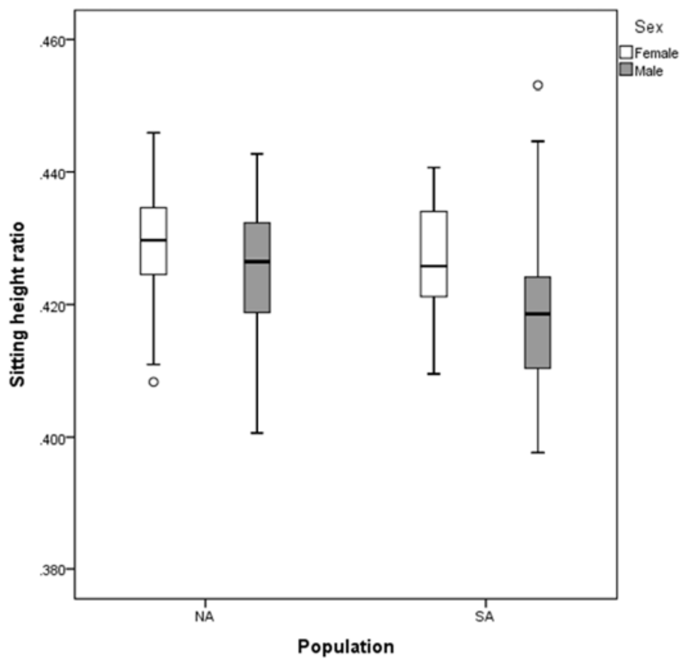


Figure 7.64 Differences in the osteometric sitting height ratio between white South African and North American males and females over the total period.

Chapter 8: Discussion

Human populations display a variety of phenotypic features including differences in skin colour and overall shape and size. These features have been studied for centuries by generations of researchers in order to better understand the evolution of the species *Homo sapiens* (Bogin, 1999). Early studies made use of stature and limb proportions in order to organize individuals into biologically distinct groups. However, the expression of certain features appears to be significantly related to adaptation to the environment rather than being an indication of separate biological groups. Human body proportions vary greatly in living populations as well as in fossil hominids with well demonstrated clines (Eveleth and Tanner, 1976; Ruff, 1994, 2000).

Understanding the changes that are continuously taking place in the human body will not only assist in providing physiological explanations of certain phenomena (i.e., thermoregulation), but will also assist in offering information on genetics, nutrition and socio-economic status (SES) of population groups. It will also aid in design (ergonomics) and have several medical implications. Differential limb proportions between ancestral groups may be maintained regardless of the environment due to genetic influences (Hamill *et al.*, 1973; Martorell, *et al.*, 1988). Also, based on information from nutrition studies, negative or absent secular trends should be observed in countries and individuals of lower SES while the opposite is true in high SES populations (Bailey, 1970; Goldstein 1971; Rea, 1971; Davie et. al., 1972; Cook *et al.*, 1973; Eveleth and Tanner, 1976; Bogin and MacVean, 1978, 1981 and 1984; Tobias and Netscher, 1977; Wolanski, 1978; Roche, 1979; Fogel *et al.*, 1983; Tobias, 1985; Price *et al.*, 1987; Henneberg and van der Berg, 1990; Tobias, 1990; Louw and Henneberg, 1997). There are thus a multitude of factors that play a role in the overall body size and shape of populations and these sizes and shapes are not constant.

It should be taken into account that any changes usually occur gradually over time. For this reason, the current study looked at secular change, starting at individuals born from 1900, and ancestry differences in shape and size related to limb proportions and stature between population groups in South Africa. In addition, the South African population groups were compared to groups from Europe and North America in order to determine whether differences exist between individuals in the southern hemisphere and the northern hemisphere.

This study made use of a combination of anthropometric and osteometric data. Due to a lack of osteometric remains from individuals born after the 1980's, anthropometric data were used to represent the current changes taking place in South Africa. Additionally, the anthropometric data comprised of larger sample sizes which were limited in the osteometric data. Therefore, any secular changes or ancestry differences may be more clearly visible in the anthropometric sample. However, the osteometric data provided information on differences between groups at the turn of the century.

8.1 Ancestry differences and secular trends in the anthropometric and osteometric stature of South African population groups

Significant differences were observed in the overall mean stature (osteometric and anthropometric) between South African population groups with white South African groups consistently having statistically significant taller statures than black South African groups (Tables 4.1, 4.2, 6.1 and 6.2). As expected, males were taller than females (Figure 4.5). In this aspect the results of this study are similar to those obtained by Henneberg and van der Berg (1990) and Steyn and Smith (2007) for South African groups (Table 8.1), who also reported taller stature for whites. The mean statures of SAWM, SABM, SABF and SAWF reported in the current study were slightly taller than those of Steyn and Smith (2007) even though this study also made use of Ergotech data. A possible reason for this is that the current study made use of a larger sample size with additional data collected between 1993 and 2013. Furthermore, mean stature of SAWM in the current sample were shorter than those of Henneberg and van der Berg (1997). This is possibly due to the fact that they made use of medical students who could have been of higher SES (Steyn and Smith, 2007) or otherwise possible increases in stature during the last two decades may have altered the mean statures. The current female statures are higher than those reported by Henneberg and van der Berg which may also indicate a slight secular increase.

Table 8.1 Mean statures of South African population groups as reported in various studies.

Group	Current study		Henneberg and van der Berg (1990)		Steyn and Smith (2007)	
	n	**Mean**	**n**	**Mean**	**n**	**Mean**
SAWM	715	1786.1	86	1793	288	1784.5
SABM	2668	1711.9		-	1208	1710.1
SAWF	895	1661.5	63	1649	592	1660.8
SABF	1881	1598.1		-	844	1596.0

Population groups from the North-west fringe of Europe (e.g. the Netherlands) are said to be the tallest individuals in the world (Eveleth and Tanner, 1976). White South Africans have a considerate amount of Dutch ancestry which may account for the higher statures seen in this group (Steyn and Iscan, 1998; Bogin, 1999; L'Abbe et al., 2011). However, black South Africans arose from Bantu-speaking individuals with gene flow from Khoesan groups (Herbert, 1990; Greef, 2007; Stynder, 2009). The Khoesan is one of the shortest population groups in the world which may thus have contributed to the shorter statures observed in black South African groups (Eveleth and Tanner, 1976; Herbert, 1990; Stynder, 2009). Also, the extreme political pressures on black South African groups may have resulted in a chronic situation of poor nutrition, education and low levels of health. This in turn may have caused a lack of positive secular trends resulting on overall shorter statures with time (Price et al., 1987).

Minimal secular increases in the statures of all South African groups were observed and the socio-economic status (SES) of the sample may have played a role. The sample comprised of individuals representing lower to middleclass South Africans. For example, the osteometric data of black South Africans mostly consist of unclaimed or donated bodies from poorer South African groups. Individuals from more affluent South Africans (e.g. medical students as used in the Henneberg and van der Berg (1990) study) may have marked higher mean statures and thus positive secular trends as opposed to those represented by the current sample. Also, the small sample sizes of certain groups in the osteometric data may have resulted in inaccurate representations of the statures in South Africa. For example, the skeletal collections in South Africa have limited female specimens and the female samples are biased toward older individuals which could not be used for this study. Therefore, some birth cohorts had only one or five individuals which make the analyses of secular trends during these periods impossible.

The osteometric data indicates no statistically significant secular trends in the stature of any of the groups. However, slight (non-significant) increases were observed in the TSH of SAWM, SABM and SABF while a slight (non-significant) decrease was observed in SAWF. However, the osteometric sample size of SAWF was very small which may have resulted in an inaccurate representation of the true secular trend. Similarly, slight (non-signficant) overall increases were observed in the anthropometric stature of SAWM, SAWF and SABM. However, only black males exhibited a statistically significant positive trend over the whole period. Henneberg and van der Berg (1990) observed a gradual increase in the stature of both black and white South African males at a rate of 4.5 mm/decade for white males and 2.4 mm/decade in black males between 1880 and 1970. However, the current study observed that although the stature initially decreased in SABM, the rate of increase gradually became larger over time, especially during the last two decades with increases of 6.7 mm in the 1980's and up to 10.6 mm in the 1990's. This indicates that a greater positive secular trend is observed in SABM from the 1980's than between 1880 and 1970. Similar to what was found by Henneberg and van der Berg (1990) and Louw and Henneberg (1997), the stature of SAWM remained unchanged with small non-directional fluctuations and a slow overall positive rate of 2.1 mm to 7.3 mm per decade between 1941 and 1990. The statures of SAWF and SABF also exhibited non-directional fluctuations with a slight overall increase over the combined birth cohorts.

The significant positive secular trend in SABM and slight (non-significant) increases in the stature of SABF is a relatively recent phenomenon. Tobias (1990) observed no secular trends between the stature of black South African groups born in 1910 – 1914 and those born in 1945 to 1954. The current study observed no significant secular trends in the TSH of SABM, with non-directional fluctuations observed for the 1900's to 1970's. However, a large increase of 40.8 mm was observed in the 1980's. From the anthropometric data it would appear than this increase continued into the 1990's. A gradual increase was also observed in SABF during this period with 5.1 mm and 3.0 mm in the 1960's and 1970's, respectively. This increase in the stature of black South African groups during the later part of the 20th century is possibly due to improved living conditions compared to the latter part of the 19th century and early 20th century (Price et al., 1987, Henneberg, 2001a, 2001b). Numerous studies of groups with low SES such as those conducted in India (Vogel 1971), Peru (Frisancho et al., 1975), Guatemala (Bogin and MacVean, 1984), Mexico (Malina et al., 1980, 1983), Malawi, Kenya, Uganda, Angola, South Africa and South West Africa/Namibia (Kark, 1954; Shaper and Saxton, 1969; Shaper et al., 1969; Burgess and Wheeler, 1970;

Tobias, 1975a, 1975b, 1986) have recorded evidence of negative secular trends which were attributed to lower SES and poor nutrition. Furthermore, poor nutrition during growth in the 18th century and World War II (WWII) resulted in a "catch-up" growth with stronger positive secular trends only observed from the mid-19th century onwards (Komlos, 1985; Floud et al., 1990, Hauspie et al., 1996; Cole, 2003). Third world countries or countries with civil unrest often exhibit negative or null secular trends in stature even in population groups with similar SES (Bogin and Keep, 1998). This indicates that there may have been a slight improvement in the SES of black South Africans after the 1940's compared to before the 1900's, but this has not had a considerable influence on their stature.

The lack of a significant positive secular trend in white South African groups could suggest that, even with the implementation of Apartheid, the poor economic and social development in South Africa resulted in shorter statures in white South African groups than expected. According to numerous researchers (Cavalli-Sforza and Bodmer, 1971; Mueller, 1976; Roberts et al., 1978), 56% to 99% of the variance in stature is due to heritability while less than a quarter is due to environmental influences (Bielicki et al., 1981; Jedlinska, 1985; Henneberg and van der Berg, 1990). However, the increase in stature is significantly less than that of Dutch groups (Louw and Henneberg, 1997; Bogin 1999; Henneberg, 2001a, 2001b) or other European counties (e.g. Eveleth and Tanner, 1976; Meadows and Jantz, 1995; Bogin, 1999; Cole, 2003; Federico, 2003; Komlos and Baur, 2004; Komlos and Lauderdale, 2007; Komlos, 2009; Steckel 2009; Bogin and Varela-Silva, 2010; Staub et al., 2011) with whom there is a significant genetic relationship, which elucidates the effect of factors other than heredity.

Comparisons of the stature throughout most of the 20th century of South African population groups with European means provide evidence of the impeded secular trends in white South African stature. From 1946 to 1955, thus following WWII, SAWM had statures that were similar to Dutch individuals. However, the Dutch conscripts exhibited a strong positive secular trend from the 1940's while a non-significant increase was observed in SAWM during this period. Dutch individuals became much taller over time until 1980 when they were significantly taller than SAWM.

Swiss males, who were significantly shorter than Dutch and South African males during WWII, exhibited a strong positive secular trend from 1946 to 1980 (Figure 4.10). Due to the lack of secular trend in the stature of SAWM, the difference between the statures of SAWM and Swiss males became smaller over time. The stature of Swiss males increased until no significant differences were observed between SAWM and Swiss males from 1981 to

1995. However, a "genetic plateau" or generically determined ceiling is visible in Swiss males during this period with the increase in stature becoming more gradual. This plateau has been observed in Europe (Schmidt et al., 1995; Larnkjaer et al., 2006; Staub et al., 2011) and North America (Komlos and Baur, 2004; Komlos and Lauderdale, 2007). Usually the direction and rate of secular trends of population groups should correspond with the standard of living with rapid increases seen in countries with increased average income. However, once the upper limit of the genetic potential for stature is reached, population groups will no greater exhibit marked secular trends (Staub et al., 2011). It is unlikely that the lack of secular trends in the white South African population groups is due to this genetic plateau being reached as the SAWM are significantly shorter than the Dutch group with whom many share a common ancestral gene pool (Price et al., 1987; Louw and Henneberg, 1997; Henneberg, 2001a, 2001b). Therefore, the stature of white South African groups may possibly increase in the future with increased standards of living.

Further comparisons of South African population groups with those from North America indicate the influence of both heritability and environment. The result from the comparisons between South African statures and North American cadaver heights indicated that SAWM are significantly taller than NAWM. Again, the possible reason for the taller stature in SAWM is due to the common Dutch gene pool. However, NABM were significantly taller than SABM. A combination of various factors may be responsible for the taller statures of NABM including a different genetic origin, better SES than SABM during Apartheid as well as increased gene flow from white North American groups and Native Americans (Parra et al., 1998). Changes in mating practises resulting in increased gene flow may have led to a greater degree of heterosis within North American groups compared to South African groups (Wolanski, 1978; Henneberg and van der Berg, 1990; Henneberg, 2001a, 2001b). Although white South Africans did have some admixture with European migrants and with native groups, the rate was much lower than that of North American groups which may account for the smaller stature in SABM. Another possible reason for the higher statures in NABM could be the selective agents acting (e.g. selection of taller, more robust individuals) on the particular population group during the African slave trade. The comparisons of anthropometric means between South African population groups and current living means of North American groups also indicate that SABM and SABF are the shortest of the groups, whereas SAWM and SAWF were significantly taller than their North American counterparts. White South African groups were also significantly taller than their black South African counterparts while the NAWM and NAWF were only slightly taller than their black North American counterparts. Fulwood et al. (1981) observed that the average stature between North American black and white groups did not differ significantly if factors such as income, education and urban and rural residence are controlled for. Numerous genetic studies, making use of markers found in individuals of European descent which is absent in African individuals, have estimated that approximately 1/5 to 1/4 of the genes in black North Americans are of European origin (Reed, 1969; Parra et al., 1998, 2001). This again suggests a greater lack of heterozygosity in the South African population compared to North American groups.

The significant positive secular trend in SABM is a relatively current phenomenon. It may be possible that the standard of living in black South African groups has increased slightly from the 1900's. However, at this stage it is not clear why SABM exhibit a significant positive secular trend under relatively lower SES while SAWM are merely exhibiting a gradual increase in stature. This may suggest an overall greater influence of genetics on stature than environmental influences.

Eveleth and Tanner (1976) observed that individuals of African descent in the United States are taller and mature faster at all ages than children of European descent even if they had a lower SES. Garn et al. (1973) also observed that black children were taller than white children even if they were of lower SES while Steckel (1987) observed that slaves in the United States during the 19th century exhibited little evidence of reduced stature. Thus, it may be possible that the genetic inclination towards an increase in stature in SABM is greater than in SAWM. Also, SABM may be more resistant to environmental stresses than SAWM.

Many researchers have also noted that males are more sensitive to environmental stresses than females (Greulich, 1951; Tanner, 1962; Stini, 1972, 1979; Tobias, 1972; Wolanski and Kasprzak, 1976; Stinson, 1985) which explains why several studies revealed greater levels of secular trends in males (Shapiro, 1939; Acheson and Fowler, 1964; Froelich, 1970; Bielicki and Charzewski, 1977) relative to females with improved conditions. The current study indicates that female stature exhibited no significant improvement in the last century. While SABM and SABF were subjected to similar socio-economic stresses, only the males showed a significant increase in stature. This indicates the possible greater resistance to environmental stresses in black females compared to black males.

In conclusion, white South African groups are taller than their black South African counterparts due to differences in ancestry. Overall, all South African population groups exhibited a slight (non-significant) overall increase in stature except for SABM that exhibited a significant positive secular trend. However, the increase in stature in SABM is a recent phenomenon which no trends observed before the 1940's. Also, a positive trend is observed in SABM while no significant trend is observed in SAWM despite the possible higher SES of SAWM. This indicates possible improvements in the standard of living in SABM as well as possible greater resistance to environmental stresses compared to SAWM. Furthermore, secular trends in SAWM are significantly slower than those observed in European males.

8.2 Ancestry differences and secular trends in the anthropometric and osteometric limb proportions of South African population groups

In this section the ancestry differences in limb lengths and proportions between individuals of African and European descent will be discussed. The secular changes that are taking place in the limb proportions will also be discussed to provide information on the possible differences or similarities in trends between ancestry groups in South Africa in relation to what is happening in North America.

8.2.1 Ancestry differences in limb lengths

Similar to what was found in other studies (Krogman, 1970; Hamill et al., 1973; Trotter and Gleser, 1952; Meadows and Jantz, 1995; Holliday and Falsetti, 1999; Bogin and Varela-Silva, 2010), the limb proportions in South African population groups exhibited distinct ancestry differences. These ancestry differences were observed in both the anthropometric and osteometric data. However, small differences were seen between the two samples.

All anthropometric absolute limb lengths were greater in SAWM than SABM while the osteometric maximum radius and ulna lengths were greater in SABM. Thus, SABM had greater forearm lengths despite having smaller statures than SAWM. SAWF also had greater absolute limb lengths except for the anthropometric forearm length and the osteometric radius and ulna maximum lengths which were significantly greater in SABF. This indicates that, due to the taller statures in white South African groups, greater absolute lower limb lengths are observed in white South African groups compared to the black South African groups. However, regardless of the smaller relative size of black South African groups, they still exhibited greater forearm lengths.

The greater forearm lengths in groups of African ancestry correspond with the results from North American groups. Meadows and Jantz (1999) observed that black North American males and females have consistently greater forearm lengths than white North American groups. However, unlike what was observed by Meadows and Jantz, the femur length was greater in white South African groups as opposed to the black South African groups. This is possibly due to the greater difference in overall stature between black and white South African groups, while smaller differences are observed in the stature of North American groups (Garn et al., 1973). Thus, white South African groups have greater limbs due to their larger absolute size. In order to study the differences in the relative limb length between groups, the effect of size has to be eliminated by making use of ratios.

8.2.2 Ancestry differences in limb proportions

Overall, SABM and SABF had greater upper limb lengths and lower limb lengths relative to stature than SAWM and SAWF, respectively (Figures 5.1, 5.6, 5.16, 5.21, 7.1, 7.7, 7.19 and 7.25). This supports the genral notion of greater limbs in people who originated from warmer climates. Furthermore, black South African groups had greater forearm lengths relative to stature than their corresponding white South African groups. Thus, distinct ancestry differences exist in the upper limb and lower limb ratios.

However, differences are also observed in the proximal limb segments of the upper and lower limbs between groups. No significant difference was observed in the arm lengths between groups except for the anthropometric arm ratio which was higher in SABF than in SAWF. In the lower limb, the thigh lengths relative to stature were greater in black South African groups than in white South African groups. This indicates that the greater lower limb lengths relative to stature are due to both greater proximal and leg lengths.

Higher brachial indices as well as higher osteometric crural indices were observed in black South African groups which indicate significantly greater distal limb lengths relative to proximal limb lengths compared to white South African groups. Therefore, even though SABM and SAWM had similar arm ratios and SABF had higher arm ratios than SAWF, the forearm lengths had a greater contribution to upper limb length in the black South African groups.

No significant difference was observed in the anthropometric crural index of males while higher crural indices were observed in SAWF. This indicates that the leg length relative to thigh length did not differ between males while SAWF had greater leg lengths relative to thigh lengths than SABF. This difference between the anthropometric data and osteometric data may possibly be due to the higher SES of individuals in anthropometric sample resulting in periods of "catch up" grow which my alter the pattern of ancestry differences (i.e. greater limb lengths relative to stature and greater distal limb lengths relative to proximal limb lengths in black South African groups compared to white South African groups). For example, the anthropometric upper limb ratios of SABF indicate a period of significant fluctuations (Table 5.5). The arm lengths relative to stature were slightly higher in SAWF from 1940's to the 1960's after which SABF had greater arm lengths to stature. Also, the forearm length relative to the arm length did not differ significantly during the 1980's which indicates that a recent change took place where the arm length increased at a much faster rate than the forearm length. This is clearly demonstrated by the higher arm ratio during the 1970's and 1980's in SABF compared to SAWF.

The intermembral index of both male and females groups exhibited no ancestry differences indicating that the ratios of the arm lengths relative to the lower limb lengths are similar between groups (Figures 5.12, 5.27, 7.15 and 7.33). Thus, although black individuals have greater arm and lower limb lengths relative to stature than white groups, the ratios between the upper and lower limb between the two groups are similar.

The sitting height ratio also exhibited a significant difference between ancestry groups (Figures 5.14, 5.29, 7.17 and 7.35). Overall, white South Africans had higher sitting heights relative to stature than their corresponding black South African groups while females had slightly higher sitting height ratios than males. This indicates that the lower limb lengths have a greater contribution to stature in males than in females as well as in black South African groups compared to white South African groups (i.e. greater lower limbs relative to stature).

Numerous studies have observed similar limb proportion differences between individuals of European and African descent as observed in the current study. Krogman (1970) observed that at the same height, individuals of African descent exhibited greater extremities with shorter trunks than individuals of European decent. This was especially evident in the greater distal extremities relative to stature which were also observed in the South African sample. Numerous factors have been suggested for this difference in limb proportions between the groups. However, it would appear that when individuals share a common environment, even with interbreeding taking place, significant limb proportion diffrences are still observed (Holliday and Falsetti, 1999). In the current study, white South Africans exhibited limb proportions which were more similar to those of individuals from Europe or colder environments. Black South Africans exhibited typical limb proportions of individuals descendent from warm, tropical environments. These differences between the groups indicate the applicability of Allen's rules as well as the heritability of certain limb proportions.

However, some exceptions to the rule are visible in the South African sample. For example, there is lack of a significant difference in the anthropometric crural index between SAWM and SABM while a significant difference is still observed in the brachial index. The possible reason for this difference in the lower limb proportions may be related to secular trends taking place in South Africa. According to Meadows and Jantz (1995), the upper limb bones are almost isometric with stature while the lower limb bones are positively allometric with stature. This means that greater proportional variation is observed in the lower limbs, especially the leg, than in the upper limb.

The main disadvantage of making use of ratios to examine differences in limb proportions between groups is that it is not possible to discern whether it is the numerator or the denominator which is responsible for the change (Eveleth and Tanner, 1976). By also observing the secular trends in each of the limb proportions the differences between the groups can be observed.

8.2.3 Secular changes in South African limb proportions

Secular changes in the upper limb proportions

Due to the overall small sample size of the osteometric data with a lack of adequate samples in each birth cohort, no secular trends were observed in the osteometric sample. Therefore, only the secular trends observed in the anthropometric data will be discussed. Although distinct ancestry differences were observed in the limb proportions between the ancestry groups, secular trends indicated an overall trend toward similar limb proportions with similar changes taking place in both groups

Secular trends in the upper limb proportions of SABM revealed a general increase in the upper limb lengths relative to the stature with an increase in the arm lengths and a decrease in the forearm lengths relative to stature. This indicates that the arm lengths are increasing at a faster rate than the decrease in the forearm lengths resulting in an overall increase in the upper limb length. This is confirmed by the decrease in the brachial index where the forearm lengths are decreasing relative to the arm length.

In SAWM, no significant changes were observed in the upper limb lengths and forearm lengths relative to stature. However, there was an increase in the arm lengths relative to stature with an associated decrease in the brachial index. This indicates that the forearm lengths remained unchanged while the arm lengths increased resulting in lower brachial indices. However, the changes in the arm lengths were not to such an extent that the total upper limb length is changing. Overall, a positive trend is seen in the upper limb lengths of SABM which is possibly due to a continued trend towards adaptation to the warm climate in South Africa. Although distinct ancestry differences are still visible, the arm lengths of both SAWM and SABM are increasing while the forearm lengths relative to stature is decreasing only in SABM (Figures 5.33 and 5.34). This indicates a trend where some of the limb proportions of SABM and SAWM are becoming more similar, possibly in response to environmental conditions although the exact mechanism / reason for this is not clear.

In females, mixed pattern are observed. SABF exhibited no significant change in the upper limb lengths relative to stature, while the arm lengths are increasing and the forearm lengths relative to stature are decreasing with an associated decrease in the brachial indices. SAWF exhibited an increase in the upper limb lengths with an increase in the arm lengths and forearm lengths relative to stature with the brachial index remaining unchanged. However, in the 1980's no difference was observed in the brachial index between SABF and SAWF. This is possibly due to a larger increase in the arm than the decrease in the forearm of SABF. During the 1940's to 1960's, SAWF had slightly (non-significant) greater arm lengths relative to stature than SABF but during the 1970's and 1980's SABF had significantly greater arm lengths relative to stature. This indicates that the arm proportions of SABF and SAWF are changing to become more similar (Figures 5.31, 5.32 and 5.34).

The result for the upper limb proportions differ distinctly from those observed by Meadows and Jantz (1999) in white and black North American groups. They observed a decrease in the relative humerus lengths in males while it remained unchanged in females. They also observed a decrease in the relative ulna lengths in black females but not in any of the other North American groups. In contrast, the current study observed increases in the arm lengths over time in both males and females as well as a decrease in the forearm lengths in all groups. The reason for this difference is not clear and requires further study. However, it is possible that these changes reflect adaptation to different or changing use of the upper limbs.

Secular trends in lower limb proportions

In SABM an increase in the lower limb lengths relative to stature was seen. Also, the thigh length increased while the leg lengths relative to stature decreased with a corresponding decrease in the crural index. This indicates that the increase in lower limb length is due to the greater increase in the thigh lengths with a slower decrease in the distal length lengths. In SAWM the lower limb lengths increased relative to stature but the total lower limb lengths remained unchanged indicating a small decrease of talo-calcaneal height over time while the rest of the lower limb became greater (Figures 5.8 and 5.9). Similar to SABM, the thigh lengths increased while the leg lengths relative to stature decreased in SAWM. This indicates a rapid increase in the thigh lengths with a slower decrease in the leg lengths. This was also demonstrated by the decrease in the leg length relative to the thigh lengths in SAWM. However, the overall increase in stature of SABM indicates that the increase in the lower limb lengths are much greater compared to SAWM.

South African females exhibited more complex secular trends in the lower limbs than males. In SABF the trend was similar to what was seen in the males with an increase in the lower limb lengths relative to stature with an overall increase in the thigh lengths and a decrease in the leg lengths relative to stature. This indicates that the thigh lengths increased at a faster rate than the decrease in the leg lengths (Figure 5.38 and 5.39). However, the increase in the lower limb lengths was only observed from the 1980's onwards. During the 1960's and 1970's, the lower limb length decreased due to a large decrease in the thigh ratio and a small decrease in the leg ratio (with a small increase observed in the 1950's to 1960's) resulting in an increase in the crural index. From the 1980's the crural index decreased with the rapid increase in the thigh lengths relative to the small decrease in the leg lengths with an overall increase in lower limb lengths (Figure 5.35). In SAWF a more stable pattern was observed. The lower limb lengths and thigh lengths relative to stature remained unchanged (slight non-significant increase) with a decrease in the leg lengths relative to stature (Figures 5.36 and 5.37). This is also demonstrated by the decrease in the crural index due to the decrease in the leg lengths relative to the thigh lengths. However, the slight (non-significant) increase in the thigh ratios with the small decrease in the leg ratio did not result in a significant change in the lower limb lengths. Therefore, the reverse pattern where SAWF had greater leg lengths relative to thigh lengths compared to SABF is due to the rapid increase observed in the thigh lengths relative to stature in combination with the rapid decrease in the leg lengths of SABF in the 1980's. In both female groups the thigh lengths relative to stature is increasing while the leg lengths are decreasing, however the trend is much more rapid in

SABF after the 1980’s. Again, the patterns indicate a tendency for the ancestral groups to move toward a similar point, possibly as a result of the same environmental pressures or improved living standards of living in SABF (Figure 5.39).

Meadows and Jantz (1999) only observed changes in the relative femur lengths of black North American females while changes were observed in the relative tibia and fibula lengths of males but not in females. However, in contrast to what was reported for North Americans, the thigh lengths of all groups in the current study were increasing while the leg lengths were decreasing. Meadows and Jantz also observed that the leg lengths between white and black North American females overlapped at times which was also observed in the current study when the leg lengths of all South Africa females were becoming similar (albeit only in the 1980’s).

Secular trends in the intermembral index

The intermembral index, which represents the ratio of the upper limbs to the lower limbs, is an important indicator to assess whether changes are occurring more rapidly in the upper limb or the lower limbs. In SABM, the index decreased indicating that the increase in limb lengths are occurring more rapidly in the lower limb compared to the upper limbs. This is as expected, with the overall increase in stature seen in the SABM. No change was observed in the intermembral index of SAWM and SAWF which indicates an equal increase in both upper and lower limbs. This is reflected by the lack of an increase in stature in white South African groups resulting in lower limbs that are increasing no faster than the increase in the upper limbs. However, in SABF the intermembral index increased from the 1940’s to 1960’s and then decreased from the 1970’s. This indicates that the changes in the lower limb were slower than in the upper limb from the 1940’s to the 1960’s and then increased more rapidly from the 1970’s. This is especially clear by the rapid increase observed in the thigh lengths relative to stature during the 1980’s. Therefore, the lower limb lengths of black South African groups increased at a faster rate than the upper limbs while white South African groups exhibited equal rates of increase between the lower and upper limbs.

Secular trends in the sitting height ratio

The sitting height indicates how the lower limbs change relative to the trunk. In both SAWM and SABM, the sitting height ratio decreased indicating that the lower limb lengths increased more rapidly than the trunk. Since a significant stature increase is only observed in SABM, this indicates that the majority of the stature increase is due to the increase in lower limb lengths. The sitting height of SAWM possibly decreased slightly during this time as the stature remained unchanged while the lower limb lengths increased. The sitting height ratio of females demonstrates the fluctuations observed in the lower limb lengths of South African females. The sitting height ratio of SAWF increased indicating that the sitting height contributed more to stature over time than the lower limb lengths (i.e. the trunk increased at a faster rate than the lower limbs). However, in SABF the sitting height ratio increased during the 1940's to 1960's but then decreased from the 1970's. This indicates that, while initially the sitting height contributed more to stature, the rapid increase in the lower limb lengths from the 1970's resulted in a smaller contribution from the sitting height.

8.2.4 Comparisons of secular trends in limb proportions between South African and North American population groups

Compared to other studies on secular trends in limb proportions (e.g., Eveleth and Tanner, 1976; Tanner et al., 1982; Bolzan et al., 1993; Meadows and Jantz, 1995, 1999; Katzmarzyk and Leonard, 1998; Bogin, 1999; Bogin and Varela-Silva, 2010), South African populations exhibited unique trends. According to various researchers there is a general tendency towards an increase in lower limb lengths and stature with improvement of SES (Eveleth and Tanner, 1976). However, in South Africa, the lower limb lengths seem to be increasing in groups of lower SES (SABM and SABF), but to a lesser extent in groups with higher SES (SAWM and SAWF).

Factors such as SES, nutrition and urbanization may result in smaller lower limb lengths over time (Bogin, 1999; Bogin and Varela-Silva, 2010). Also, improvements in living standards will result in increased lower limb lengths relative to stature. In the South African population increases in the limb lengths were observed in both white and black groups, although the rates were more variable. The upper limb lengths of SAWM and SABF and the lower limb lengths in SAWF did not increase in length. Furthermore, in all groups the leg length relative to the stature decreased while the forearm ratio increased in SAWF and remained unchanged in SAWM. Meadows and Jantz (1999) observed that the changes in the upper limbs are smaller (isometric) than in the lower limb, however distinct changes in both upper and lower limb were taking place in South Africans. Furthermore, unlike what was reported by Meadows and Jantz (1995, 1999), the distal limb proportions changed at a much slower rate than the proximal limb proportions in the South African groups.

Although the groups were of different SES during the Apartheid era, and maybe to some extent still are, it would appear that the overall trend favours an increase in the limb proportions with greater proximal lengths relative to distal lengths. It appears if the limb proportions of South African groups are changing with white South Africans taking on more tropical/heat-related features (greater limb lengths relative to stature or lower sitting height ratios) while black South Africans are exhibiting smaller forearm lengths relative to stature. Thus, the change in the limb proportions seems to be less influenced by the SES of the individuals but rather other factors specific to South Africa. This is clearly demonstrated by the differences observed in the limb proportions between white groups from North America to those in South Africa.

Differences in osteometric limb proportions between South African and North American population groups

Distinct differences were observed in the limb proportions of white North American males and females and white South African males and females. Overall, NAWM had significantly smaller upper limb lengths and arm lengths relative to stature than SAWM while SAWM had slightly (non-significant) greater forearm lengths relative to stature. However, NAWM had significantly greater forearm lengths relative to arm lengths than SAWM. This is possibly due to the rapid increase in the arm lengths relative to stature observed in SAWM while the forearm lengths remained unchanged. A similar pattern is observed in NAWF and SAWF although the SAWF are exhibiting an increase in upper limb lengths due to an increase in the proximal and distal elements. The lower limb lengths and thigh lengths of SAWM are greater relative to stature than in NAWM with slightly (non-significant) leg lengths relative to stature. However, NAWM had greater leg lengths relative to thigh lengths. No differences were observed in the lower limb lengths of females or in the intermembral indices. However, the sitting height indicated that the lower limb lengths contributed more to stature in SAWM than in NAWM. In females the same phenomenon was observed but it was not significant.

These patterns clearly illustrate the changes that are occurring in white South Africans. Again, it would appear that white South Africans, especially males, are exhibiting limb proportions which are more similar to greater limbs in black South Africans. The greater leg lengths in NAWM are possibly due to differences in SES rather than ancestry (Meadow and Jantz, 1995). Overall, like black South African groups, white South Africans are getting greater limbs with smaller distal limb lengths which are observed in the negative secular trend in the crural index of all four groups. Thus, it would seem that factors other than SES and nutrition play a role in the secular trends observed in South African population groups as the secular trends in all groups are following a similar direction regardless of socio-economic standing. This is especially true for the significant increase in stature observed in SABM as well as the greater rates of secular trends observed in the thigh lengths of black South Africans. Therefore, as postulated by Henneberg and van der Berg (1990) and Henneberg (2001a, 2001b) and confirmed by Louw and Henneberg (1997), the changes in South Africa seem to be specific to the country/region rather than a response to improvement of SES.

8.3 The implication of secular changes in stature and limb proportions on stature estimations in South Africa

The differences and secular changes in limb proportions have important implications for the estimation of stature using regression formulae. Feldesman et al. (1990) suggested the use of the femur stature ratio to estimate stature in individuals of unknown ancestry. However, Feldsman and Fountain (1996) later observed distinct differences between ancestral groups. The current study also revealed significant differences in the thigh ratio indicating that the femur:stature ratio cannot be applied to estimate stature in individuals of unknown ancestry. The femur stature ratio of South African population groups differed from the observed value of 3.74 (Sjovold 2000). According to Feldesman and Fountain (1996), the femur length constitutes approximately 26.75% of the stature across all ancestry groups and 27.13% in individuals of African descent and 26.48% in individuals of European decent. However, as seen in Table 8.2, the values of South African groups are distinctly higher (29 to 30%). Furthermore, the value of SABM (30.09%) and SABF (30.18%) in the current study is also higher than the SABM (27.48%) and SABF (27.47%) measured by Lundy (1984). This probably reflects the secular trends that are taking place in the limb proportions of South African groups. As already discussed, a very high rate of increase is observed in the thigh ratio of South African groups indicating that the thigh lengths are increasing at a faster rate than the overall stature. Although the ratios are very similar, black South Africans still have slightly higher ratios than white South Africans. Therefore, the ancestry differences and secular trends in limb proportions need to be considered before making use of the femure:stature ratio to estimate stature. From the current study, it would appear that the humerus:stature ratio (21.03% – 21.43% across all groups) may provide less population variation when estimating stature if the ancestry of the individuals is unknown.

Table 8.2 The ratios of limb proportions to stature in South African population groups

Group	Humerus:Stature		Radius:Stature		Ulna:Stature	
	Ratio	Percentage	Ratio	Percentage	Ratio	Percentage
SAWM	4.67	21.43%	6.24	16.04	5.80	17.24
SABM	4.72	21.22%	5.93	16.90	5.55	18.06
SAWF	4.73	21.15%	6.52	15.36	6.07	16.49
SABF	4.77	21.03%	6.12	16.37	5.67	17.68
Group	Femur:Stature		Tibia:Stature		Fibula:Stature	
	Ratio	Percentage	Ratio	Percentage	Ratio	Percentage
SAWM	3.34	29.96	4.07	24.62	4.12	24.29
SABM	3.33	30.09	3.91	25.59	4.34	24.77
SAWF	3.39	29.54	4.14	24.19	4.20	23.81
SABF	3.32	30.18	3.95	25.37	4.05	24.76

Meadows and Jantz (1995) suggested the use of the upper limb lengths as they are isometric with stature. However, the limb proportions in South Africa exhibited definite secular trends in the upper limb which makes the use of outdated regression formulae inappropriate. Although the osteometric arm ratio exhibited no significant differences between SAWM and SABM, the small sample sizes require that additional research is done to confirm the validity of using the humerus to estimate stature in unknown male individuals. Furthermore, Meadows and Jantz (1995) suggested making use of the femur rather than the tibia to estimate stature if needed. In contrast, the proximal limbs may be changing at a faster rate than the distal limb proportions in South Africa. This may suggest that making use of the distal limb bones may more appropriate for stature estimation when ancestry specific formulae are available. Caution should be applied when making use of regression formulae from single long bones to estimate stature. As shown, significant secular changes are taking place in almost all the limbs of South African population groups with very rapid changes observed in SABM and SABF especially after the 1980's. For example, making use of the distal limb bones, which are exhibiting a negative secular trend, may result in an underestimation of stature. Similarly, using the proximal limb lengths, which are increasing, may lead to an over-estimation of stature. Thus, the regression formulae need to be frequently updated in order to keep track of these changes and to ensure accurate stature estimations.

8.4 Limitations of the study and future recommendations

The limitations of this study are mostly attributed to the small sample sizes and lack of comparative information, especially for the osteometric data. No data were available for comparisons with limb proportions of black North American or any European samples. This study therefore provided unique data that can in future be used by other researchers from other regions for comparative purposes.

Another drawback is a lack of anthropometric data before 1940 and the lack of osteometric samples of individuals born after 1990. Although the patterns between the osteometric and anthropometric data could be compared, no direct comparisons could be made due to the effect of soft tissue. Furthermore, anthropometric measurements were only collected from the right side of the body and the effect of handedness could not be evaluated.

Also, overall, there was a lack of female specimens for the osteometric data due to a bias in the osteometric collections with more males than females. A limited number of younger females were available but the remains were not always complete making the estimation of TSH impossible. The drawback of using military conscripts to analyse secular trends is that female data are often not available. In the current study osteological female data were limited; however the anthropometric data consisted of large samples of both males and females. This thus also allowed for the analysis of changes occurring in South African females, which is not common in the literature and provided valuable insight.

Due to sample size constraints of individuals in each birth cohort, the effect of age was not taken into consideration. However, the sample comprised of individuals across the whole age range representing the stature of most adult individuals in South Africa. Future research will need to make use of larger sample sizes, also incorporating age correction factors. Additionally, secular trend data from other countries need to be collected and compared to South African population groups to better understand the secular trends occurring in limb proportions. Also, continued research is required in order to follow the secular changes that are taking place. Although studies have indicated that changes in stature and limb lengths may be a sensitive indicator of changes in SES, the current study revealed that factors other than SES may be involved. The increases in SABM and the recent increases in the thigh lengths of SABF suggest improved living conditions. The Gini-index (measurement of extent to which the distribution of income within an economy deviates from a perfectly equal distribution) could be used to evaluate the influence of SES. Unfortunately, information on the SES of individuals in the anthropometric sample is not available and data regarding the average income between black and white South Africans are not currently available. Thus, more research is required using individuals of similar SES to identify other possible factors which may be responsible for these trends.

Further research will be undertaken to determine whether the current limb proportion differences can be used to estimate sex and/or ancestry. The preliminary results for the use of ratios to estimate the sex and ancestry of individuals seem promising. However, additional measurements need to be collected to ensure large enough sample sizes to increase the overall accuracy of this method. Also, new regression formulae will have to be created in order to take the secular trends into account for more accurate estimation of stature. Finally, further research will be undertaken to determine whether sex differences exist between the groups since the changes in SABF appear to be a more recent phenomenon. Thus, the effects of sexual dimorphism in secular trends need to be investigated to determine whether differences in SES have a greater or lesser influence on a specific group.

Knowledge of secular changes in South African population groups is not only necessary to better understand the factors influencing growth and development in South Africa, but has implications for ergonomics and design. For example, a better understanding of the changes taking place in the body shape of South African groups will allow for better designed medical instruments to benefit patients and healthcare practitioners.

Chapter 9: Conclusions

In this study, both anthropometric and osteometric data were used to assess ancestry differences and secular trends between South African population groups and between northern and southern hemisphere groups as far as stature and limb proportions are concerned. The current study elucidated the secular changes or lack thereof that have been taking place in the stature and limb proportions of South African population groups in the time period from 1900 and 2000. The major conclusions include the following:

1. White South Africans are significantly taller than their black South African counterparts. This may be a result of different heredity with most white South Africans having considerable Dutch ancestry while black South Africans have gene flow from the smaller Khoesan populations.
2. Significant positive secular trends in overall stature are only observed in SABM while SAWM, SAWF and SABF did not increase significantly in height during the past 60 years. However, the positive secular trends in the stature of SABM are still relatively small (only 18.3 mm over the last 6 decades). Although both SAWM and SABM may have had lower SES than other developed countries, only the stature of SABM exhibited a significant increase. This suggests that other factors than SES may have an effect on growth and development of South African groups.
3. The secular trends in stature of SAWM are significantly smaller than those observed in other European countries, such as the Netherlands and Switzerland. This is interesting as many white South Africans are descendants from Dutch ancestors. Dutch and SAWM statures were similar after WWII, but only the Dutch group experienced a significant increase in stature.
4. White South African groups are significantly taller than white North American groups while black South African groups are significantly shorter than black North American groups. Also, the difference in stature is much greater between South African groups than between North American groups.
5. Significant ancestry differences are observed in the limb proportions between South African groups. Overall, black South Africans have greater limb lengths and distal limb lengths relative to stature than white South African groups. This probably reflects their adaptation to living in a warmer climate.

6. Changes in the limb proportions of SABF are only taking place from the 1980's onwards resulting in them having lower crural indices than SAWF (i.e. greater leg lengths relative to thigh lengths) while no differences are observed in the crural indices of males. The secular changes in the lower limb of SABF are also more pronounced than in SAWF. The thigh ratios in SABF exhibited a considerable increase with a large decrease in the leg ratio from the 1980's. This could suggest a possible "catch-up" growth in the limb proportions of SABF with better SES, although the reasons for this are not clear.
7. Secular changes in the limb proportions indicate a trend where the different South African population groups are converging with similar trends observed in the various limb proportions between groups regardless of the socio-economic differences. This may indicate an overall adaptation to the warm climate, or gene flow between the groups.
8. White South African groups differ significantly from white North American groups. Overall, white South African males and females have greater upper limb lengths and arm lengths relative to stature than in white North American males and females while no differences exist in the forearm ratio. South African groups have lower brachial indices which is probably the result of the rapid increase in arm lengths and the decrease in the forearm lengths relative to stature. Similar results are observed in the lower limb proportions except that no difference is observed between females indicating a less prominent secular change in SAWF. This suggests a possible greater resistance in females to external factors during growth compared to males. The sitting height ratio is significantly higher in NAWM and slightly higher in NAWF than their corresponding South African groups. This indicates that the lower limb lengths have a greater contribution to stature in South African groups than in North American groups.
9. The differences in limb proportions imply that formulae developed from North American standards cannot be used to estimate stature in South African population groups. The secular changes in the limb proportions will require that regression formulae to estimate stature need to be regularly updated. This will allow the most accurate stature estimations to be made which may improve the chances of identifying an unknown individual. It is suggested that causion is used when applying previously developed regression formulae for

estimating stature in South African populations as this may lead to an over/underestimation of stature. Also, the effect of SES on the stature of specific groups needs to be considered when analysing unknown human remains. Furthermore, knowledge of changes in stature and limb proportions is also important in medicine where arm span is used to estimate stature in patients that are unable to stand. This may result in inaccurate stature estimations which may influence dosages of medicines or test results. Lastly, knowledge of changes in body dimensions is important in the field of ergonomics as this allows improved design of furniture, clothing and the design of medical equipment (e.g., orthopaedic equipment).

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Appendix A: Composition of the samples used for anthropometric and osteometric analysis

Appendix A1: The minimum, maximum and average age ranges of the South African anthropometric sample

Table A.1.1 The minimum, maximum and average age ranges for South African black males (anthropometric)

DOB	Min	Max	Average
1941-1950	52	64	57
1951-1960	41	59	51
1961-1970	31	52	41
1971-1980	21	42	30
1981-1990	17	32	22
1991-2000	18	22	20
1900-2000	**17**	**64**	**30**

Table A.1.2 The minimum, maximum and average age ranges for South African white males (anthropometric)

DOB	Min	Max	Average
1931-1940	68	68	68
1941-1950	55	66	61
1951-1960	45	59	52
1961-1970	33	50	42
1971-1980	22	40	31
1981-1990	18	30	24
1991-2000	18	18	18
1900-2000	**17**	**68**	**42**

Table A.1.3 The minimum, maximum and average age ranges for South African black females (anthropometric)

DOB	Min	Max	Average
1941-1950	50	67	54
1951-1960	40	56	46
1961-1970	30	50	36
1971-1980	20	41	29
1981-1990	18	31	22
1991-2000	18	22	20
1900-2000	**18**	**67**	**29**

Table A.1.4 The minimum, maximum and average age ranges for South African white females (anthropometric)

DOB	Min	Max	Average
1941-1950	50	62	54
1951-1960	40	59	47
1961-1970	30	50	38
1971-1980	20	40	27
1981-1990	17	31	20
1900-2000	**17**	**62**	**32**

Appendix A2: The minimum, maximum and average age ranges of the South African osteometric sample

Table A.2.1 The minimum, maximum and average age ranges for South African black males (osteometric)

DOB	Min	Max	Average
1900-1910	25	60	39
1911-1920	20	61	41
1921-1930	26	63	53
1931-1940	39	58	51
1941-1950	30	58	45
1951-1960	26	48	39
1961-1970	23	40	31
1971-1980	18	27	25
1900-2000	**18**	**63**	**42**

Table A.2.2 The minimum, maximum and average age ranges for South African white males (osteometric)

DOB	Min	Max	Average
1900-1910	42	48	45
1911-1920	38	65	53
1921-1930	43	59	53
1931-1940	28	64	52
1941-1950	32	56	47
1951-1960	45	47	46
1961-1970	28	28	28
1900-2000	**28**	**65**	**50**

Table A.2.3 The minimum, maximum and average age ranges for South African black females (osteometric)

DOB	Min	Max	Average
1900-1910	24	50	36
1911-1920	21	60	36
1921-1930	21	59	35
1931-1940	24	58	44
1941-1950	22	56	39
1951-1960	23	47	35
1961-1970	25	36	30
1971-1980	22	26	24
1900-2000	**21**	**60**	**37**

Table A.2.4 The minimum, maximum and average age ranges for South African white females (osteometric)

DOB	Min	Max	Average
1900-1910	65	65	65
1911-1920	43	62	51
1921-1930	43	61	52
1931-1940	46	57	54
1941-1950	29	62	48
1951-1960	42	42	42
1981-1990	22	22	22
1900-2000	**22**	**65**	**50**

Appendix A3: The minimum, maximum and average age ranges of the North American osteometric sample

Table A.3.1 The minimum, maximum and average age ranges for North American white males (osteometric)

DOB	Min	Max	Average
1931-1940	49	55	52
1941-1950	39	59	49
1951-1960	31	57	47
1961-1970	24	48	39
1971-1980	26	37	32
1900-2000	**24**	**59**	**44**

Table A.3.2 The minimum, maximum and average age ranges for North American white females (osteometric)

DOB	Min	Max	Average
1941-1950	45	56	53
1951-1960	38	59	51
1961-1970	44	48	46
1971-1980	29	39	34
1900-2000	**29**	**59**	**47**

Appendix A4: The intra-observer and interobserver correlations

Table A.4 The intra-observer and interobserver correlations for osteometric measurements

Measurement	Intra-observer correlation	Interobserver correlation
Basibragmatic height	0.991	0.997
Vertebral heights	0.978	0.992
Sitting height	0.983	0.994
Total skeletal height	0.988	1.000
Humerus max length	0.999	1.000
Radius max length	1.000	1.000
Ulna max length	0.999	1.000
Femur max length	1.000	1.000
Femur bicondylar length	1.000	1.000
Tibia condylo-malleolar length	0.996	0.997
Fibula max length	0.999	1.000
Talo-calcaneal height	0.922	0.994

Appendix B: Ancestry differences and secular trends in the anthropometric limb lengths of South African population groups

B1: Ancestry differences and secular trends in the anthropometric limb lengths of South African black and white males

Table B1.1 The sample sizes, mean anthropometric upper limb lengths and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Upper limb length					Arm length					Forearm length				
		N	**Mean**	**SD**	**Chi-Squared value**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared value**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared value**	**p-value**
1941-1950	SABM	12	571.3	41.89	3.8006	0.0512	12	352.8	46.43	3.3292	0.0681	12	291.6	14.34	0.3276	0.5671
	SAWM	18	605.3	36.23			18	382.4	16.99			18	295.2	13.86		
1951-1960	SABM	96	608.2	53.78	0.1967	0.6574	96	348.5	35.80	17.0006	**<0.0001**	94	288.5	15.63	4.1046	**0.0428**
	SAWM	130	605.0	40.23			133	368.3	29.61			125	293.6	16.05		
1961-1970	SABM	469	588.2	36.72	75.3751	**<0.0001**	467	355.0	29.62	62.3123	**<0.0001**	469	290.2	14.92	4.5540	**0.0328**
	SAWM	826	605.6	28.89			824	367.8	21.73			101	294.8	16.47		
1971-1980	SABM	888	591.3	36.88	5.2608	**0.0218**	887	361.2	28.95	34.3314	**<0.0001**	884	292.4	16.43	2.4673	0.1162
	SAWM	137	600.0	37.71			138	377.4	29.16			138	294.6	16.21		
1981-1990	SABM	1093	594.9	38.88	22.9370	**<0.0001**	1095	365.8	28.97	65.7776	**<0.0001**	1065	289.4	15.50	22.1928	**<0.0001**
	SAWM	290	607.3	37.96			288	385.0	35.50			287	294.6	15.86		
1991-2000	SABM	10	582.3	33.02	1.6236	0.2026	10	345.9	31.99	5.7927	**0.0161**	10	287.3	18.80	1.6236	0.2026
	SAWM	4	608.3	13.15			4	390.8	20.01			4	297.3	5.38		
1941-2000	SABM	2568	592.8	38.67	114.8761	**<0.0001**	2567	361.5	29.83	111.5406	**<0.0001**	2534	290.6	15.79	28.5001	**<0.0001**
	SAWM	1406	605.4	33.11			1406	372.6	27.51			674	294.5	15.95		

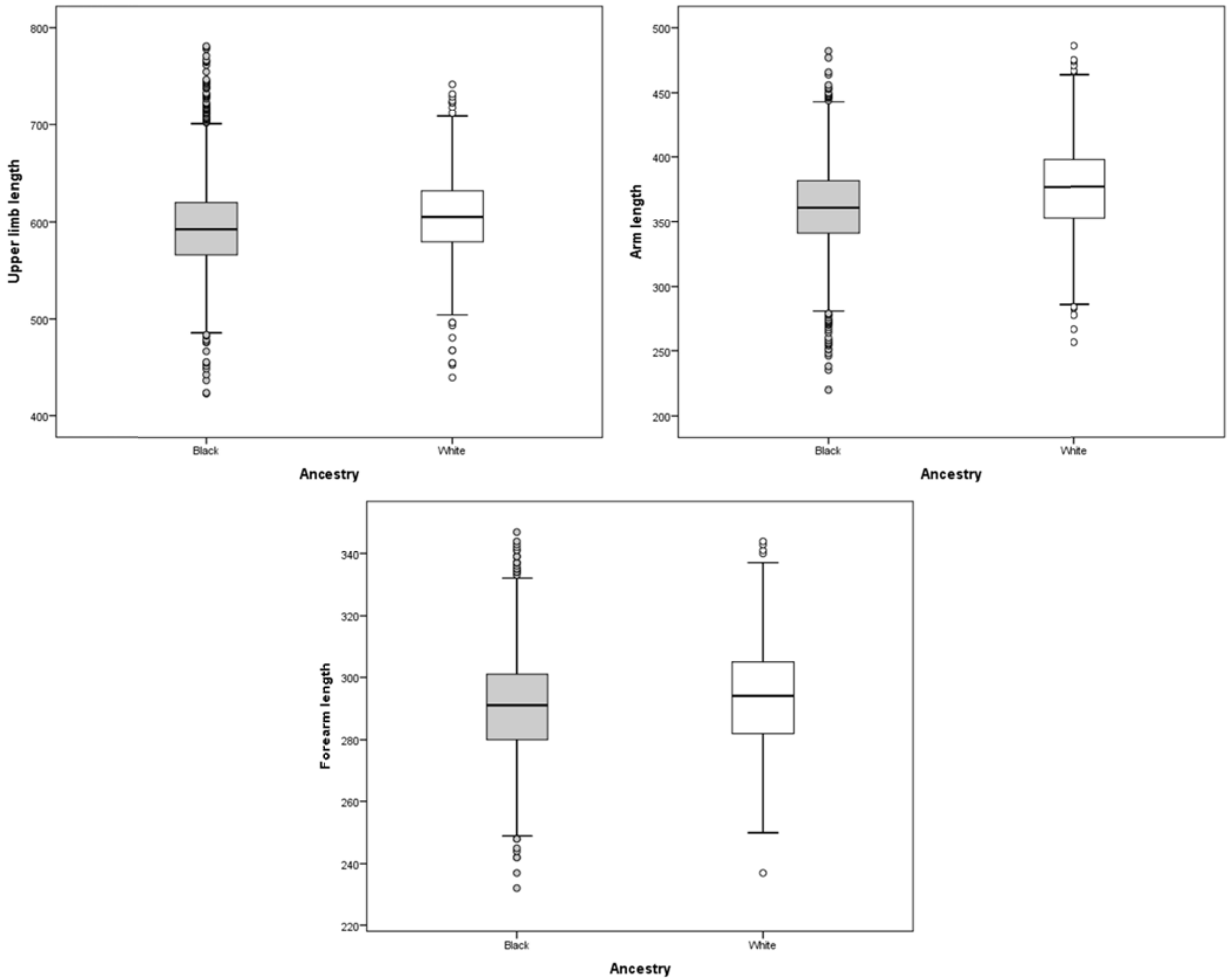

Figure B1.1 Ancestry differences in the anthropometric upper limb lengths between South African black and white males over the total period.

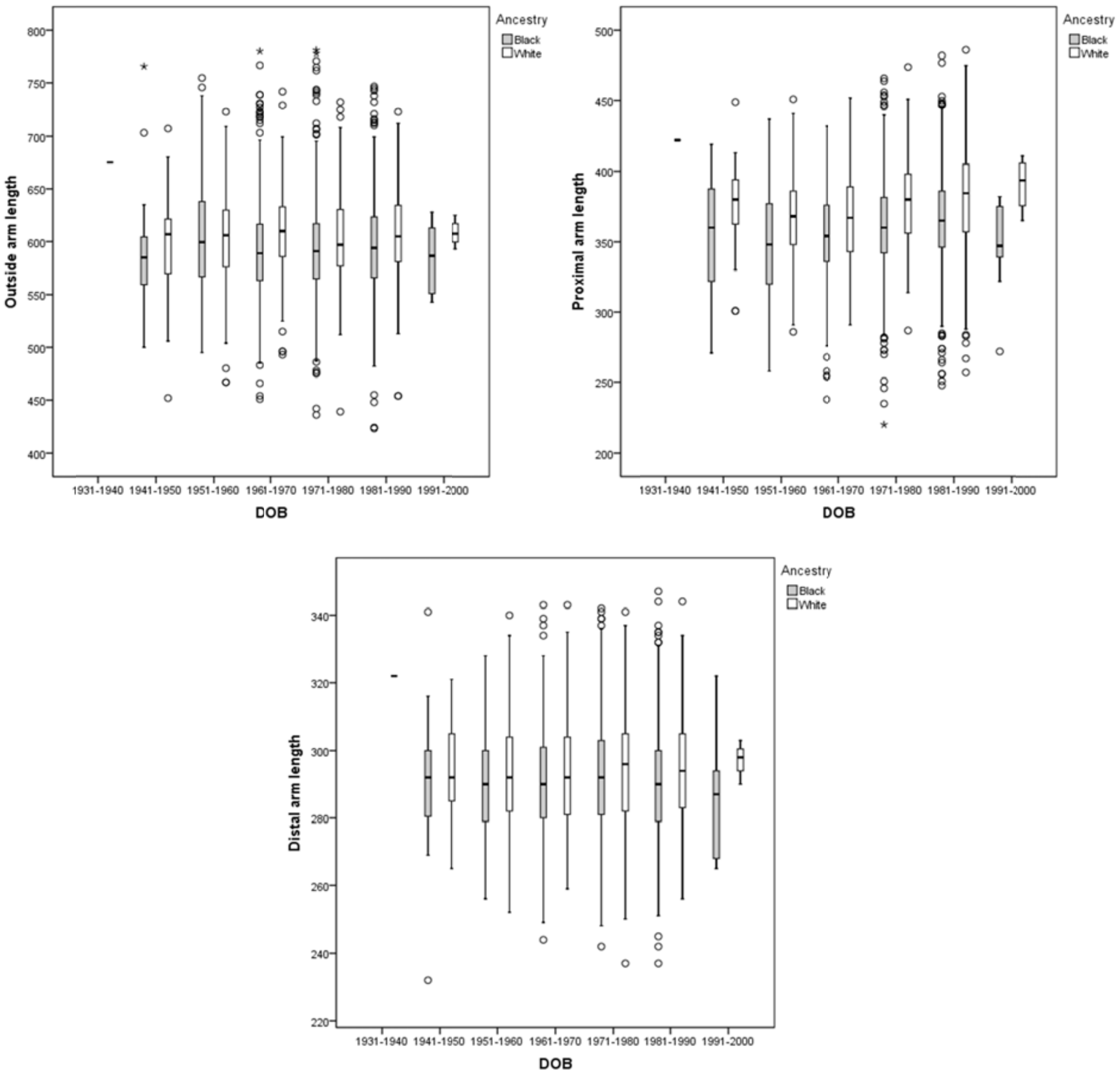

Figure B1.2 Secular trends in the anthropometric upper limb lengths of South African black and white males.

Table B1.2 The sample sizes, mean anthropometric lower limb lengths and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Lower limb length					Thigh length*					Leg length**				
		N	Mean	SD	Chi-Squared value	p-value	N	Mean	SD	Chi-Squared value	p-value	N	Mean	SD	Chi-Squared value	p-value
1941-1950	SABM	14	836.9	51.95	0.3190	0.5722	14	400.4	42.50	0.0130	0.9092	14	436.5	37.90	0.3190	0.5722
	SAWM	19	854.7	47.04			18	405.4	31.82			19	447.0	42.44		
1951-1960	SABM	93	843.5	51.07	15.3946	**<0.0001**	93	411.8	44.90	4.8306	**0.0280**	93	431.7	28.14	8.6678	**0.0032**
	SAWM	129	875.3	56.90			127	428.1	53.91			128	446.2	36.01		
1961-1970	SABM	473	841.1	45.53	42.5415	**<0.0001**	476	412.9	35.85	20.4001	**<0.0001**	475	428.5	29.21	11.8886	**0.0006**
	SAWM	110	875.3	46.98			111	432.6	46.69			111	443.4	40.36		
1971-1980	SABM	890	845.3	42.96	20.3914	**<0.0001**	893	428.2	36.35	1.5073	0.2196	893	417.0	32.28	12.2051	**0.0005**
	SAWM	128	863.0	40.61			133	432.9	40.60			129	428.3	32.93		
1981-1990	SABM	1087	855.1	43.17	12.7092	**0.0004**	1085	433.8	35.98	18.4296	**<0.0001**	1092	421.4	29.76	0.4280	0.5130
	SAWM	289	866.2	46.09			289	444.5	38.66			289	421.2	34.27		
1991-2000	SABM	10	854.8	52.01	2.4200	0.1198	10	417.0	26.61	2.8863	0.0893	10	437.8	38.69	0.8469	0.3574
	SAWM	4	896.0	17.68			4	439.3	17.42			4	456.8	18.73		
1941-2000	SABM	2567	848.6	44.27	92.8260	**<0.0001**	2571	427.0	37.36	28.2237	**<0.0001**	2577	421.7	30.92	34.9298	**<0.0001**
	SAWM	680	868.8	47.76			683	436.2	44.00			681	431.9	37.22		

* Thigh link **Calf link

Table B1.2 (continued) The sample sizes, mean anthropometric lower limb lengths and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Total lower limb length*					Lateral femoral epicondyle height				
		N	**Mean**	**SD**	**Chi-Squared value**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared value**	**p-value**
1941 - 1950	SABM	14	892.5	54.59	1.7210	0.1896	14	492.1	38.65	2.0726	0.1500
	SAWM	19	921.5	46.37			19	513.2	41.16		
1951-1960	SABM	93	904.5	50.99	19.6038	**<0.0001**	93	492.7	27.28	13.6102	**0.0002**
	SAWM	129	940.2	56.62			128	510.8	35.50		
1961-1970	SABM	477	903.0	44.66	56.0394	**<0.0001**	479	490.2	28.40	23.5610	**<0.0001**
	SAWM	111	942.3	46.56			112	510.4	39.57		
1971-1980	SABM	894	908.7	43.74	35.1622	**<0.0001**	897	480.3	31.49	34.0186	**<0.0001**
	SAWM	132	933.1	41.77			133	499.2	33.96		
1981-1990	SABM	1089	917.5	43.51	34.1089	**<0.0001**	1093	483.8	30.45	9.4260	**0.0021**
	SAWM	290	936.3	47.43			290	491.3	34.46		
1991-2000	SABM	10	919.1	55.92	2.0000	0.1573	10	502.1	43.66	0.5000	0.4795
	SAWM	4	956.5	17.02			4	517.3	23.10		
1941-2000	SABM	2577	911.2	44.56	150.2333	**<0.0001**	2586	484.2	30.68	101.5965	**<0.0001**
	SAWM	686	937.2	48.13			687	500.5	36.60		

*Trochanterion height

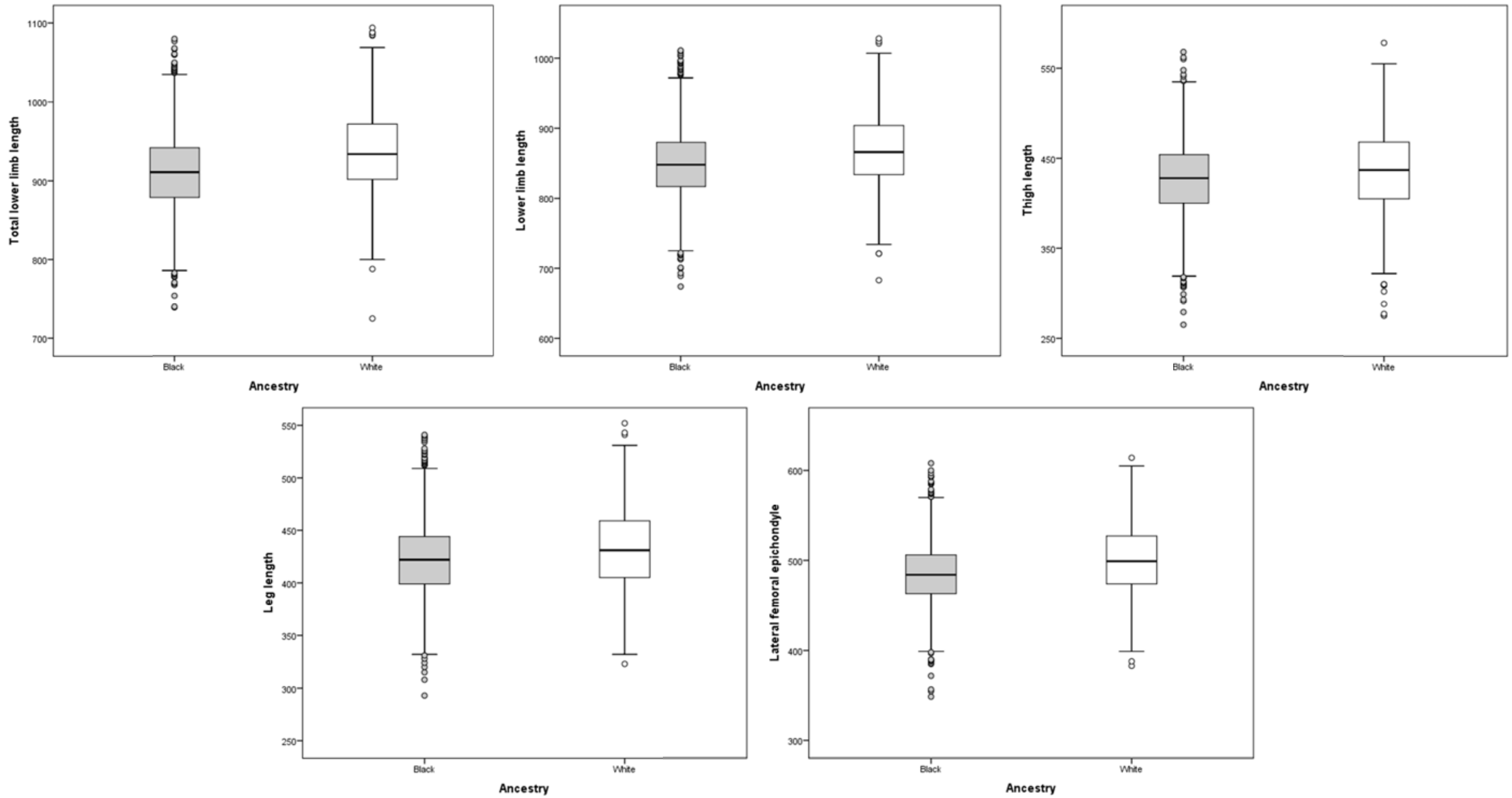

Figure B1.3 Ancestry differences in the anthropometric lower limb lengths between South African black and white males over the total period.

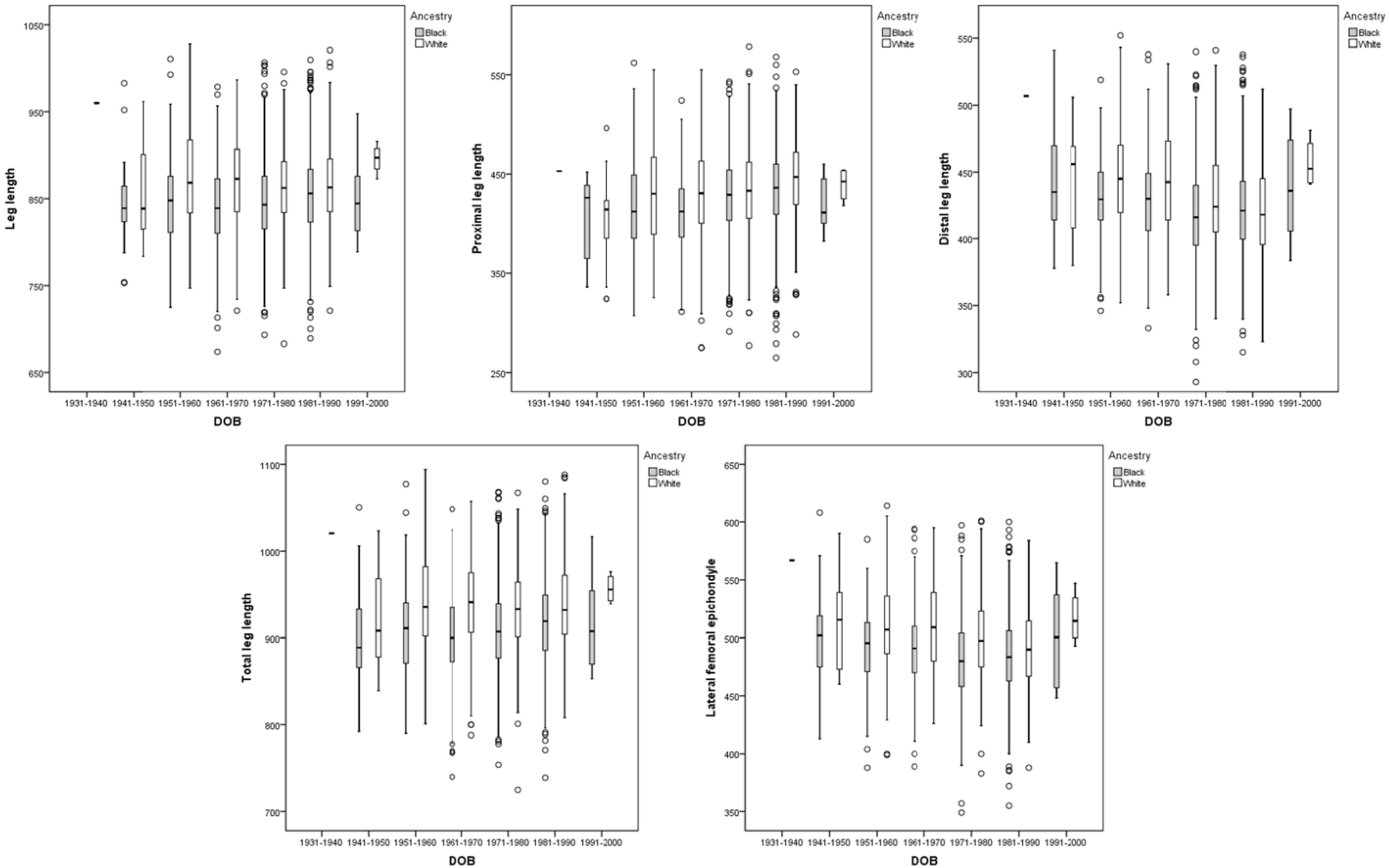

Figure B1.4 Secular trends in the anthropometric lower limb lengths of South African black and white males.

Table B1.3 The sample sizes, mean anthropometric sitting heights and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared value	p-value
1941 - 1950	SABM	15	872.9	31.30	15.4307	**<0.0001**
	SAWM	23	931.1	43.70		
1951-1960	SABM	97	868.1	33.59	108.1315	**<0.0001**
	SAWM	132	932.1	35.79		
1961-1970	SABM	497	862.7	35.39	218.8623	**<0.0001**
	SAWM	117	936.5	32.64		
1971-1980	SABM	910	866.1	31.33	248.6059	**<0.0001**
	SAWM	142	931.9	37.62		
1981-1990	SABM	1123	865.9	34.16	434.5094	**<0.0001**
	SAWM	297	928.4	36.85		
1991-2000	SABM	9	867.7	33.19	5.4167	**0.0199**
	SAWM	4	923.3	39.79		
1941-2000	SABM	2651	865.5	33.42	1122.3708	**<0.0001**
	SAWM	716	931.1	36.39		

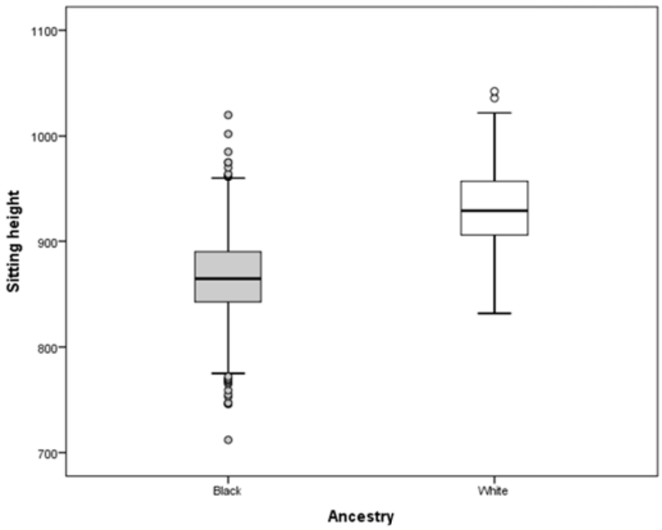

Figure B1.5 The ancestry difference in the anthropometric sitting height between South African black and white males over the total period.

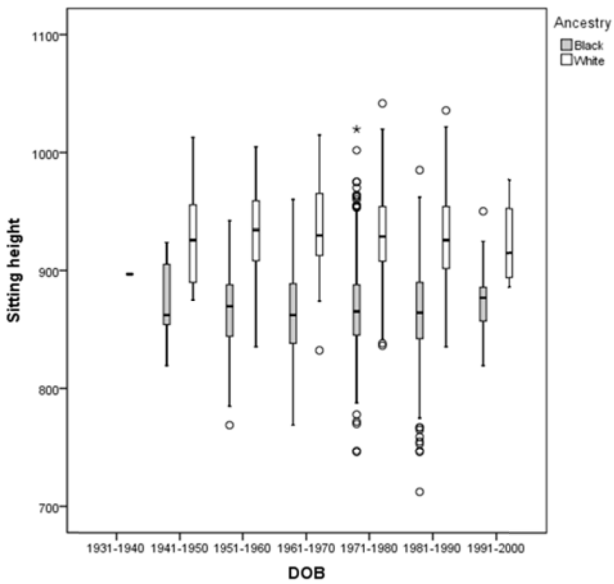

Figure B1.6 Secular trends in the anthropometric sitting heights of South African black and white males.

B2: Ancestry differences and secular trends in the anthropometric limb lengths and proportions of South African black and white females

Table B2.1 The sample sizes, mean anthropometric upper limb lengths and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Upper limb length					Arm length					Forearm length				
		N	**Mean**	**SD**	**Chi-Squared value**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared value**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared value**	**p-value**
1941-1950	SABF	11	542.7	22.24	0.0007	0.9789	11	315.6	29.04	2.9037	0.0884	11	267.3	20.12	0.0566	0.8120
	SAWF	34	543.7	28.82			34	335.4	25.84			34	265.3	13.20		
1951-1960	SABF	70	550.4	40.50	0.2021	0.6530	70	322.6	26.09	17.9407	**<0.0001**	72	271.8	17.38	0.2566	0.6125
	SAWF	130	551.7	33.33			128	340.4	27.37			130	270.0	14.05		
1961-1970	SABF	431	545.1	38.35	4.4719	**0.0345**	434	319.4	28.50	40.9197	**<0.0001**	436	269.3	16.13	0.1485	0.7000
	SAWF	191	551.2	31.57			193	335.5	26.49			192	268.7	14.90		
1971-1980	SABF	569	546.4	37.02	1.2757	0.2587	566	323.8	29.03	13.3629	**0.0003**	569	270.0	15.49	15.8743	**<0.0001**
	SAWF	313	544.3	31.57			313	331.4	26.11			313	265.6	13.86		
1981-1990	SABF	656	546.7	36.51	1.2889	0.2562	653	336.6	28.71	1.2529	0.2630	642	269.3	14.39	1.3787	0.2403
	SAWF	181	550.1	35.10			180	339.7	26.05			179	270.9	14.00		
1991-2000	SABF	36	547.6	23.08	-	-	36	338.1	21.93	-	-	36	265.7	11.98	-	-
1941-2000	SABF	1773	546.4	36.98	1.8133	0.1781	1770	327.6	29.47	41.6941	**<0.0001**	1766	269.5	15.32	4.8039	**0.0284**
	SAWF	849	548.2	32.62			848	335.6	26.56			848	268.0	14.27		

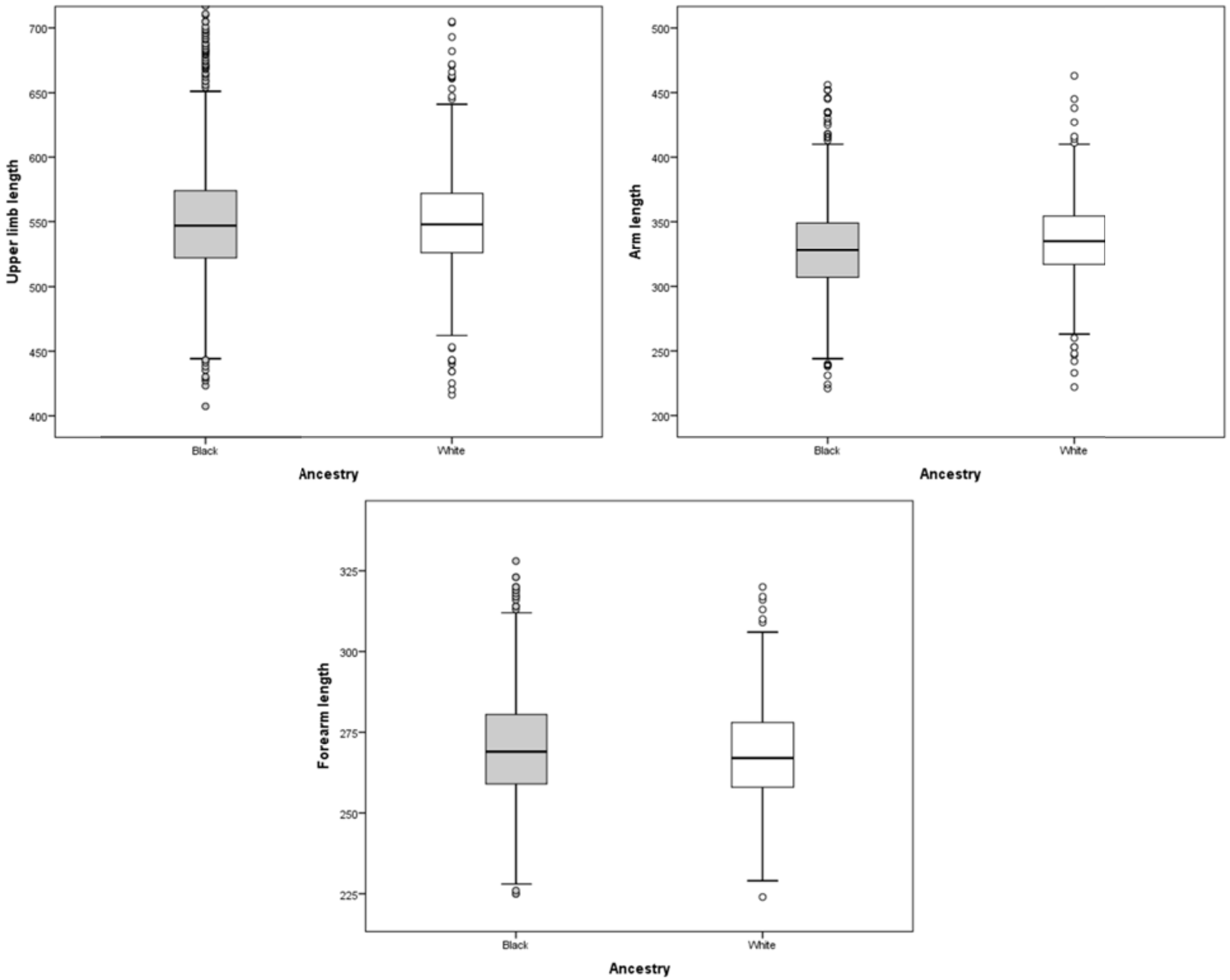

Figure B2.1 Ancestry difference in the anthropometric upper limb lengths between South African black and white females over the total period.

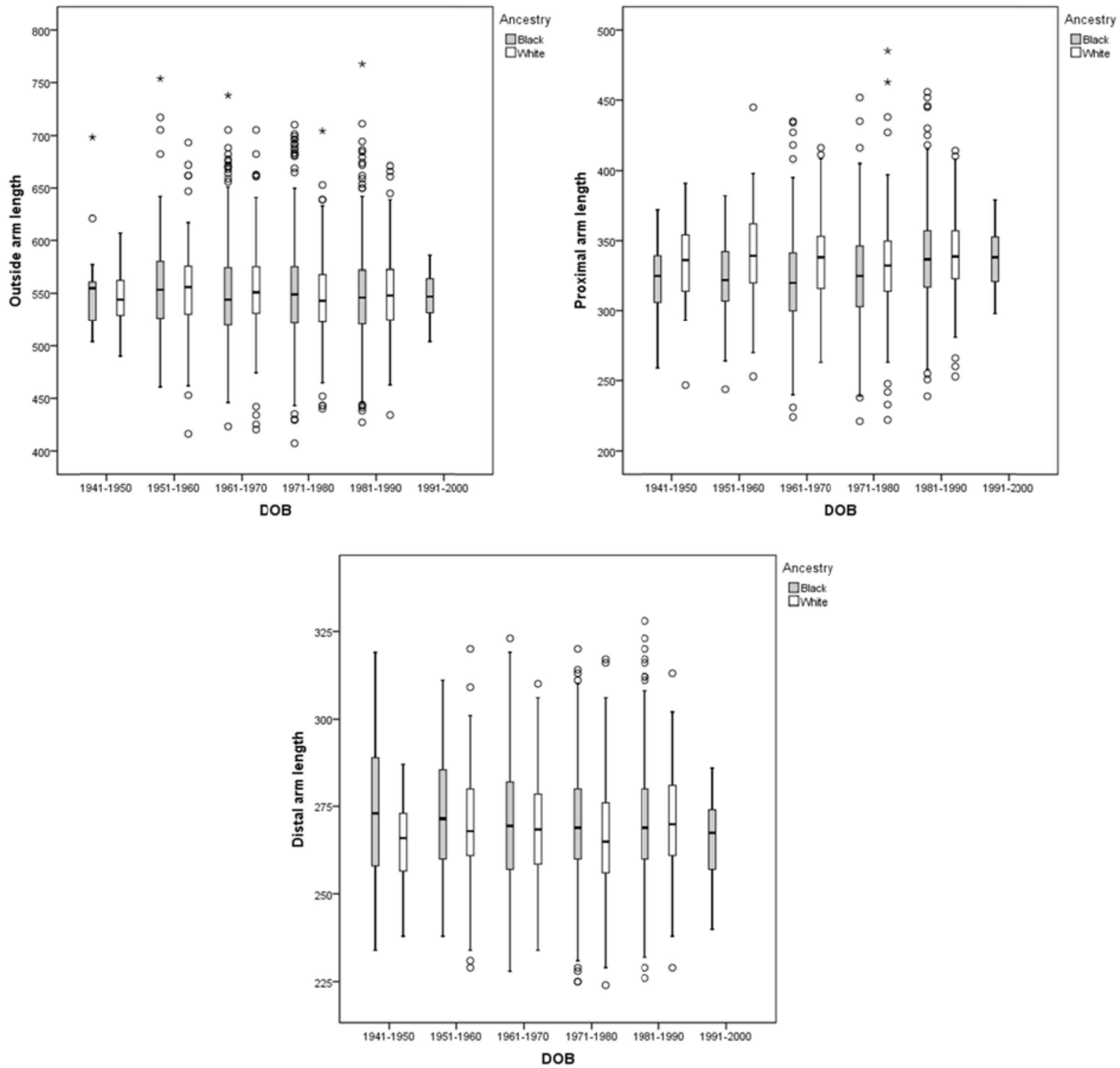

Figure B2.2 Secular trends in the anthropometric upper limb lengths of South African black and white females.

Table B2.2 The sample sizes, mean anthropometric lower limb lengths and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Lower limb length					Thigh length*					Leg length**				
		N	**Mean**	**SD**	**Chi-Squared value**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared value**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared value**	**p-value**
1941-1950	SABF	7	791.7	35.82	0.0455	0.8310	7	382.4	32.75	0.4606	0.4973	7	409.3	22.60	1.1660	0.2802
	SAWF	30	788.3	37.13			30	368.3	47.31			29	416.6	33.63		
1951-1960	SABF	73	794.2	67.29	0.6578	0.4173	74	388.5	62.67	0.0522	0.8193	73	407.3	28.05	4.2313	**0.0397**
	SAWF	135	803.6	64.42			135	387.4	66.54			132	417.3	27.06		
1961-1970	SABF	451	784.5	59.92	4.3131	**0.0378**	454	376.3	58.12	1.8052	0.1791	449	407.5	28.44	8.6202	**0.0033**
	SAWF	200	797.1	66.22			198	382.9	67.11			196	415.8	29.49		
1971-1980	SABF	576	787.6	56.68	3.2502	0.0714	580	382.4	54.27	1.0078	0.3154	577	405.8	32.67	1.8272	0.1765
	SAWF	319	794.5	51.49			320	385.7	54.05			322	408.8	28.20		
1981-1990	SABF	679	790.4	54.07	1.7957	0.1802	679	404.9	40.82	9.0463	**0.0026**	678	385.7	37.15	31.4163	**<0.0001**
	SAWF	184	797.1	51.68			184	394.6	42.27			181	403.0	34.70		
1991-2000	SABF	36	818.2	28.86	-	-	36	423.0	21.53	-	-	36	395.2	16.99	-	-
1941-2000	SABF	1822	788.7	56.69	9.9990	**0.0016**	1830	390.3	52.19	3.0548	0.0805	1820	398.6	34.52	69.6599	**<0.0001**
	SAWF	868	796.8	56.94			867	386.6	57.16			860	410.7	30.38		

* Thigh link **Calf link

Table B2.2 (continued) The sample sizes, mean anthropometric lower limb lengths and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Total lower limb length*					Lateral femoral epicondyle height				
		N	**Mean**	**SD**	**Chi-Squared value**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared value**	**p-value**
1941 - 1950	SABF	7	837.3	38.75	0.9783	0.3226	7	454.9	22.50	2.9806	0.0843
	SAWF	30	845.6	37.17			30	477.3	36.53		
1951-1960	SABF	74	844.2	66.09	3.5138	0.0609	75	455.9	32.23	16.7074	**<0.0001**
	SAWF	136	862.7	62.11			135	475.1	30.83		
1961-1970	SABF	457	833.6	61.00	13.8087	**0.0002**	455	457.6	28.30	38.2163	**<0.0001**
	SAWF	202	855.8	65.54			198	474.5	30.86		
1971-1980	SABF	580	840.1	56.96	10.5129	**0.0012**	585	457.6	32.40	20.2824	**<0.0001**
	SAWF	320	853.0	51.10			322	467.5	28.75		
1981-1990	SABF	679	846.1	52.76	2.9825	0.0842	679	441.2	37.44	33.6294	**<0.0001**
	SAWF	184	855.0	52.10			184	460.3	36.98		
1991-2000	SABF	36	872.4	29.34	-	-	36	449.4	18.92	-	-
1941-2000	SABF	1833	841.5	56.75	28.5446	**<0.0001**	1837	451.3	34.07	150.2620	**<0.0001**
	SAWF	872	855.3	56.35			869	469.1	32.15		

*Trochanterion height

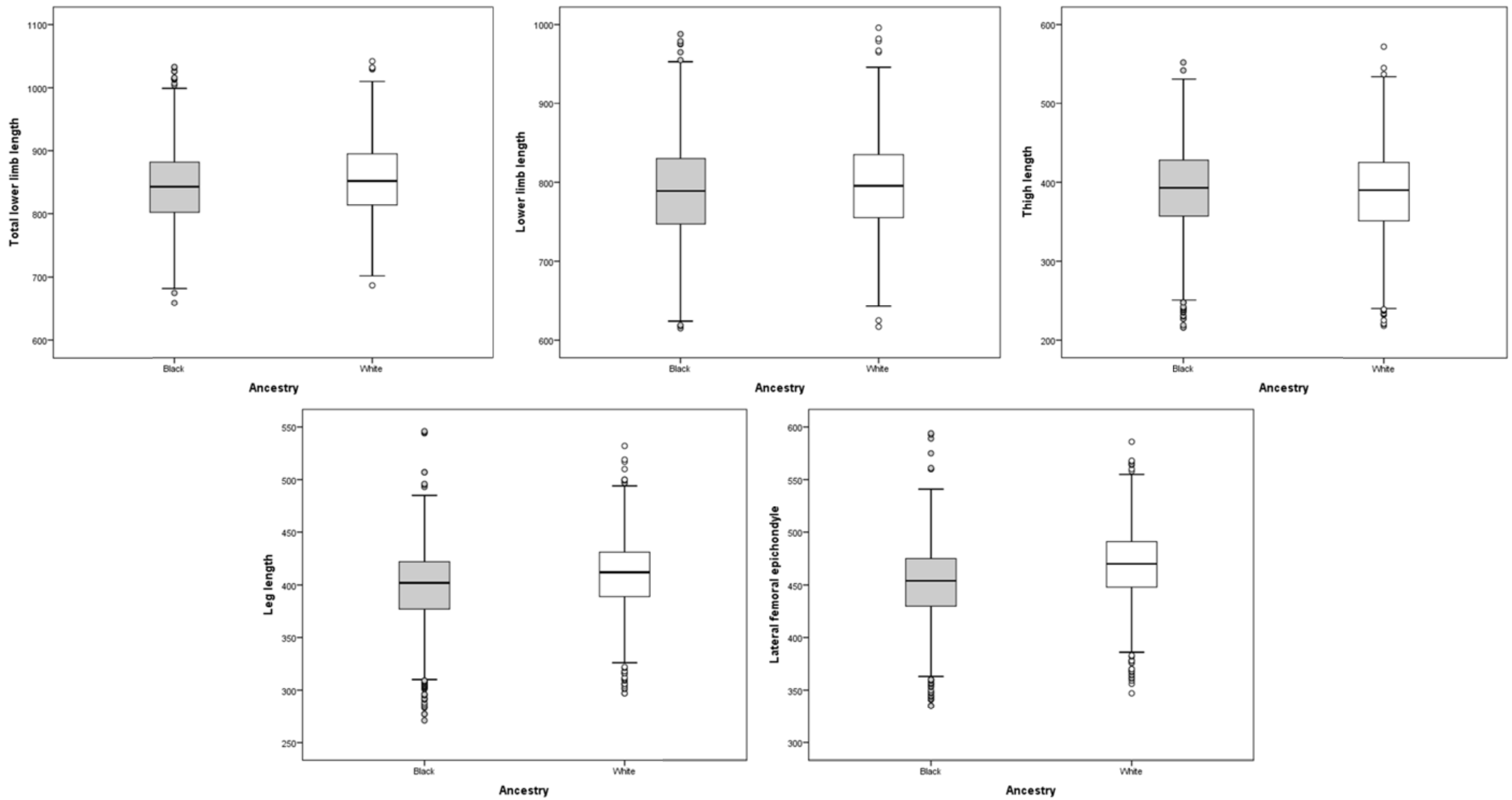

Figure B2.3 Ancestry differences in the anthropometric lower limb lengths between South African black and white females over the total period.

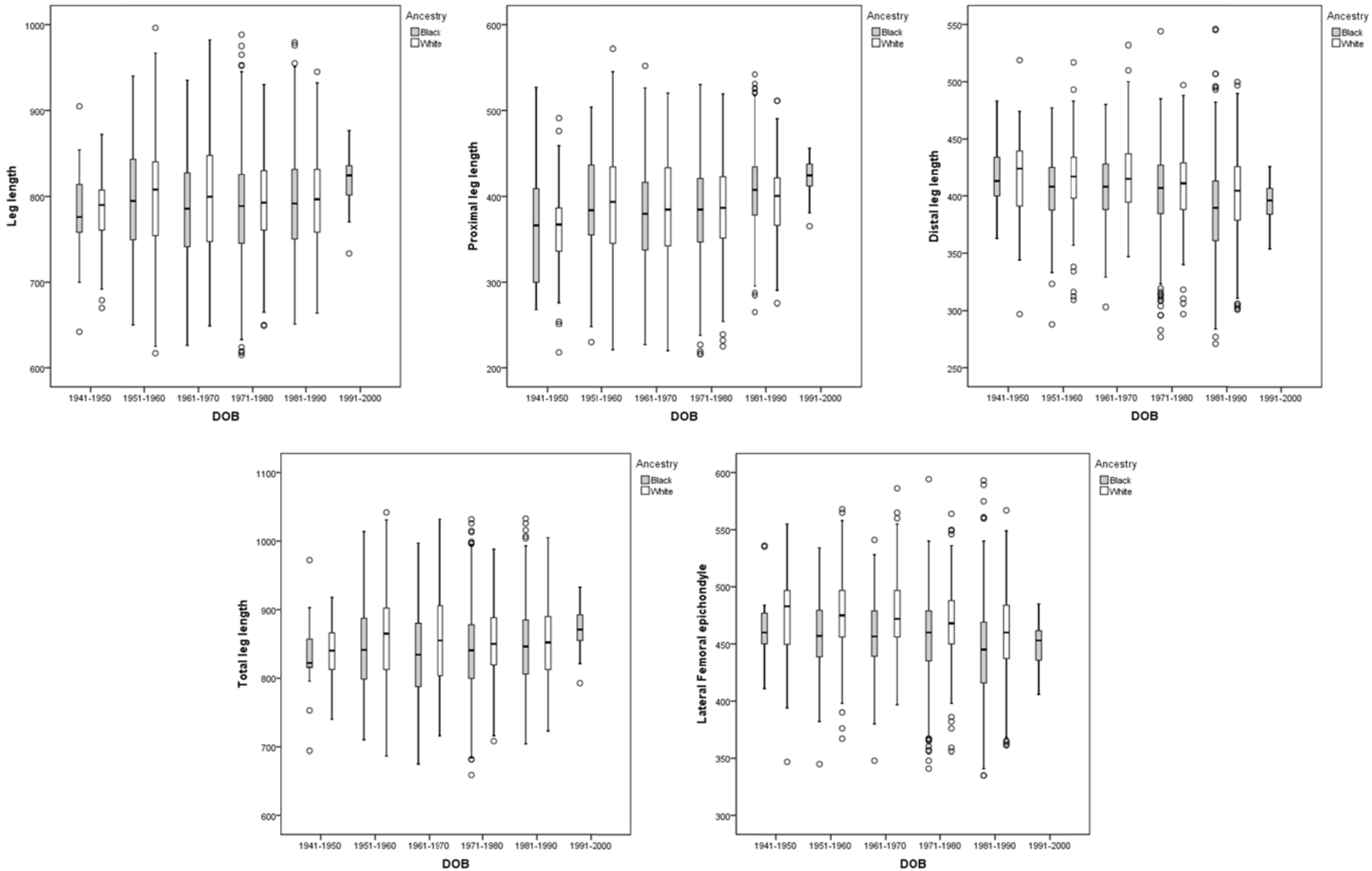

Figure B2.4 Secular trends in the anthropometric lower limb lengths of South African black and white females.

Table B2.3 The sample sizes, mean anthropometric sitting heights and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Squared value	p-value
1941-1950	SABF	12	835.6	34.98	4.2695	**0.0388**
	SAWF	33	865.6	43.96		
1951-1960	SABF	76	847.3	46.19	13.2790	**0.0003**
	SAWF	143	870.4	37.34		
1961-1970	SABF	457	849.9	40.99	75.4588	**<0.0001**
	SAWF	203	879.2	35.43		
1971-1980	SABF	588	844.7	41.32	134.8220	**<0.0001**
	SAWF	326	876.9	34.28		
1981-1990	SABF	691	829.4	32.64	222.2832	**<0.0001**
	SAWF	192	881.3	36.60		
1991-2000	SABF	36	834.3	28.70	-	-
1941-1990	SABF	1860	840.1	39.13	485.6230	**<0.0001**
	SAWF	897	876.9	36.08		

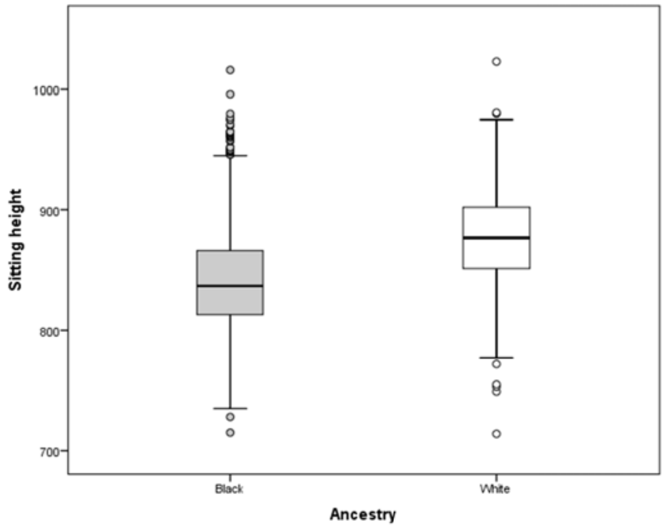

Figure B2.5 Ancestry differences in the anthropometric sitting height between South African black and white females over the total period.

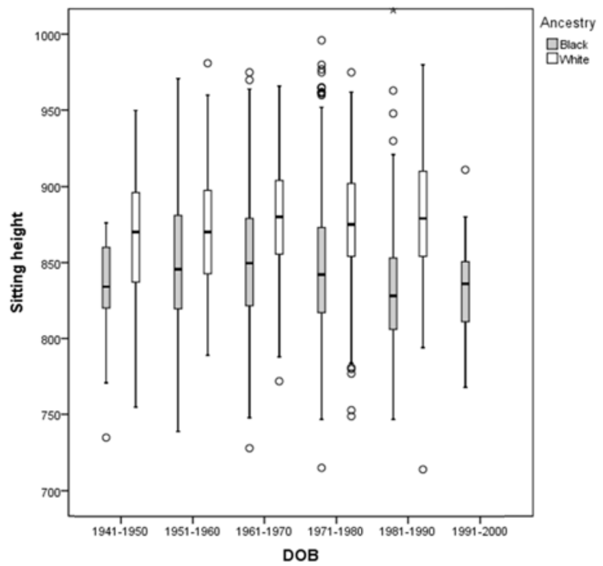

Figure B2.6 Secular trends in the anthropometric sitting heights of South African black and white females.

Appendix C: Ancestry differences and secular trends in the osteometric limb lengths of South African population groups

C1: Ancestry differences and secular trends in the osteometric limb lengths of South African black and white males

Table C1.1 The sample sizes, mean osteometric upper limb lengths and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Arm length*					Humerus max length					Radius max length					Ulna max length				
		N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value
1900-1910	SABM	28	584.6	28.55	-	-	28	324.5	16.25	-	-	28	260.1	14.21	-	-	28	276.3	14.53	-	-
	SAWM	2	605.5	4.95			2	348.0	5.66			2	257.5	0.71			2	274.0	1.41		
1911-1920	SABM	31	575.0	29.28	1.3318	0.2485	31	320.2	17.14	9.9594	**0.0016**	31	254.9	13.87	1.0986	0.2946	30	272.6	15.09	0.5202	0.4708
	SAWM	10	588.0	19.36			12	337.5	9.39			10	251.5	10.35			11	270.6	9.15		
1921-1930	SABM	33	573.6	30.32	1.3151	0.2515	33	319.5	15.55	10.3195	**0.0013**	33	254.1	15.72	2.5168	0.1126	31	272.4	15.64	2.5470	0.1105
	SAWM	13	585.7	25.31			14	336.6	15.37			13	248.2	10.48			13	266.5	11.10		
1931-1940	SABM	48	572.2	27.23	2.8534	0.0912	49	319.4	15.03	12.9285	**0.0003**	48	252.9	13.54	0.6545	0.4185	45	269.9	13.07	0.1651	0.6845
	SAWM	21	586.3	29.65			21	335.4	18.23			21	250.9	13.31			21	269.1	13.47		
1941-1950	SABM	58	585.6	29.68	2.3844	0.1226	58	325.7	16.25	9.2318	**0.0024**	58	259.9	16.00	0.3102	0.5776	56	276.8	17.64	0.0004	0.9844
	SAWM	17	596.4	30.66			17	339.9	18.70			17	256.5	13.65			17	275.3	14.00		
1951-1960	SABM	45	584.0	29.82	-	-	45	325.2	17.13	-	-	45	258.8	13.59	-	-	44	276.5	14.31	-	-
	SAWM	3	578.5	15.02			3	329.7	10.50			3	248.8	10.28			3	268.7	13.58		
1961-1970	SABM	37	577.7	28.11	-	-	37	321.3	15.79	-	-	37	256.4	13.98	-	-	36	274.4	14.94	-	-
	SAWM	1	533.0	-			1	306.0	-			1	227.0	-			1	253.5	-		
1971-1980	SABM	11	570.3	35.20	-	-	11	318.5	21.54	-	-	11	251.8	15.86	-	-	11	269.6	17.63	-	-
1900-1980	SABM	291	579.0	29.44	6.6037	**0.0102**	292	322.3	16.41	41.8066	**<0.0001**	291	256.6	14.67	6.9747	**0.0083**	281	274.1	15.35	3.6530	0.0560
	SAWM	67	588.4	27.35			70	336.8	16.20			67	251.7	12.48			68	270.3	12.46		

*Humerus max length + radius max length

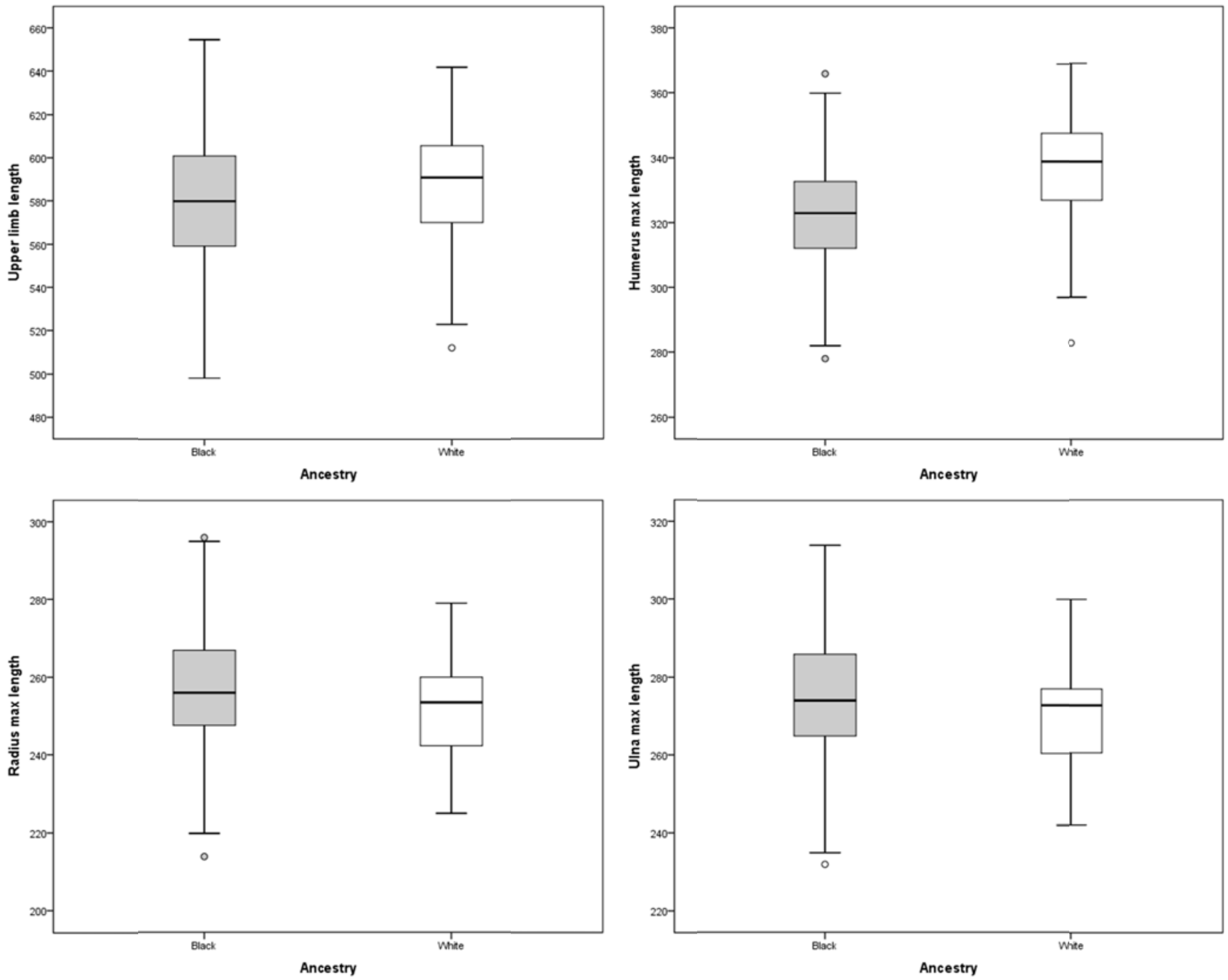

Figure C1.1 Ancestry differences in the osteometric upper limb lengths between South African black and white males over the total period.

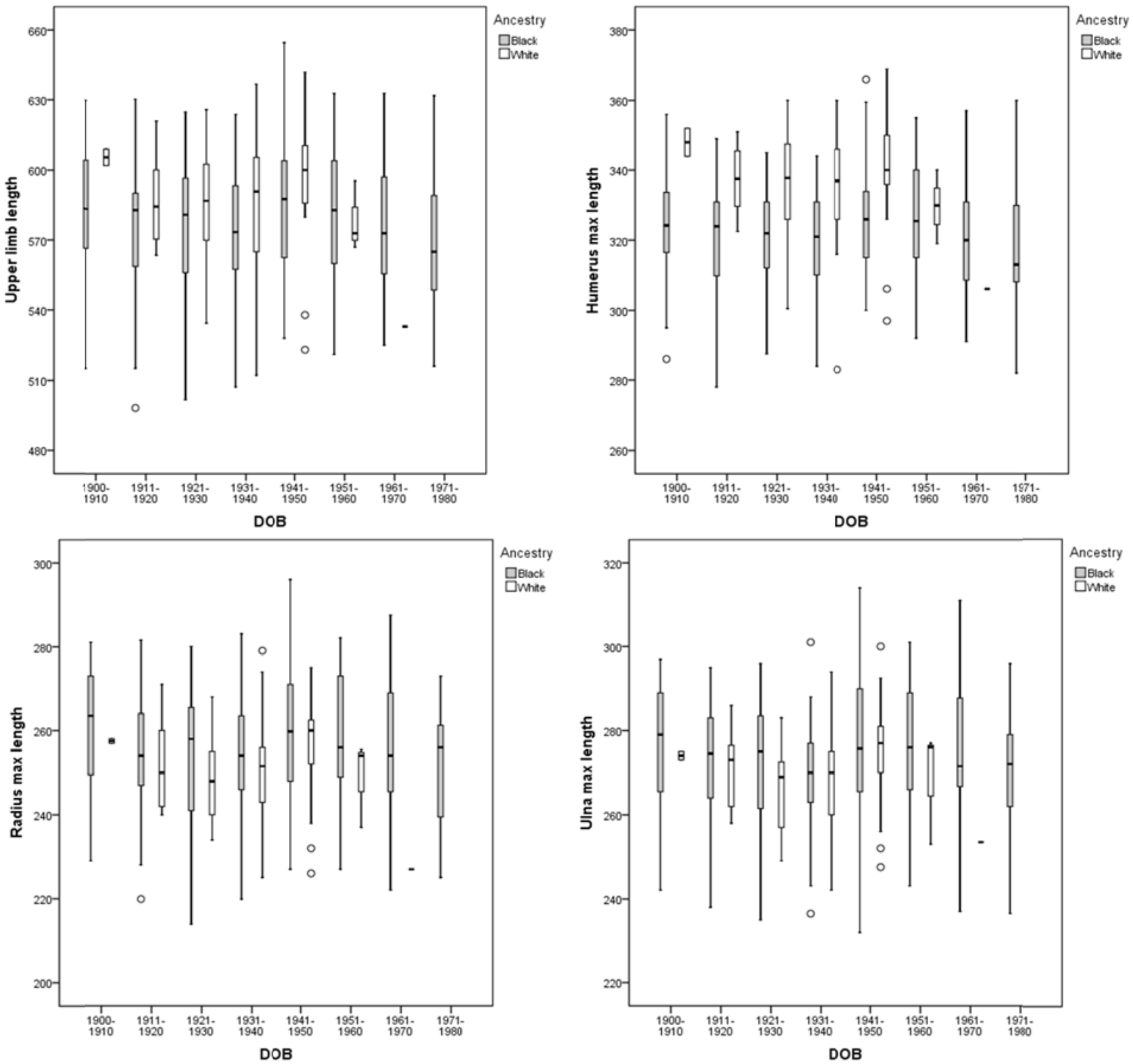

Figure C.1.2 Secular trends in the osteometric upper limb lengths of South African black and white males.

Table C1.2 The sample sizes, mean osteometric lower limb lengths and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Total lower limb length					Lower limb length					Femur max length				
		N	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**
1900-1910	SABM	24	907.4	42.66	-	-	27	850.4	50.15	-	-	28	461.0	26.64	-	-
	SAWM	2	958.5	3.54			2	891.5	6.36			2	487.5	6.36		
1911-1920	SABM	24	899.6	49.93	0.6004	0.4384	29	835.6	48.27	0.2965	0.5861	30	454.0	24.10	3.3787	0.0660
	SAWM	10	918.5	36.44			12	850.3	32.18			12	468.3	16.87		
1921-1930	SABM	23	907.0	48.27	0.3323	0.5643	33	839.3	44.37	0.7293	0.3931	33	455.6	23.80	2.7683	0.0961
	SAWM	13	918.5	43.68			13	851.0	41.02			14	468.6	24.54		
1931-1940	SABM	16	923.0	41.20	2.8752	0.0900	48	838.5	41.58	2.3341	0.1266	49	454.8	21.16	6.7717	**0.0093**
	SAWM	39	902.5	40.53			20	857.9	39.30			21	469.8	22.49		
1941-1950	SABM	55	911.9	49.77	3.8624	**0.0494**	58	850.6	49.75	3.1133	0.0777	58	459.8	26.95	6.7646	**0.0093**
	SAWM	13	938.9	46.03			14	872.3	42.73			17	477.9	22.79		
1951-1960	SABM	39	910.6	42.41	-	-	44	846.6	39.48	-	-	44	458.8	22.14	-	-
	SAWM	3	917.0	19.31			3	853.0	21.52			3	471.7	8.14		
1961-1970	SABM	33	896.9	40.19	-	-	34	834.7	37.54	-	-	34	452.7	21.00	-	-
	SAWM	1	823.0	-			1	765.0	-			1	425.0	-		
1971-1980	SABM	11	895.0	60.47	-	-	11	833.2	57.52	-	-	11	452.9	28.10	-	-
1900-1980	SABM	248	905.4	45.60	9.7589	**0.0018**	284	842.5	45.05	8.1483	**0.0043**	287	456.7	23.87	23.9256	**<0.0001**
	SAWM	58	924.0	42.30			65	857.6	39.68			70	471.2	21.94		

Table C1.2 (continued) The sample sizes, mean osteometric lower limb lengths and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	Femur bicondylar length					Tibia condylo-malleolar length					Fibula max length				
		N	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**	**N**	**Mean**	**SD**	**Chi-Squared**	**p-value**
1900-1910	SABM	28	457.4	27.02	-	-	27	393.1	24.06	-	-	25	382.4	24.84	-	-
	SAWM	2	483.5	3.54			2	408.0	9.90			2	402.8	0.35		
1911-1920	SABM	29	450.7	23.94	3.5785	0.0585	31	383.8	25.12	0.0090	0.9245	27	353.8	89.35	0.0270	0.8694
	SAWM	12	465.7	16.76			12	384.5	17.12			9	378.9	17.84		
1921-1930	SABM	33	452.8	23.28	2.8847	0.0894	33	386.5	22.46	0.1340	0.7143	30	377.1	23.59	0.1985	0.6559
	SAWM	14	465.6	24.70			13	384.7	18.00			12	381.7	14.17		
1931-1940	SABM	48	451.7	21.01	7.2898	**0.0069**	48	386.7	21.90	0.0102	0.9196	44	378.6	22.13	0.5126	0.4740
	SAWM	21	467.0	22.56			20	388.2	21.48			17	384.5	18.02		
1941-1950	SABM	58	456.9	26.39	6.3754	**0.0116**	58	393.6	25.49	0.7284	0.3934	52	378.7	53.02	1.4936	0.2217
	SAWM	17	474.3	22.53			15	396.8	21.10			13	391.0	22.54		
1951-1960	SABM	44	456.1	21.98	-	-	45	390.7	18.73	-	-	40	366.1	77.53	-	-
	SAWM	3	468.0	8.89			3	385.0	13.11			3	378.7	12.71		
1961-1970	SABM	34	448.5	21.85	-	-	36	387.2	19.02	-	-	29	379.6	20.85	-	-
	SAWM	1	419.0	-			1	346.0	-			1	343.0	-		
1971-1980	SABM	11	449.3	28.71	-	-	11	383.9	29.99	-	-	11	377.2	28.27	-	-
1900-1980	SABM	285	453.6	23.82	24.5816	**<0.0001**	289	388.9	22.85	0.0175	0.8948	258	374.3	51.29	2.1318	0.1443
	SAWM	70	468.1	21.94			66	388.6	20.22			57	384.1	18.79		

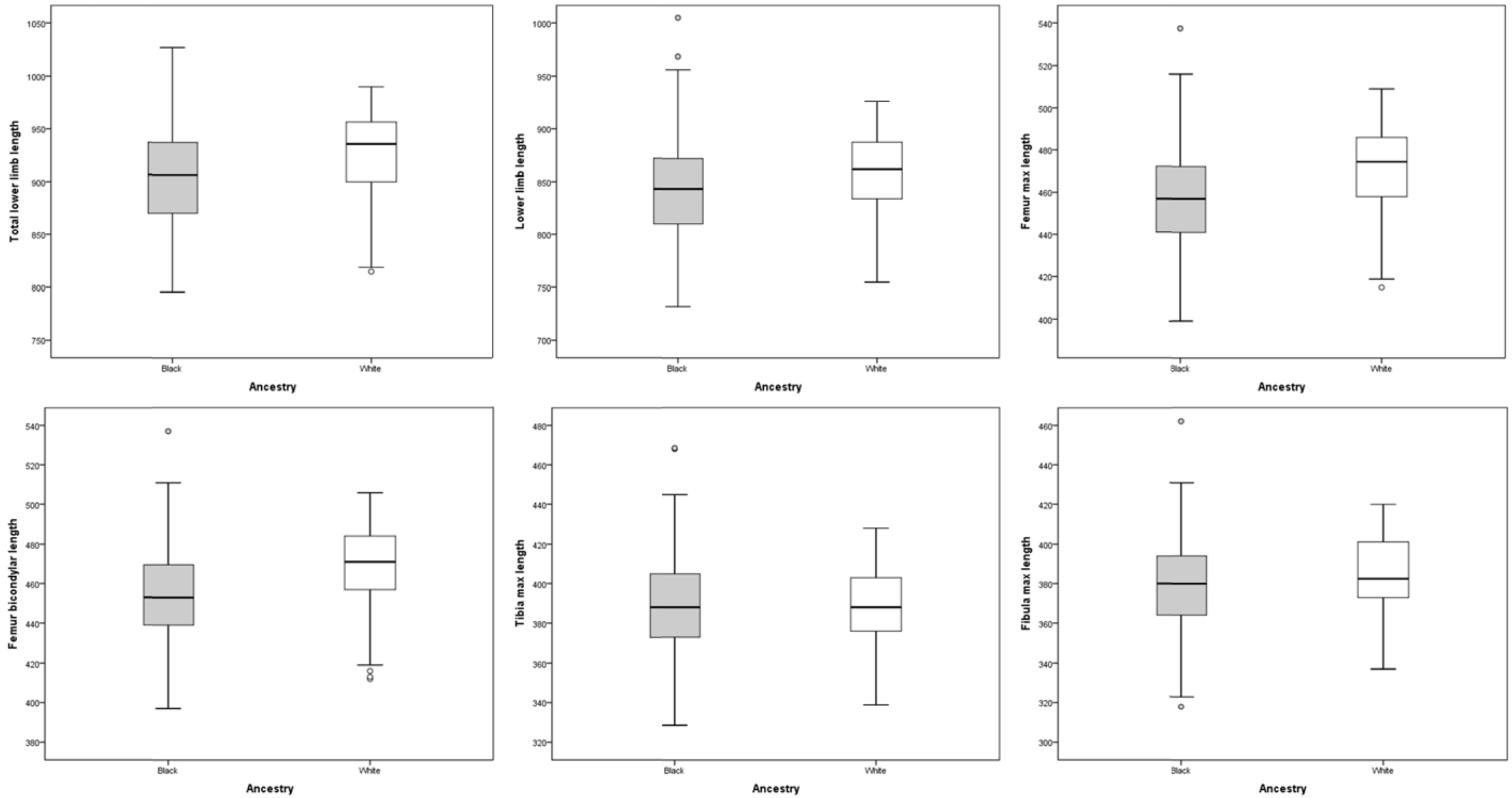

Figure C1.3 Ancestry differences in the osteometric lower limb lengths between South African black and white males over the total period.

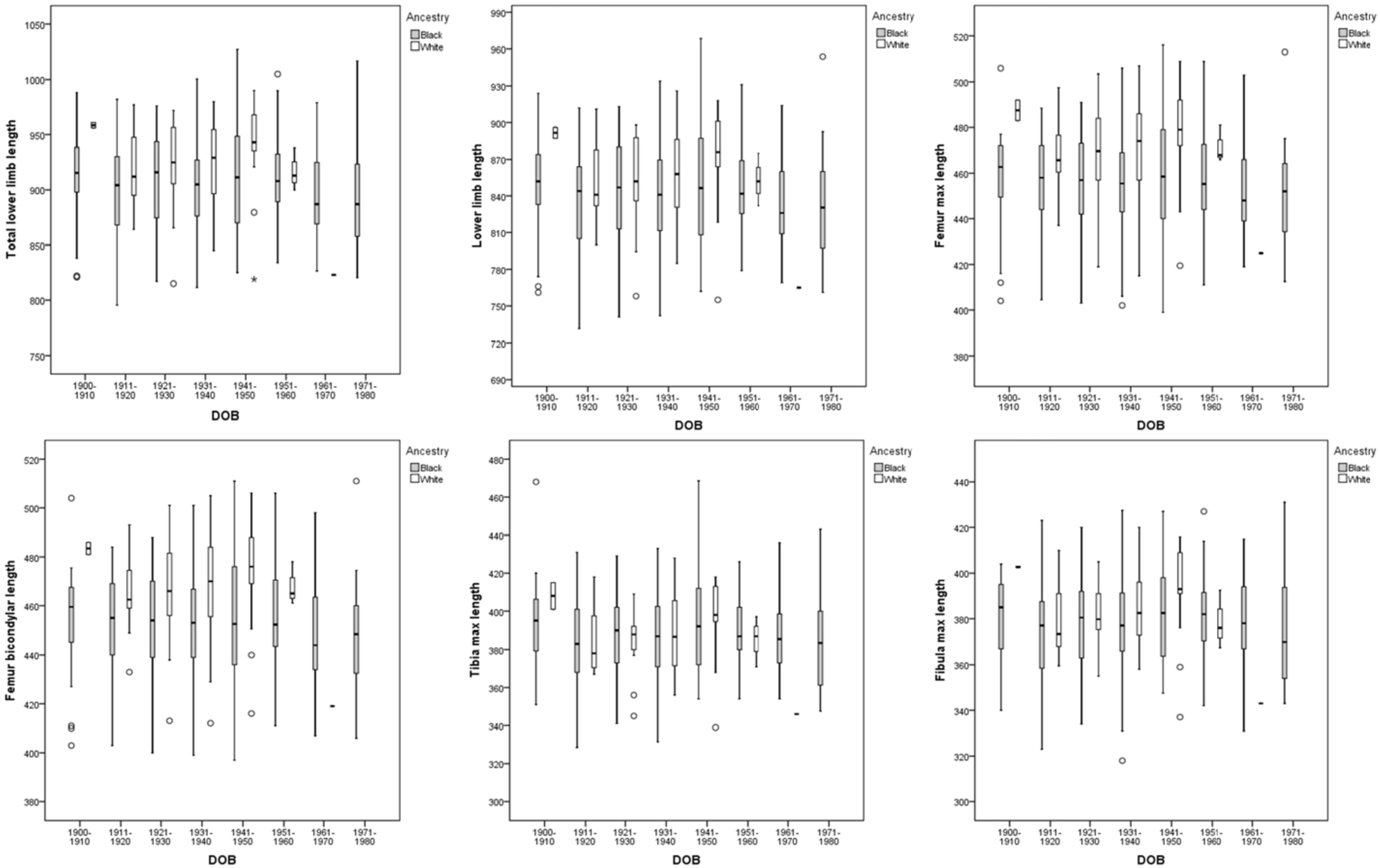

Figure C1.4 Secular trends in the osteometric lower limb length of South African black and white males.

Table C1.3 The sample sizes, mean osteometric sitting heights and Kruskal-Wallis test results between South African black and white males per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Square	p-value
1900 - 1910	SABM	24	613.5	24.59	-	-
	SAWM	1	529.4	-		
1911-1920	SABM	23	608.4	36.94	13.2721	**0.0003**
	SAWM	10	654.1	21.93		
1921-1930	SABM	19	619.9	27.15	9.7353	**0.0018**
	SAWM	11	655.2	24.41		
1931-1940	SABM	31	622.2	25.23	14.2553	**0.0002**
	SAWM	14	659.1	43.48		
1941-1950	SABM	34	624.0	26.78	18.7128	**<0.0001**
	SAWM	16	668.4	27.55		
1951-1960	SABM	33	624.6	24.60	-	-
	SAWM	3	665.0	9.07		
1961-1970	SABM	24	619.0	22.27	-	-
	SAWM	1	573.0	-		
1971-1980	SABM	7	621.1	14.04	-	-
1900-1980	SABM	195	619.6	26.62	60.9308	**<0.0001**
	SAWM	56	656.6	36.23		

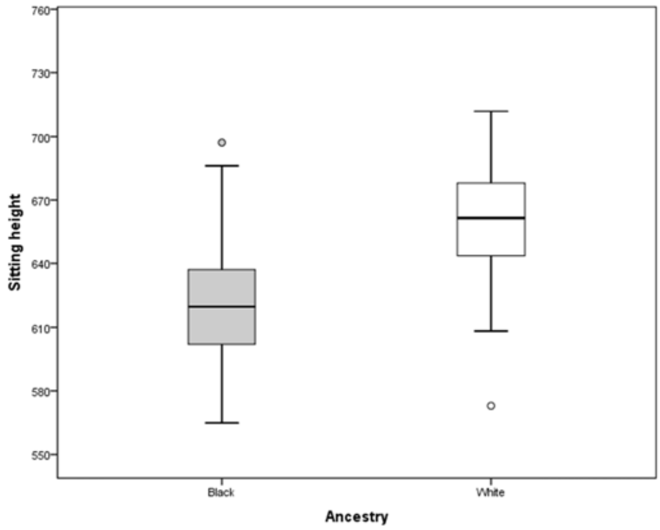

Figure C1.5 Ancestry differences in the osteometric sitting height between South African black and white males over the total period.

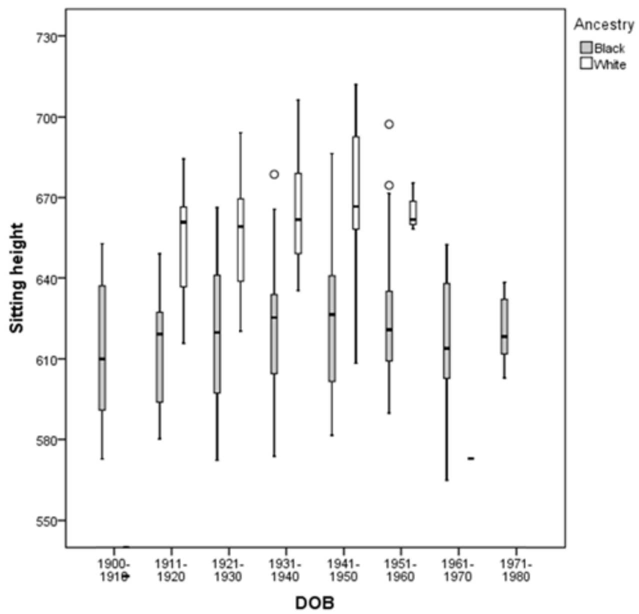

Figure C1.6 Secular trends in the osteometric sitting heights of South African black and white males.

C2: Ancestral differences and secular trends in the osteometric limb lengths of South African black and white females

Table C2.1 The sample sizes, mean osteometric arm lengths and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Arm length*					Humerus max length					Radius max length					Ulna max length				
		N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value
1900-1910	SABF	24	532.0	27.08	0.0192	0.8897	25	299.7	15.11	1.9634	0.1612	24	232.7	12.77	0.6950	0.4045	25	251.4	13.72	1.1389	0.2859
	SAWF	1	541.0	-			1	318.0	-			1	223.0	-			1	239.0	-		
1911-1920	SABF	28	518.4	30.19	0.0812	0.7757	29	292.0	23.49	3.3184	0.0685	28	226.3	10.08	2.7370	0.0980	28	244.9	9,.15	3.5468	0.0597
	SAWF	4	520.0	22.64			4	302.5	11.39			4	217.5	11.73			4	234.3	13.43		
1921-1930	SABF	31	531.9	23.27	0.4347	0.5097	31	297.2	13.20	3.6216	0.0570	31	234.7	11.04	6.4789	**0.0109**	31	253.5	10.85	8.8726	**0.0029**
	SAWF	7	526.4	20.17			7	305.9	9.97			7	220.6	11.93			7	237.1	11.54		
1931-1940	SABF	35	530.3	27.20	1.9339	0.1643	35	298.4	15.09	4.7410	**0.0295**	35	231.9	13.27	0.1847	0.6674	35	250.1	13.51	0.1803	0.6711
	SAWF	5	544.2	12.74			6	312.9	8.09			5	229.5	6.44			6	246.9	7.47		
1941-1950	SABF	38	537.2	32.59	0.2428	0.6222	39	302.3	18.42	2.0231	0.1549	38	235.5	16.10	0.9717	0.3243	37	255.4	15.64	3.3900	0.0656
	SAWF	8	502.3	111.72			7	311.8	14.69			8	229.5	13.10			8	244.3	13.03		
1951-1960	SABF	29	530.0	29.61	2.8083	0.0938	29	298.7	17.29	2.8090	0.0937	30	232.0	13.51	0.8032	0.3701	28	250.0	13.43	0.8068	0.3691
	SAWF	1	582.5	-			1	336.0	-			1	246.5	-			1	264.00	-		
1961-1970	SABF	19	521.2	28.49	-	-	19	293.3	17.36	-	-	19	227.9	12.84	-	-	19	245.9	12.40	-	-
1971-1980	SABF	7	531.6	31.72	-	-	7	296.6	18.61	-	-	7	235.1	15.74	-	-	7	224.1	86.02	-	-
1981-1990	SAWF	1	533.5	-	-	-	1	307.5	-	-	-	1	226.0	-	-	-	1	241.0	-	-	-
1900-1990	SABF	211	529.6	28.85	0.5777	0.4472	214	297.7	17.46	15.2657	**<0.0001**	212	232.1	13.33	4.8060	**0.0284**	210	249.7	20.12	9.2762	**0.0023**
	SAWF	27	524.5	62.54			27	310.1	12.04			27	225.7	11.95			28	242.0	12.01		

*Humerus max length + radius max length

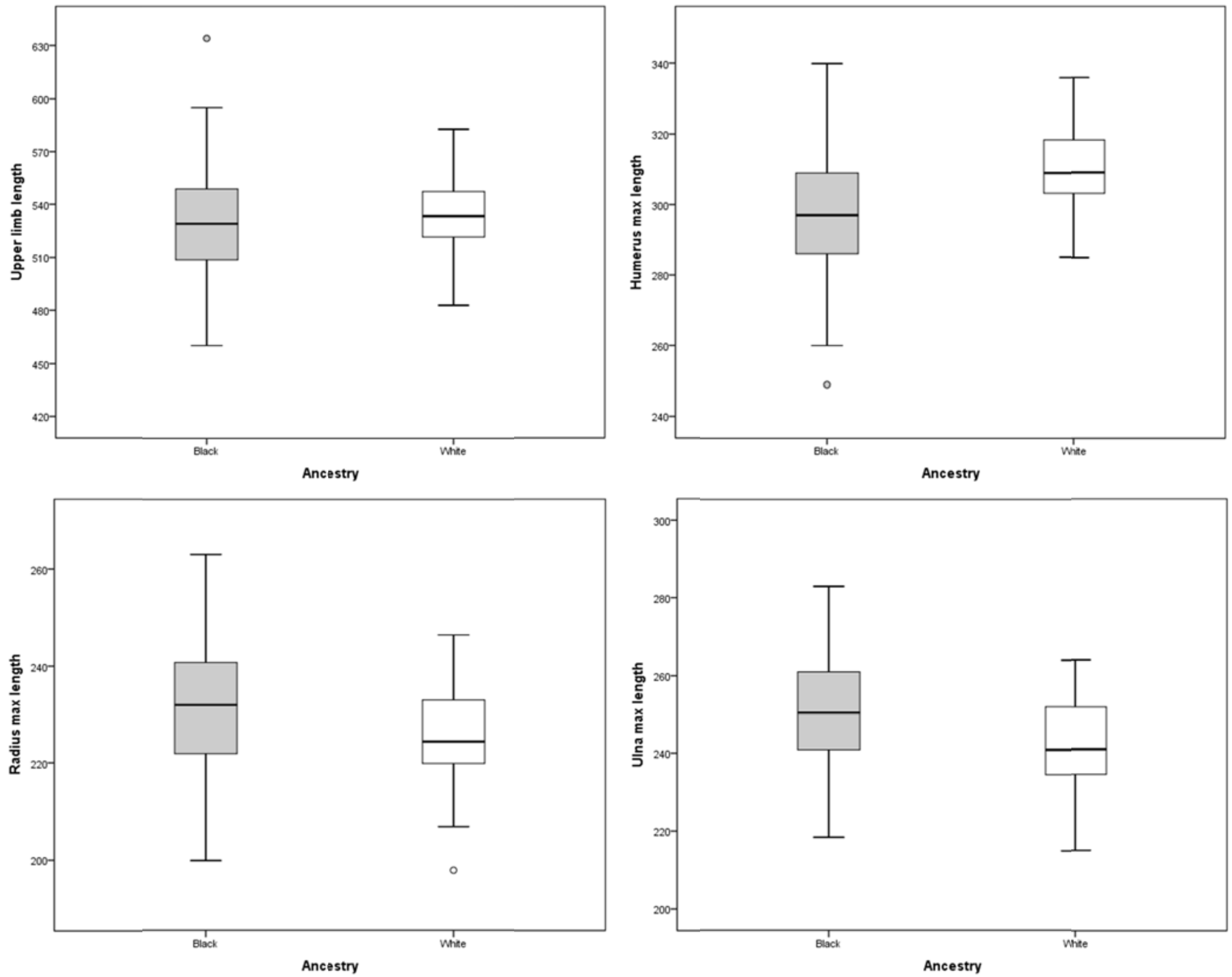

Figure C2.1 Ancestry differences in the osteometric upper limb lengths between South African black and white females over the total period.

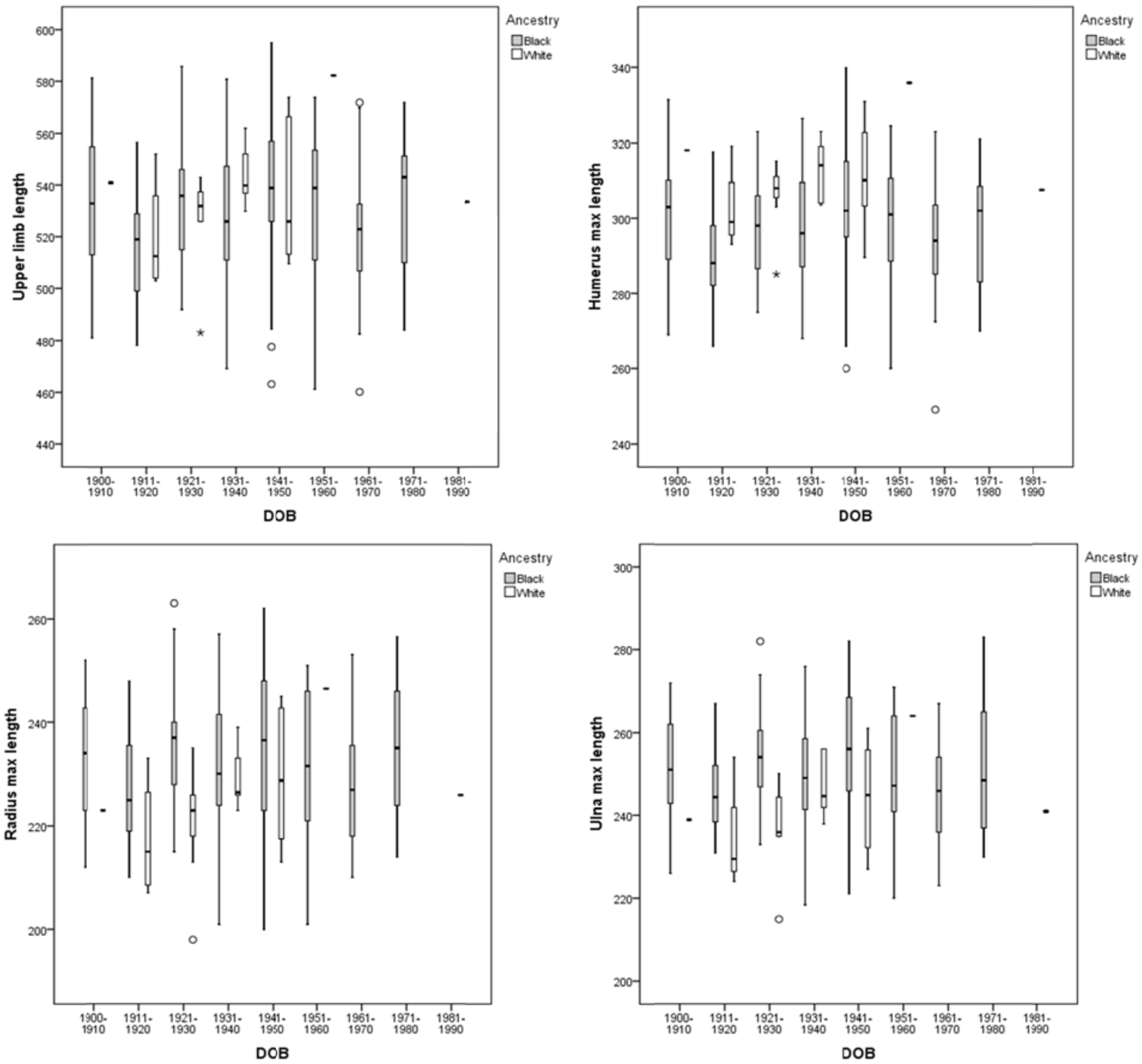

Figure C2.2 Secular trends in the osteometric upper limb lengths of South African black and white females.

Table C2.2 The sample sizes, mean osteometric lower limb lengths and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Total lower limb length					Lower limb length					Femur max length				
		N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
1900-1910	SABF	18	838.1	40.16	-	-	24	781.7	36.34	0.9423	0.3317	25	428.5	20.72	-	-
	SAWF	1	879.0	-			1	818.0	-			1	448.0	-		
1911-1920	SABF	24	815.4	30.69	-	-	27	759.6	27.99	2.2110	0.1370	29	415.0	16.08	-	-
	SAWF	3	794.8	15.00			3	737.0	16.52			3	406.0	9.54		
1921-1930	SABF	26	844.5	29.10	0.0121	0.9123	29	788.6	28.76	0.3839	0.5355	31	429.9	15.17	0.3633	0.5467
	SAWF	7	838.0	30.84			7	777.9	26.89			7	432.9	13.14		
1931-1940	SABF	29	847.8	42.92	0.0148	0.9032	33	789.2	39.50	0.0117	0.9140	34	430.4	24.41	0.3676	0.5443
	SAWF	5	849.9	47.11			5	789.4	45.39			6	437.3	21.65		
1941-1950	SABF	37	854.8	50.75	0.0435	0.8348	39	796.6	50.00	0.0579	0.8098	39	433.4	25.57	0.2743	0.6004
	SAWF	7	854.1	45.27			8	793.3	40.15			8	438.8	21.83		
1951-1960	SABF	28	839.7	46.13	-	-	29	782.2	43.73	-	-	29	427.7	24.80	-	-
	SAWF	1	913.0	-			1	851.0	-			1	463.0	-		
1961-1970	SABF	19	837.4	43.00	-	-	19	783.3	43.51	-	-	19	427.8	22.62	-	-
1971-1980	SABF	7	837.9	49.15	-	-	7	783.1	46.28	-	-	7	427.8	25.84	-	-
1981-1990	SAWF	1	864.0	-	-	-	1	807.0	-	-	-	1	442.0	-	-	-
1900-1990	SABF	188	841.0	42.93	0.1864	0.6659	207	784.0	40.82	0.0428	0.8361	213	427.9	22.33	2.2260	0.1357
	SAWF	25	845.4	41.86			26	785.6	39.11			27	434.6	20.19		

Table C2.2 (continued) The sample sizes, mean osteometric lower limb lengths and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	Femur bicondylar length					Tibia condylo-malleolar length					Fibula max length				
		N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value	N	Mean	SD	Chi-Squared	p-value
1900-1910	SABF	25	424.4	20.25	-	-	24	357.9	17.65	-	-	-	-	16.82	-	-
	SAWF	1	444.0	-			1	374.0	-			-	-	-		
1911-1920	SABF	29	410.6	15.92	-	-	27	349.2	13.54	-	-	28	341.2	12.51	-	-
	SAWF	3	402.7	11.02			4	338.8	9.98			3	333.3	13.32		
1921-1930	SABF	30	425.2	14.31	0.5153	0.4728	29	362.9	15.54	2.7555	0.0969	29	355.2	16.42	2.7569	0.0968
	SAWF	7	428.4	12.59			7	349.5	14.70			7	344.7	13.24		
1931-1940	SABF	34	425.5	23.86	0.8273	0.3630	35	361.4	18.52	0.1846	0.6675	33	353.6	19.24	0.2640	0.6074
	SAWF	6	433.5	21.36			5	357.8	22.32			4	349.3	13.74		
1941-1950	SABF	39	428.7	25.39	0.3209	0.5711	40	367.5	26.61	0.8645	0.3525	38	355.8	28.92	0.1923	0.6610
	SAWF	8	434.4	21.29			9	359.1	18.88			7	354.2	20.15		
1951-1960	SABF	29	423.3	24.38	-	-	29	358.9	20.33	-	-	28	337.8	59.47	-	-
	SAWF	1	460.0	-			1	391.0	-			1	385.0	-		
1961-1970	SABF	19	423.2	23.04	-	-	19	360.2	22.11	-	-	19	352.6	21.10	-	-
1971-1980	SABF	7	423.1	25.39	-	-	7	360.0	21.18	-	-	6	357.9	20.08	-	-
1981-1990	SAWF	1	439.0	-	-	-	1	368.0	-	-	-	1	361.0	-	-	-
1900-1990	SABF	212	423.3	22.03	2.7890	0.0949	210	360.3	20.39	1.1318	0.2874	204	350.2	29.42	0.3436	0.5577
	SAWF	27	430.6	19.91			28	355.6	18.97			23	349.4	17.71		

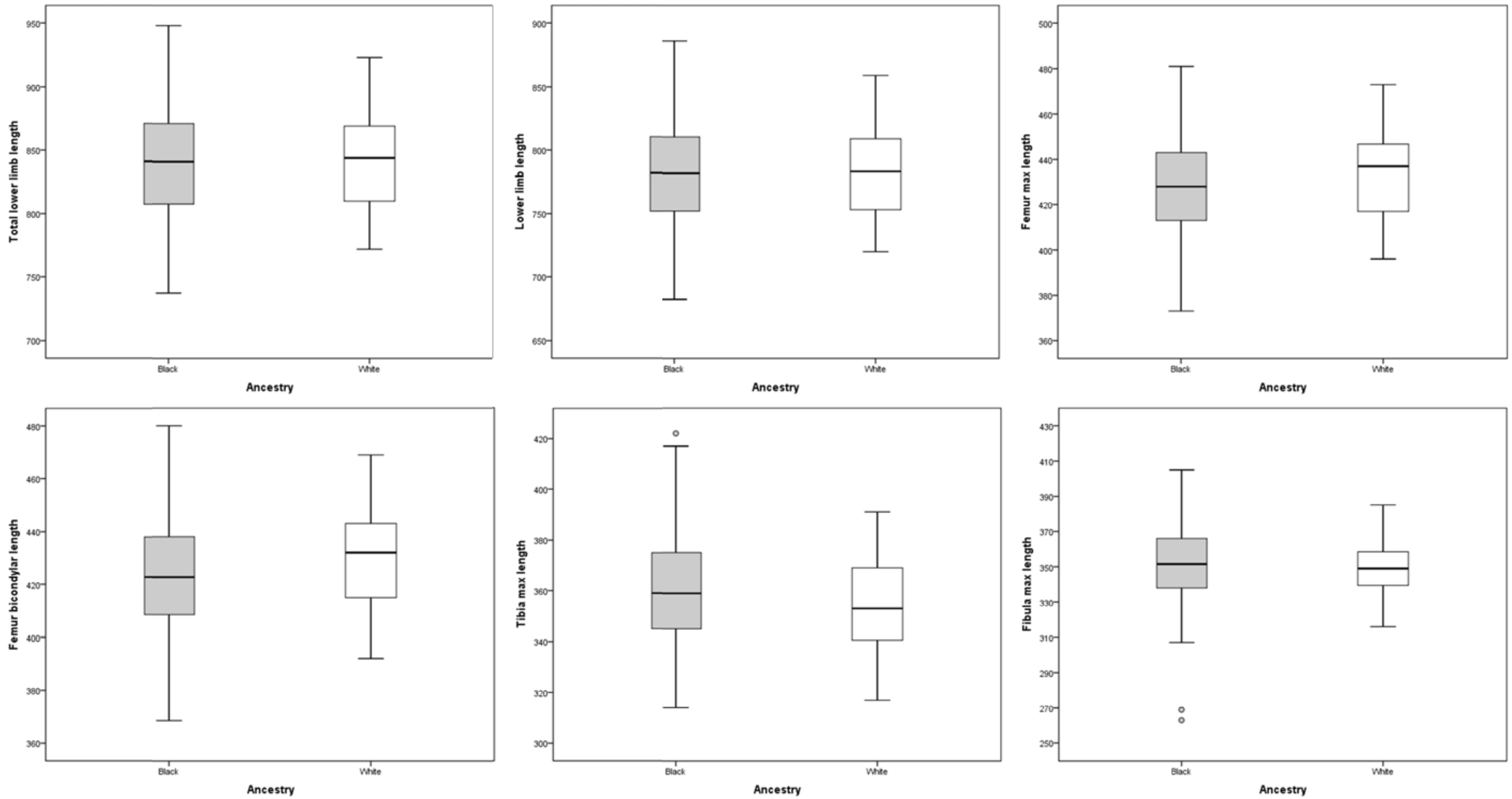

Figure C2.3 Ancestry differences in the osteometric lower limb lengths between South African black and white females over the total period.

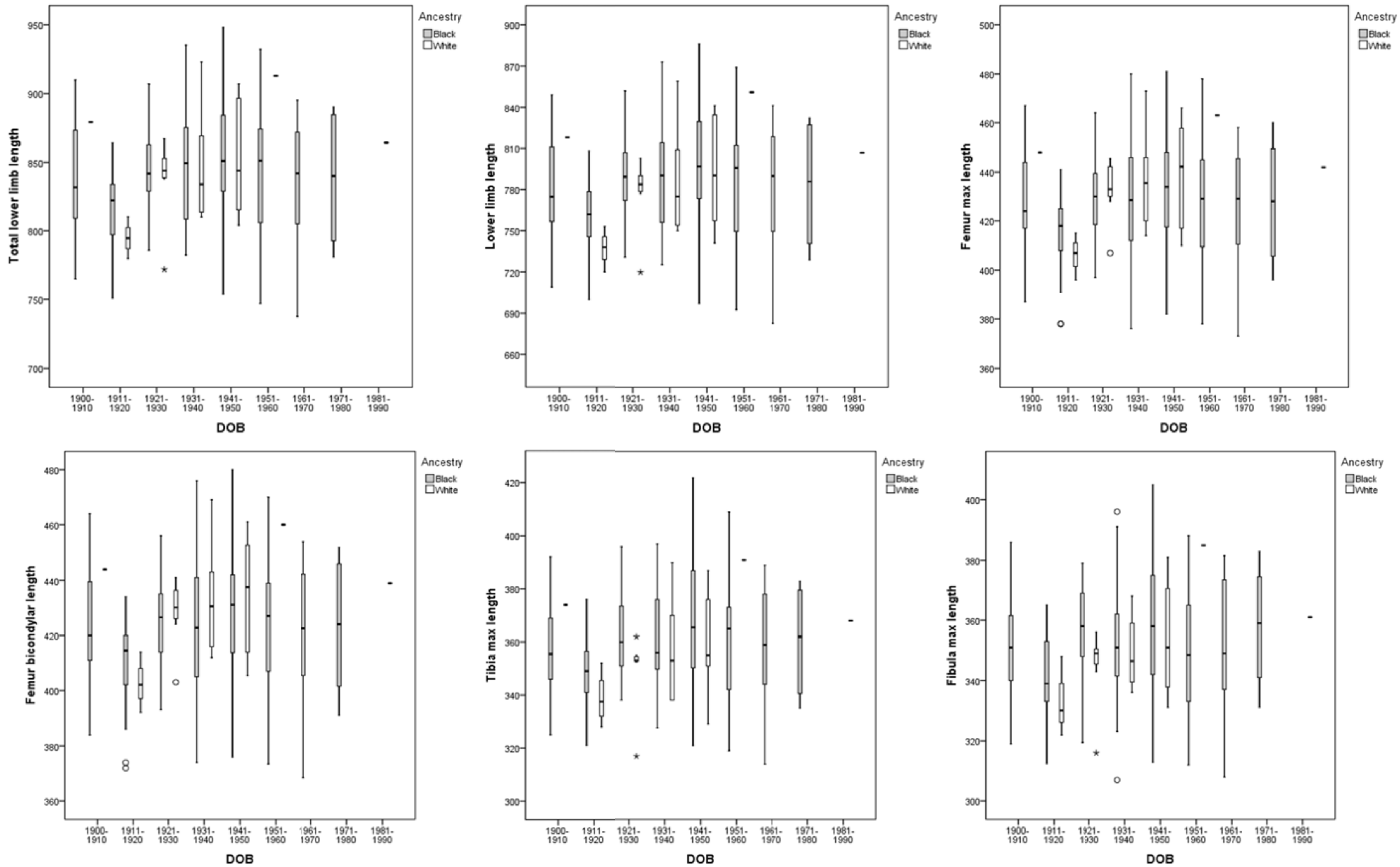

Figure C2.4 Secular trends in the osteometric lower limb lengths of South African black and white females.

Table C2.3 The sample sizes, mean osteometric sitting heights and Kruskal-Wallis test results between South African black and white females per decade and overall period.

DOB	Ancestry	N	Mean	SD	Chi-Square	p-value
1900 - 1910	SABF SAWF	21 1	581.8 645.8	35.28 -	-	-
1911-1920	SABF SAWF	29 3	574.1 597.2	40.35 15.17	-	-
1921-1930	SABF SAWF	28 7	576.7 624.7	35.78 17.15	11.7160	**0.0006**
1931-1940	SABF SAWF	28 5	587.6 634.9	35.57 7.83	10.3261	**0.0013**
1941-1950	SABF SAWF	30 6	584.5 604.5	41.84 54.88	3.8126	**0.0509**
1951-1960	SABF SAWF	22 1	588.1 664.3	39.46 -	-	-
1961-1970	SABF	16	585.6	19.41	-	-
1971-1980	SABF	5	584.9	24.08	-	-
1981-1990	SAWF	1	634.5	-	-	-
1900-1990	SABF SAWF	179 24	582.3 621.3	36.36 32.70	33.2370	**<0.0001**

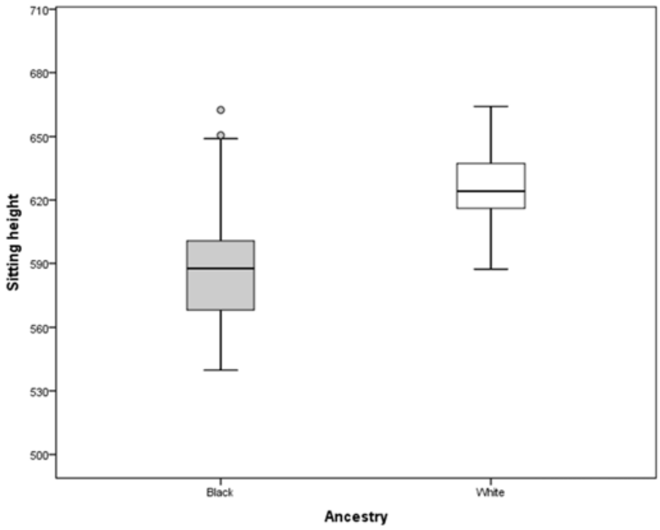

Figure C2.5 Ancestry differences in the osteometric sitting height between South African black and white females over the total period.

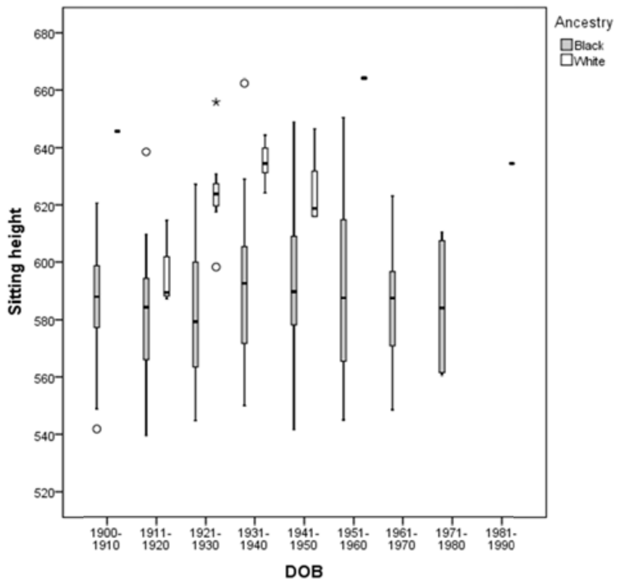

Figure C2.6 Secular trends in the osteometric sitting heights of South African black and white females.

C3: Discriminant function analysis of the indices of South African black and white population groups

Table C3.1 Cross-validation results using quadratic discriminant function of 7 indices* of South African population groups.

Population groups	**Black males**	**Black females**	**White males**	**White females**
Black males (n = 176)	**143**	25	7	1
Average posterior probability	**0.8136**	0.7179	0.6281	0.5991
Black females (n = 154)	43	**101**	8	2
Average posterior probability	0.7020	**0.7829**	0.5776	0.7699
White males (n = 47)	10	7	**23**	7
Average posterior probability	0.6029	0.8077	**0.6735**	0.6266
White females (n = 23)	0	3	8	**12**
Average posterior probability	0	0.8699	0.7417	**0.6883**
TOTAL	196	136	46	22
Average posterior probability	0.7784	0.7742	0.6618	0.6721
PRIORS	0.44	0.385	0.1175	0.0575

*Indices: Intermembral index, forearm ratio 3 (ulna physiological length/TSH), arm ratio, brachial index, total lower limb ratio, thigh ratio 1 and thigh ratio 2

Wilks' Lambda	<0.0001
Hit ratio	69.75%
Proportional chance criterion	0.35891
Suggested threshold	0.6089

Table C3.2 Cross-validation results using quadratic discriminant function of arm indices* of South African population groups.

Population group	Black males	Black females	White males	White females
Black males (n = 186) Average posterior probability	**150** **0.7724**	20 0.5713	15 0.5538	1 0.8531
Black females (n = 165) Average posterior probability	92 0.6759	**40** **0.6554**	29 0.5275	4 0.6279
White males (n = 49) Average posterior probability	11 0.5380	7 0.7757	**20** **0.5937**	11 0.6642
White females (n = 23) Average posterior probability	0 0	2 0.6660	6 0.6561	**15** **0.7158**
TOTAL Average posterior probability	253 0.7271	69 0.6435	70 0.5631	31 0.6906
PRIORS	0.43972	0.39007	0.11584	0.05437

*Arm Indices: Forearm ratio 3 (ulna physiological length/TSH), forearm ratio 1, brachial index, upper limb ratio

Wilks' Lambda	<0.0001
Hit ratio	53.19%
Proportional chance criterion	0.3621
Suggested threshold	0.6121

Table C3.3 Cross-validation results using quadratic discriminant function of lower limb indices* of South African population groups.

Population group	Black males	Black females	White males	White females
Black males (n = 178)	**134**	34	10	0
Average posterior probability	**0.6851**	0.6172	0.4971	0
Black females (n = 158)	57	**89**	9	3
Average posterior probability	0.6208	**0.7187**	0.4893	0.3951
White males (n = 49)	19	12	**17**	1
Average posterior probability	0.6150	0.5244	**0.4879**	0.4094
White females (n = 23)	3	13	6	**1**
Average posterior probability	0.4252	0.5327	0.4669	**0.4404**
TOTAL	213	148	42	5
Average posterior probability	0.6580	0.6633	0.4874	0.4070
PRIORS	0.43627	0.38725	0.1201	0.05637

*Leg Indices: Total lower limb ratio, thigh ratio 1, thigh ratio 2 and leg ratio 1

Wilks' Lambda	<0.0001
Hit ratio	59.07%
Proportional chance criterion	0.3579
Suggested threshold	0.6079

Appendix D: Osteometric differences in the limb lengths between white South African and North American males and females

D1: Differences in the osteometric arm lengths between white South African and North American males and females

Table D1. The sample sizes, mean osteometric upper limb lengths and Kruskal-Wallis test results between white South African and North American males and females for the overall period.

Ancestry	Arm length					Humerus max length					Radius max length					Ulna max length				
	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value
SAWM	67	588.4	27.35	0.1054	0.7455	70	336.8	16.20	4.5233	0.0334	67	251.7	12.48	4.1052	0.0428	68	270.3	12.46	2.6802	0.1016
NAWM	72	588.2	24.80			73	332.3	14.18			72	255.7	11.78			72	273.3	13.31		
SAWF	27	524.5	62.54	0.2112	0.6458	27	310.1	12.05	0.5990	0.4390	27	225.7	11.95	1.7782	0.1824	28	242.0	12.01	1.1507	0.2834
NAWF	45	537.3	23.58			45	307.6	14.12			45	229.6	10.79			45	245.4	10.82		

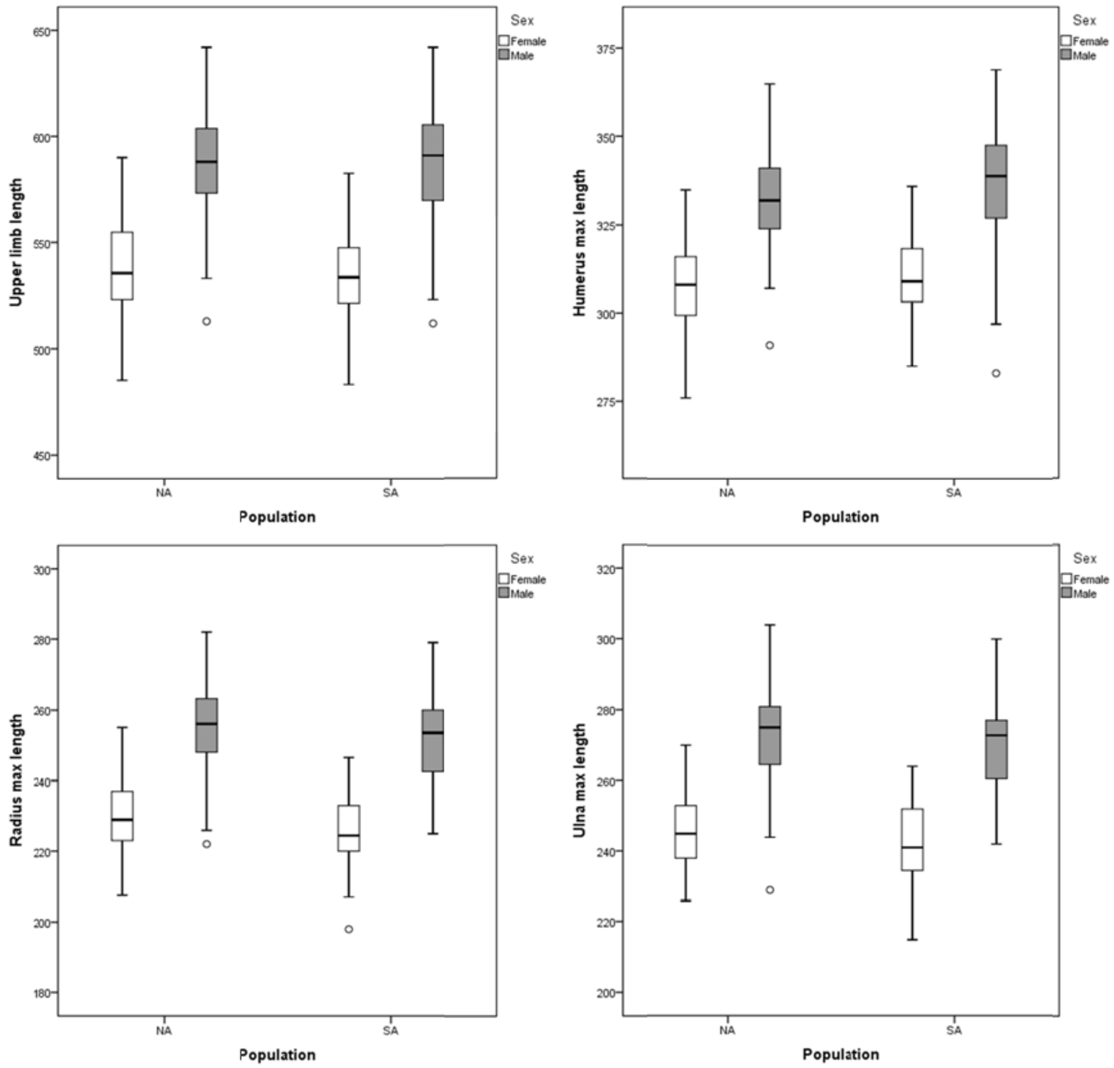

Figure D1. Differences in the osteometric upper limb lengths between white South African and North American males and females.

D2: Differences in the osteometric lower limb lengths between white South African and North American males and females

Table D2 The sample sizes, mean osteometric lower limb lengths and Kruskal-Wallis test results between white South African and North American males and females for the overall period.

Ancestry	Total lower limb length					Lower limb length					Femur max length				
	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value
SAWM	58	924.0	42.30	0.0635	0.8010	65	857.6	39.68	0.0411	0.8394	70	471.2	21.94	0.1218	0.7271
NAWM	68	924.6	42.40			72	858.1	39.76			72	471.5	22.88		
SAWF	25	845.4	41.86	1.1146	0.2911	26	785.6	39.11	0.5655	0.4521	27	434.6	20.19	0.4803	0.4883
NAWF	43	855.8	40.49			45	784.3	79.79			44	438.4	21.08		

Ancestry	Femur bicondylar length					Tibia condylo-malleolar length					Fibula max length				
	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value	N	Mean	SD	Chi-Square	p-value
SAWM	70	468.1	21.94	0.4344	0.5098	66	388.6	20.22	0.5315	0.4660	57	384.1	18.79	0.7454	0.3879
NAWM	72	466.7	20.73			72	391.4	21.19			72	387.2	21.18		
SAWF	27	430.6	19.91	0.4886	0.4845	28	355.6	18.97	0.8554	0.3550	23	349.4	17.71	0.6465	0.4214
NAWF	44	434.3	20.72			45	359.6	19.49			45	354.0	18.40		

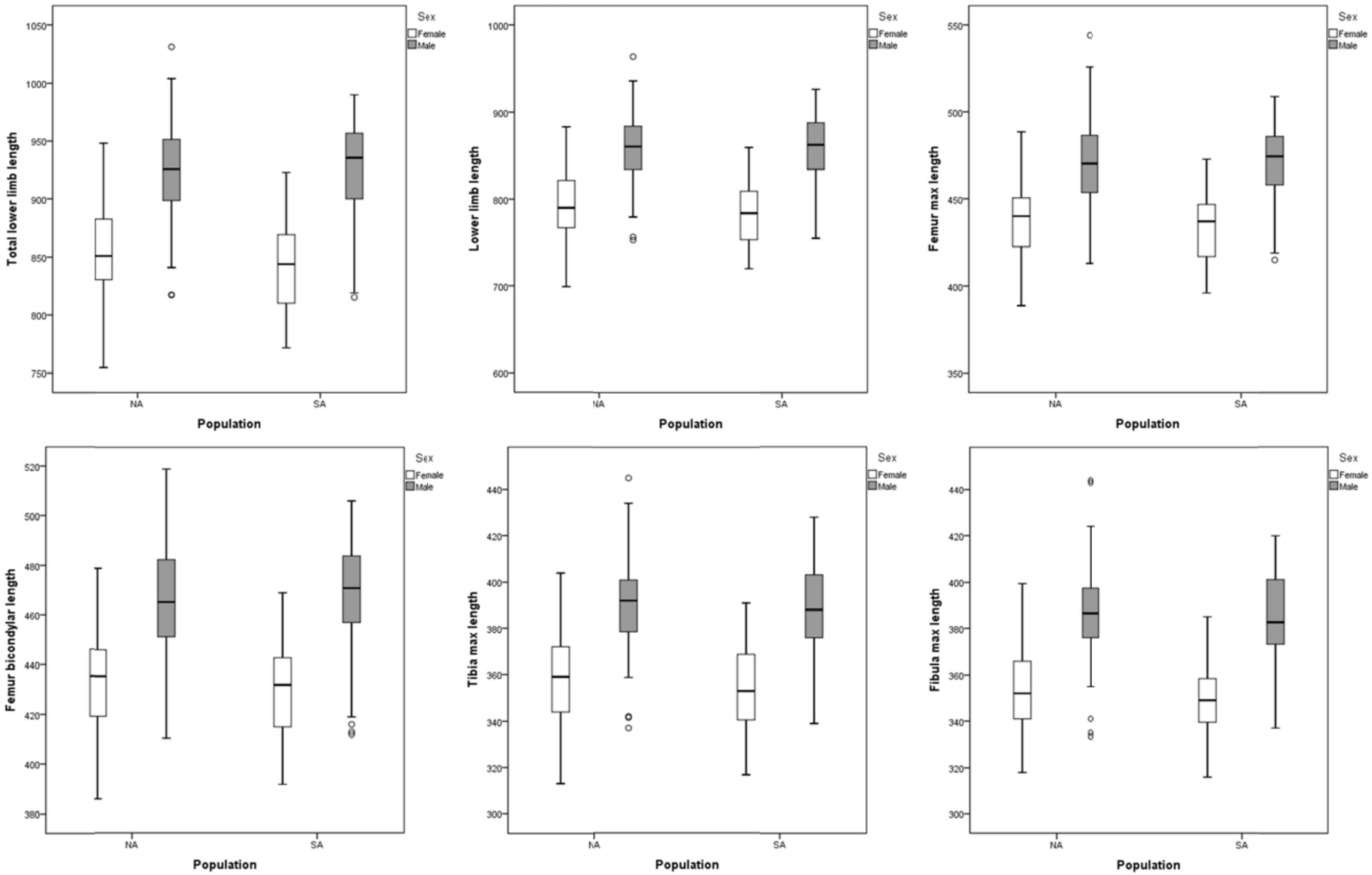

Figure D2 Differences in the osteometric lower limb lengths between white South African and North American males and females.

D3: Differences in the osteometric sitting heights between white South African and North American males and females

Table D3 The sample sizes, mean osteometric sitting heights and Kruskal-Wallis test results between white South African and North American males and females for the overall period.

Ancestry	N	Mean	SD	Chi-Square	p-value
SAWM	56	656.6	36.23	21.6398	**<0.0001**
NAWM	69	682.9	22.76		
SAWF	24	621.3	59.42	8.7882	**0.0030**
NAWF	44	643.3	24.54		

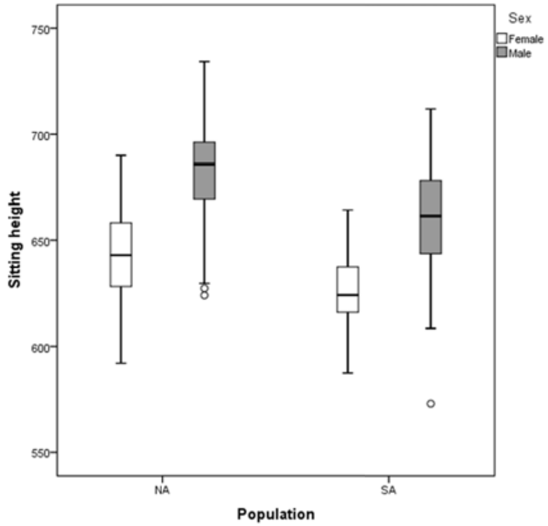

Figure D3 The differences in the osteometric sitting height between white South African and North American males and females.

The Research Ethics Committee, Faculty Health Sciences, University of Pretoria complies with ICH-GCP guidelines and has US Federal wide Assurance.
- FWA 00002567, Approved dd 22 May 2002 and Expires 20 Oct 2016.
- IRB 0000 2235 IORG0001762 Approved dd 22/04/2014 and Expires 22/04/2017.

UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

Faculty of Health Sciences Research Ethics Committee

12/05/2014

Approval Certificate
New Application

Ethics Reference No.: 80/2014

Title: Limb proportions in South Africans: secular changes, population differences and implications for stature estimation

Dear Ms Jolandie Myburgh

The **New Application** as supported by documents specified in your cover letter for your research received on the 27/02/2014, was approved, by the Faculty of Health Sciences Research Ethics Committee on the 12/05/2014.

Please note the following about your ethics approval:
- Ethics Approval is valid for 3 years
- Please remember to use your protocol number (**80/2014**) on any documents or correspondence with the Research Ethics Committee regarding your research.
- Please note that the Research Ethics Committee may ask further questions, seek additional information, require further modification, or monitor the conduct of your research.

Ethics approval is subject to the following:
- The ethics approval is conditional on the receipt of 6 monthly written Progress Reports, and
- The ethics approval is conditional on the research being conducted as stipulated by the details of all documents submitted to the Committee. In the event that a further need arises to change who the investigators are, the methods or any other aspect, such changes must be submitted as an Amendment for approval by the Committee.

We wish you the best with your research.

Yours sincerely

Dr R Sommers; MBChB; MMed (Int); MPharMed.
Deputy Chairperson of the Faculty of Health Sciences Research Ethics Committee, University of Pretoria

The Faculty of Health Sciences Research Ethics Committee complies with the SA National Act 61 of 2003 as it pertains to health research and the United States Code of Federal Regulations Title 45 and 46. This committee abides by the ethical norms and principles for research, established by the Declaration of Helsinki, the South African Medical Research Council Guidelines as well as the Guidelines for Ethical Research: Principles Structures and Processes 2004 (Department of Health).

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