UNIVERSITY OF GHANA

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CORRELATION OF SEX, HEIGHT AND HANDEDNESS WITH ANTHROPOMETRIC FOOT AND HAND MEASUREMENTS OF YOUNG ADULT GHANAIANS

BY

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DECLARATION BY CANDIDATE

I hereby declare that this thesis is a product of my own research undertaken under supervision and has neither been presented in whole nor in part for the award of another degree elsewhere. I take full responsibility for any residual flaws in this work.

Signature: …………………………….. Date: ..……/………/………

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DECLARATION BY SUPERVISORS

We hereby declare that the practical work and presentation of this thesis were supervised in accordance with the guidelines on supervision of thesis laid down by the University of Ghana.

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(Professor Clifford Nii Boi Tagoe)

DEDICATION

I dedicate this project to God Almighty, my saviour and redeemer, my strength and ultimate source of wisdom and knowledge. He has shown me his powerful hand and gentle heart throughout this academic journey. It is only by his divine protection and divine inspiration that I have been able to complete this program. I also dedicate this project to my parents; Mr. Baffour Otuo Akyeampong and Mrs. Johanna Naana Akyeampong. Dad, you never doubt my abilities and you always give direction and counsel that have shaped my life. You have been truly supportive through this academic journey in more ways than I can count and indeed like you always say, "Believers, shall enjoy". *Nyame nhyira wo na ɔnyɛ wo kɛse.* Mum, without you I would not be here. Even after age 57, you found strength and motivation to start and successfully complete a master's program. If at any point I found no reason to go on, you were my one reason to rise up and make each day count. To my grandfather, Mr. Anthony K. Interkudzie and grandmother Mrs. Elizabeth Interkudzie. You have accommodated me in your home these past few years without any complaint. I love you.

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LIST OF ABBREVIATIONS

Abbreviation/phrase	**Meaning**
2D:4D	Ratio of length of second digit to length of fourth
AER	Apical Ectodermal Ridge
AP	Anteroposterior
AR	Androgen Receptor
BMI	Body Mass Index
DHT	Dihydrotestosterone
DNA	Deoxyribonucleic Acids
DV	Dorsoventral
E	Oestrogen
E1	Oestrone
E2	Oestradiol / 17β-Oestradiol
E3	Oestriol
Erα	Oestrogen Receptor Alpha
Erβ	Oestrogen Receptor Beta
FB	Foot Breadth
FC	Foot Circumference
FH	Foot Height
FL	Foot Length
GH	Growth Hormone
GnRH	Gonadotropin-Releasing Hormone

Abbreviation/phrase	**Meaning**
HB	Hand Breadth
HC	Hand Circumference
HI	Hand Index
HL	Hand Length
IGF-I	Insulin Growth Factor I
L3-L5	Third To Fifth Lumbar Segments
LFB	Left Foot Breadth
LFC	Left Foot Circumference
LFL	Left Foot Length
LHB	Left Hand Breadth
LHC	Left Hand Circumference
LHI	Left Hand Index
LHL	Left Hand Length
LL	Leg Length
LLL	Lower Leg Length
LSB	Left Shoe Breadth
LSL	Left Shoe Length
PD	Proximodistal
RFB	Right Foot Breadth
RFC	Right Foot Circumference
RFL	Right Foot Length
RHB	Right Hand Breadth

Abbreviation/phrase	Meaning
RHC	Right Hand Circumference
RHI	Right Hand Index
RHL	Right Hand Length
RSB	Right Shoe Breadth
RSL	Right Shoe Length
SB	Shoe Breadth
Shh	Sonic hedgehog
SFL	Standardised foot length
SHL	Standardised hand length
SL	Shoe Length
SP	Sectioning Point
T	Testosterone
TL	Thigh Length
ULL	Upper Limb Length
WHR	Waist To Hip Ratio
WNT/Wnt	Wingless-Type
ZPA	Zone Of Polarizing Activity

ABSTRACT

Studies have marked the importance of the relationship between height and hand and foot dimensions for forensic research. Also, the interaction between height, sex-related asymmetries, and handedness related asymmetries in hands and feet have been shown to vary in different populations. Hence the aims of this study are to determine whether foot and hand dimensions (length, breadth and circumference) are good estimators of sex and height and whether handedness and sex are associated with the length asymmetries of the hands and feet. The study sample consisted of 100 (89 right-handed and 11 left-handed) male and 100 (90 right-handed and 10 left-handed) female students aged 18-30 years (average age: 22.37 ± 3.18 years) from the University of Ghana, College of Health Sciences, Korle-Bu. Measurements of standing height, length, breadth and circumference of both hands and both feet were taken and then handedness was determined using the Edinburgh Handedness Inventory. Statistical analysis included univariate and multivariate linear correlation and regression models for height estimation. Sex prediction involved sectioning point analysis and multivariate linear correlation and regression analyses. Mean height was 175.13 ± 7.82 cm in males and 164.23 ± 6.18 cm in females. All the height models were statistically significant ($p < 0.05$). Male left foot length (LFL) correlated most positively with height and had the highest predictability for the linear models ($r = 0.753$, $R^2 = 0.567$) while the right foot in males yielded the best coefficients for the multiple regression models ($r = 0.759$, $R^2 = 0.577$). Sex was estimated more accurately in females (RHL = 92.85%) than males (LHL = 82.85%) from sectioning point analysis and multiple regression methods (right foot: 92.85% and 80.00% respectively). In addition, sex rather than handedness had a significant influence on

standardised hand length (p = 0.007) with asymmetry mostly favouring the left in hands and feet, irrespective of handedness. These results suggest that foot and hand dimensions can be used to predict height and sex in young adults especially with dimensions of length.

CHAPTER ONE

1. INTRODUCTION

Anthropology studies human beings in aspects ranging from the biology and evolutionary history of *Homo sapiens* to the features of society and culture that decisively distinguish humans from other animal species (Hopkins et al., 2015).

Anthropometry is the scientific study of the measurement of the human body which includes (but is not limited to) the dimensions of bone, muscle, and adipose (fat) tissue. The word "anthropometry" is of Greek origin. It is derived from "anthropos" meaning "human" and "metron" meaning "measure" (National Health and Nutrition Examination Survey (NHANES), 2007). Anthropologists have emphasized the essence of anthropometry for the forensic field during identification of persons and victims of disasters (Aboul-Hagag, Mohamed, Hilal, & Mohamed, 2011; Hemy, Flavel, Ishak, & Franklin, 2013).

There is a relationship between each body part and the whole body, as this is demonstrated by the correlation that various body parts show with the height of an individual (Moorthy, Mostapa, Boominathan & Raman, 2014). Some scholars have studied the relationship between long bones and height (Jasuja & Singh, 2004; Rao, 2010). Recent studies have, however, established that the dimensions of the bones of the lower extremities have greater association with height than those of the upper extremities (Fessler, Haley, & Roshni, 2005; Nor et al., 2013). These dimensions are a function of morphology. According to Scott, Menz and Newcombe (2007), foot morphology is greatly influenced by factors such as race, sex, age and behaviour.

1.0 Sexual dimorphism

Sexual dimorphism refers to all the sex related variations that exist between males and females at either morphological or nuclear level. It is not only observable from the differential development of the internal and external genitalia but also from extragenital features which include body size, appendages and specific cellular components (Kanchan & Krishan, 2011). Modern humans are said to have evolved to become less dimorphic than their hominin ancestors (Hemy et al., 2013), nonetheless there are ample measurable morphological differences between sexes of *Homo sapiens* (Wells, 2007).

Hemy et al. (2013), reported that there were significant ($p < 0.001$) sex differences for all foot measurements. According to these authors sex can be classified using single foot variables to produce a high degree of expected accuracy (79.5 - 91.5%). Geetha, Athavale and Swathi (2015) also observed sex differences in measurements while predicting height from hand dimensions.

Generally men are thought to have longer and broader hands and feet than women of similar stature. Contrary to common thought, Wunderlich and Cavanagh (2001) demonstrated that female foot sizes are not merely scaled down versions of male foot sizes. These authors proved that females have a higher medial longitudinal arch and shallower first toe than males of comparative foot length. Similarly, females were reported to have a shorter ankle length and smaller instep circumference than men of similar foot length. These physical evidences of sexual differences within and between populations are undoubtedly a result of a complex interplay of environmental and genetic factors (France, 1998).

A discussion on sexual dimorphism is also incomplete without the mention of sex hormones which are responsible for development of certain physical features. In males, testosterone is the major sex hormone secreted. It is key for the development of secondary sexual characters and the dimorphisms in behaviour and morphology of male vertebrates (Goymann & Wingfield, 2014). It is synthesized in relatively larger amounts in males than in females. This steroid hormone increases growth of muscle, bone mineral density and strength of bones (Borst et al., 2007). Oestrogen is another hormone that affects sexual dimorphism (Zheng & Cohn, 2011). It is also synthesized in relatively larger amounts in females than in males and also plays important roles in the development of secondary sexual characteristics. Lee and Howell (2006) emphasized that oestrogen functions in the deceleration of growth in height. It is also known to decrease muscle mass and bone density.

In addition to sexual dimorphism, hands and feet have been reported to differ in size from left to right (Banik, Das, Kaushik, & Manisha, 2016). Research by Kagan (2012) points to handedness and foot dominance in order to explain this phenomenon.

1.1 Handedness and morphological asymmetries in hands and feet

Corey, Hurley and Foundas (2001) defined handedness as the individual's preference to use one hand predominantly for unimanual tasks and/or the ability to perform these tasks more efficiently with one hand. In every human population, the majority of individuals (between 70% and 95%) are right-handed while a minority (between 5% and 30%) are left-handed (Holder, 1997). According to this author, an indeterminate number of individuals can be best described ambidextrous.

In earlier studies, when measurements from the two halves of the body were compared, the values from the right half were different from those belonging to the left half (Garn, Mayor, & Shaw, 1976; Schell, Johnsmn, Smith, & Paolone, 1986). This difference is usually more obvious in the upper extremities than in the lower extremities and is believed to arise as a result of hand dominance (Ulijaszek & Mascie-Taylor, 1994). In right handed individuals, asymmetry generally favours the right hand with respect to hand width, whereas asymmetry favouring the left hand in left handers is lesser and somewhat irregular (Neumann, 1992).

Similarly morphological foot asymmetry is observed in many individuals. Sometimes this difference is not so conspicuous but is other cases, the feet may differ as much as half a shoe size. Trivers, Palestis, Fink and Manning (2015) proved that hand performance (handedness) was associated with foot asymmetry. Their research showed that boys whose right hands were faster at a unimanual tasks possessed a larger right foot than left. The pattern was similar in left handed boys. Boys whose left hands were faster at the task possessed longer left feet than right. This suggests that foot morphology is a correlate of hand preference and dexterity. The logic is that, the more biased a person is in the use of one hand over the other, the larger the sizes of body parts on that size of the body.

Some researchers have established that in many human populations, where there is a right hand preference there is also a higher probability of right foot preference (Barut, Ozer, Gumus, & Yunten, 2007). Comparatively, there is a weaker association between left-hand preference and left-foot preference according to the latter author. Thus, the theory of the differential use of hands for manual tasks alone does not provide an adequate explanation for these asymmetries. Several studies have also shown that sex contributes to foot and hand asymmetries in humans (Case & Ross, 2007; Mascie-Taylor, MacLarnon, Lanigan, & McManus, 1981).

The relationships between sex, handedness, height, foot and hand measurements must be clearly understood. This is in order to improve human life especially by exploiting its problem solving capabilities in the field of forensics, where mass disasters often create an overwhelming task for experts during preliminary identification of victims.

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1.2 PROBLEM STATEMENT

Forensic identification of persons from dismembered, mutilated and fragmented remains is a challenge to forensic experts; under such circumstances, complete identification becomes improbable and partial identification assumes importance to progress into further investigations (Kanchan et al., 2008). This problem is aggravated in cases of mass disasters, explosions, and assault cases where the body is dismembered and skeletonised, obscuring identification (Kumar, Kumar, Tyagi, & Aggar, 2009). Several morphometric studies exist that have emphasized the estimation of these parameters from lower extremities (Ahmed, 2013; Jervas et al., 2016; Sen & Ghosh, 2008), thus, the plausibility of such predictions using foot measurements. Moreover, more than a few scientists have attempted the estimation of height, age and sex by studying long bones, with variable degrees of success (Ozden, Balci, Demiru, Turgut, & Ertugrul, 2005).

Research has shown that anthropometric variables differ significantly within a family or a nation and between nations (Ismaila, 2009). Ukoha, Egwu, Ezeani and Anyabolu (2014) stated that the morphology of human foot varies significantly as a result of the combined effects of heredity, lifestyle and climatic factors. According to a study conducted by Krauss, Langbein, Horstmann and Grau (2011), these dissimilarities are also sexually dimorphic. These significant variations compound the problem of person identification and present a more daunting task in forensic analysis when both footedness and handedness must be determined.

Levy and Levy (1978) examined the correlation between handedness and foot length asymmetry in 98 females and 52 males. They found that right-handed males had longer right feet and left-handed males had longer left feet. The relationships in females were however reversed. Since then, several efforts have been made to reproduce these results but Levy and Levy's findings could not be confirmed (Mascie-Taylor & McManus, 1981; Means & Walters, 1982; Trivers et al., 2015)

1.3 JUSTIFICATION

Age, height, race and sex are considered as the big four of forensic anthropometry (Ahmed, 2013). These identification parameters represent the preliminary and most important stages of the determination of the identity of an individual (Rai, Krishan, Kaur, & Anand, 2008). The findings from this research will have useful applications in forensics. For instance, identification of victims of different geographical and ethnic origins, especially those with highly fragmented and commingled remains, as a result of mass fatalities require forensic anthropological data (Mundorff, Bartelink, & Mar-Cash, 2009; Sledzik et al., 2009).

There is growing ease of international travel. This development together with unpredictable natural and human-made disasters presents catastrophe managers with the arduous task of identifying victims from body parts without the benefit of a manifest or record(s) of the possible victims (Aboagye, Ahenkorah, Hottor & Addai 2014). DNA analysis has proven to be useful tool in many of these unpredictable events. Conversely, the utility of such analysis can be limited due to economic issues and technological constraints. Such situations demand detailed knowledge of anthropometric variants that distinguish people of disparate racial descent and gender. In aircraft accidents and other disasters it is the feet, which are recovered more intact than other parts of the body, as they are often shoe clad. Hence, feet can give excellent clues regarding personal identity (Rao & Kotian, 1990), as its measurements can be used in forensic reconstruction of height.

Footwear plays a vital role in protecting the foot from harsh temperature, moisture and mechanical trauma (Menz, Auhl, Ristevski, Frescos, & Munteanu, 2014). In their research paper, D'Aout, Pataky, De Clercq and Aerts (2009), stated that the habitual use of footwear from early childhood can influence the shape, and probably the function of the foot. Since the development and extensive popularity of fashion footwear in the 17thcentury, the functional aspect of footwear has largely been displaced by the requirements of fashion (Rossi, 1999). In effect, shoe selection may be primarily based on aesthetic considerations, many of which are incompatible with the optimal foot function. The standardised values from this research will provide very useful data for shoe-manufacturing companies and many other industries in the field of ergonomics.

The data obtained in this research will provide useful range of values of anthropometric features that can be standardised for the Ghanaian population. This work will also seeks to address the dearth of information of this nature in Ghana by obtaining measurements with minimal invasion of bodily privacy of the subjects.

1.4 HYPOTHESIS

Foot and hand dimensions correlate strongly enough with sex, height and handedness in young adult Ghanaians, to permit their use as predictors of the latter variables (sex, height & handedness).

1.5 GENERAL AIM

1. To determine whether foot and hand measurements are good predictors of sex and height of young Ghanaian adults.

2. To determine whether handedness and sex are associated with foot-length and hand-length asymmetry of young Ghanaian adults.

1.6 SPECIFIC OBJECTIVES

1. To measure seven sexually dimorphic anthropometric features in young adult Ghanaians aged 18-30. These are standing height, foot length (FL), hand length (HL), foot breadth (FB), hand breadth (HB), foot circumference (FC), and hand circumference (HC).

2. To determine which of the sexually dimorphic anthropometric foot and hand dimension(s) correlate strongest with height.

3. To produce formulae to determine:

   a) Height by univariate and multivariate linear regression analyses

   b) Sex by sectioning point method and multiple linear regression analysis

4. To determine:
    a) Handedness of all individuals in the sample.
    b) The association of handedness and sex with standardised foot length (SFL) as well as handedness with standardised hand length (SHL).
5. To determine the number and the percentages of the forefoot types in males and females.

CHAPTER TWO

2 LITERATURE REVIEW

Conspecific individuals differ in many traits which include very obvious features such as gender, age, size, shape, behaviour, or physiology (Bolnick et al., 2011). According to these authors, this observation was one of Charles Darwin's greatest insights. Anthropometry as a scientific tool operates on this premise.

2.0 Brief introduction and history of anthropometry

As already stated, "anthropology studies human beings in aspects ranging from the biology and evolutionary history of *Homo sapiens* to the features of society and culture that decisively distinguish humans from other animal species" (Hopkins et al., 2015).

Anthropometry is an essential tool of biological anthropology which involves a series of standardized measuring techniques that express quantitatively the dimensions of the human body" (Shah et al., 2016). It is the longest-used measure for understanding as well as interpreting human variation since the nineteenth century (Ulijaszek & Komlos, 2010)

"Anthropometry - Early Anthropometric Beliefs" (n.d.), states that the earliest documented records on the size of humans dates from about 3500 BC in Sumeria. The Sumerian civilization was the earliest civilization in world history; being the first to document their language using pictographs ("History of Ancient Mesopotamia," n.d.). Many texts available from this historical period point to a positive relationship between social status, health and stature. The Sumerians who were a very intelligent people noticed that groups of people who lived under good biocultural and socio-economic conditions which improved health and nutrition, developed longer arms and legs than people living under less fortunate conditions. The authors added that, by 350BCE, Greek philosophers such as Aristotle and Plato thought of living people and their cultures as deficient facsimiles of an ideal physical human being and sociocultural system. These philosophers attributed differences in body size and weight to imperfections of sociocultural systems.

According to Cuff (2004), the measurement and description of the form of the human body in the West dates back to the artists of classical civilizations. The foundation for methodical, large-scale body measurement and record keeping however arose as a result of the needs of early modern military organizations. In the mid-seventeenth century, Johann Sigismund Elsholtz, a German physician introduced the term “anthropometry”. His aim was to describe a system of quantities he had developed to study the old Hippocratic propositions that different human body proportions were related to various diseases. Anthropometry as a scientific field was expanded by naturalists and anthropologists about a century later (Albrizio, 2007). This author further reveals that by the 19th century, anthropometry had gained clinical importance as a tool in constitutional medicine. This was as a result of research of Adolphe Quetelet.

Criminal identification techniques used in law enforcement today derived its roots from the science of anthropometry (National Law Enforcement Museum, 2011). According to this publication, Alphonse Bertillion developed an anthropometric system of physical measurements of the body parts. The system mainly focused on dimensions of components of the head and face to produce a comprehensive description of a person.

This system was developed in 1879 and was known as the Bertillion system. Anthropometry is currently an important tool used by many scientists to assess the social-economic, socio-cultural and political history of human populations. It still has vital implications for health assessment of individuals and human groups in medicine

Krishan (2007) describes two major subdivisions of Anthropometry: Somatometry which is mainly concerned with measurements of living body parts as well as cadavers; and Osteometry which measures skeletal parts.

2.1 Embryology, skeletal structure and function of the human foot

The human feet during embryonic growth develop as part of the lower limb. They first appear in week four (4) of gestation as small elevations on the ventrolateral body wall (Wolff crest) (Schoenwolf, Brauer, & Francis-West, 2009). The lower buds are recognizable around day 28 between third and fifth lumbar segments (L3-L5). The limb buds are initially undifferentiated mesenchyme (mesoderm) which are covered by an epithelial (ectoderm) layer. This is a thickening under which a large marginal vein develops called the Apical Ectodermal Ridge (AER) (Hill, 2015). This author also explains that the transient structure (which lingers on, a week to the 16-20 mm stage) is critical to maintaining the outgrowth of the limb. Its removal results in truncation of limb growth. The outgrowths continue into the fifth week (11-13 mm embryo). At this time, two flat, rounded foot discs which are oriented in a transverse plane develop with its plantar surfaces pointing towards the head (Mooney, 2013). Mooney also indicates that as the limbs become longer, mesenchymal models of the bones are formed by cellular aggregations and then chondrification centres appear in the fifth week. This phenomenon leads to formation of entire cartilaginous limb skeleton, by the end of the sixth week.

As these outgrowths continue, the limbs rotate medially about their longitudinal axes but at this time the feet are still continuous with the legs, showing no dorsal angulation (Hegazy, 1999). By the third month, the feet dorsiflex at the ankles with the persistence of a mild supination, corresponding to the fetal period. As the feet continue to grow, apoptosis finally occurs in the interdigital spaces, the joint spaces, as well as in certain primitive embryonic muscle layers (Mooney, 2013). Ossification of the foot bones is not complete until approximately 20 years after the child is born (Patel, Shah, & Patel, 2007).

The human foot is highly complex. Despite its complexity, it is structurally adapted for orthograde bipedal stance and locomotion (Saltzman & Nawoczenski, 1995). The foot is the only direct means of contact with the supporting surface, and as a result plays a significant role in all weight bearing tasks (Scott et al., 2007). These authors explained that the foot is involved in shock absorption and adapts well to irregular surfaces. In addition, it contributes to producing momentum for forward propulsion.

The complex structure consists of 26 major bones, 33 joints, over 100 muscles, ligaments and tendons, blood vessels, nerves, skin and soft tissues (Tomassoni, Traini, & Amenta, 2014). The foot can be divided into 3 major parts: the hindfoot, the midfoot, and the forefoot (Panchbahavi, 2015).

The hindfoot is composed of the talus, calcaneus (heel bone) and two long bones of the lower leg (the tibia and fibula) which are connected to the superior surface of the talus. This forms the ankle joint. Connected to the talus at the subtalar joint, is the calcaneus, cushioned underneath by a layer of fat (Remedy's Health Communities, 2015). Moore, Dalley and Ori (1999) described the midfoot as being comprised of five differently shaped bones. These are the navicular, cuboid, and three cuneiform bones that fit together in two rows. The distal row is made up of three cuneiform bones and half of the cuboid. They further describe the proximal row as consisting of the posterior half of the cuboid and the navicular. The forefoot is composed of five toes and the corresponding five proximal long bones that form the metatarsus (DiGiovanni & Frey, 2004). The metatarsus is joined to the phalanges (toes) by metatarsophalangeal joints.

The numerous foot bones and joints are fastened by three layers of ligaments that arrange the foot bones to form 3 strong arches: two longitudinal arches and one transverse arch. These ligaments hold the foot bones together along with the tendons of foot muscles thereby keeping the foot compact but also providng some springiness (Wright, Ivanenko, & Gurfinkel, 2012).

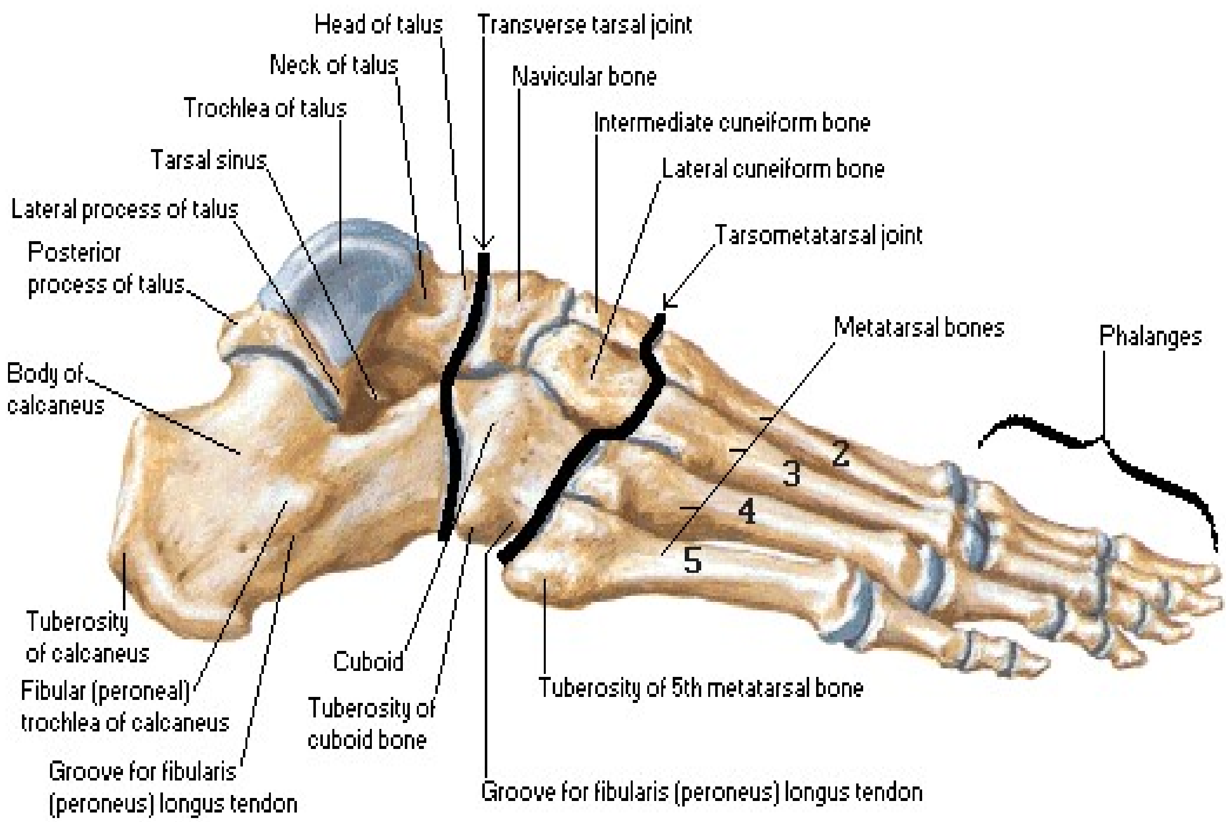


Figure 1: Skeletal anatomy of the foot and ankle (lateral view). Source: ("Bones of foot," 2015)

2.2 Embryology, skeletal structure and function of the human hand

The human hands during embryonic growth develop in a like manner as the foot. They grow as part of the upper limb. Schoenwolf et al. (2009) noted that they initially appear in the fourth week of gestation as small elevations on the ventrolateral body wall (Wolff crest) of the developing embryo. The upper limb buds are situated opposite the 8^{th}-10^{th} somites along the Wolff crest (Fritsch, 2003). The limb buds are initially undifferentiated mesenchyme (mesoderm) which are covered by an epithelial (ectoderm) layer. These are thickenings under which a large marginal vein develops called the AER (Hill, 2015). These constitute what is recognised as the progress zones which remain till the digits are formed (Fritsch, 2003). In the staging of hand development and arm formation as described by this author, the hand plates are visible by week five and within week six the subdivisions of the arm is recognised. At this stage the upper limbs now have elbow regions and digit rays. It is during the seventh and eight weeks that the elbows become flexed and the fingers separate as the limbs lengthen.

Upper limb growth and its differentiation progress along three different axes: proximodistal (PD – runs from the origin of the limb at the body wall to the tip), anteroposterior (AP – runs from the little finger to the thumb), and dorsoventral (DV – runs from the dorsum of the hand to the palm) (Sammer & Chung, 2009). The AP axis is the first to develop with its orientation already established before the formation of the limb buds (Daluiski, Yi, & Lyons, 2001). These authors clarify that a focus of specialized mesodermal tissue becomes the posterior (postaxial or ulnar) aspect of the limb which begins to secrete a protein that controls differentiation and growth along the AP axis. Findings by Tickle (1981), indicates that sonic hedgehog (Shh) is expressed by cells that comprise the zone of polarizing activity (ZPA). Tickle emphasized that although the primary function of Shh is to stimulate AP growth, it also plays an important role in maintaining growth of PD. The PD axis which is the last axis to be established refers to the elongation of the limbs controlled by the AER (Daluiski et al., 2001). This research paper makes it clear that AER secretes several fibroblast growth factors (FGFs) that provide molecular control for the AER and for differentiation and growth along the PD axis. The signaling centre for the patterning of the DV axis is transferrd from the underlying mesoderm to the ectoderm before the limb bud outgrowth. Daluiski's studies showed that mouse wingless-type gene (Wnt-7a) was key in encoding for proteins that ensured upper hand development on the DV axis. Work by Bui et al. (1997), hints that human WNT7A gene performs a similar role in humans.

The human hand is a multi-fingered organ that is located at the distal ends of the upper limbs (Healthline, 2015). It is very obvious that it represents a mechanism which is very sophisticated in its design and utility (Taylor & Schwarz, 1955). This complex structure allows the muscles and joints present in the hand to undergo a wide range of motions with precision (Informed Health Online, 2010). These include grasping, reaching, manipulating objects, pushing and adjusting.

The fingers (digits) of the hand are numbered one to five, starting with the thumb. The digits are identified by the following names: thumb (pollex), index finger, middle finger, ring finger and little finger. The parts of the hand that are readily observable include the palm, dorsum of the hand, wrist, fingers, nails, thenar eminence, hypothenar eminence, palmar creases and wrist creases.

The hand skeleton is made up of three groups of bones arranged in a proximodistal fashion, beginning at the radiocarpal joint. These are the carpals (proximal), metacarpals and phalanges (distal). The carpus consists of eight bones arranged in two rows of 4 bones each. In lateral to medial order, the proximal row is made of the scaphoid, lunate, triquetrum and pisiform while the distal row is made of the trapezium, trapezoid, capitate and hamate (Standring, 2008). The palmar surface of the triquetrum articulates with the pisiform bone while the rest of the carpal bones articulate with their neighbours. The remaining three bones in the proximal row form an arch which articulates with the radius and also with the articular disc of radio-ulnar joint, proximal to it.

The metacarpus projects from the distal row of the carpal bones. It consists of five elongated metacarpal bones with distal heads, shafts and broad bases (Informed Health Online, 2010). These are the bones that can be felt between the wrist and the fingers. All the metacarpal bones articulate with each other with the exception of the first and second metacarpals (Standring, 2008). This allows for a wider range in motion of the thumb and the first metacarpal.

The phalanges are the freely moveable part of the hand skeleton. There are a total of fourteen phalanges, two in the thumb and three in each remaining finger (Ellis, 2006). The phalanges project from the distal ends of the metacarpals and consist of a head, base and shaft which tapers distally. Each of the four fingers have a proximal phalanx, intermediate phalanx and distal phalanx. In the thumb, the intermediate phalanx is absent.

Ellis (2006) describes six major joints in the hand responsible for various axes of movement. The radiocarpal joint refers to the biaxial and ellipsoid joint between the distal end of the radius and the proximal ends of the proximal row of carpal bones (scaphoid, lunate and triquetrum). The intercarpal joints are the joints between the carpal bones found in the distal and proximal rows and the complex joints between the two rows. The carpometacarpal joints are located between the proximal carpal bones and the base of the metacarpals. The joints between the distal heads of the metacarpals and the bases of the proximal phalanges are the metacarpophalangeal joint. The interphalangeal joints are located between the phalanges: the proximal interphalangeal joint between proximal phalanges and the intermediates; and the distal between the intermediate phalanges and the distal phalanges.

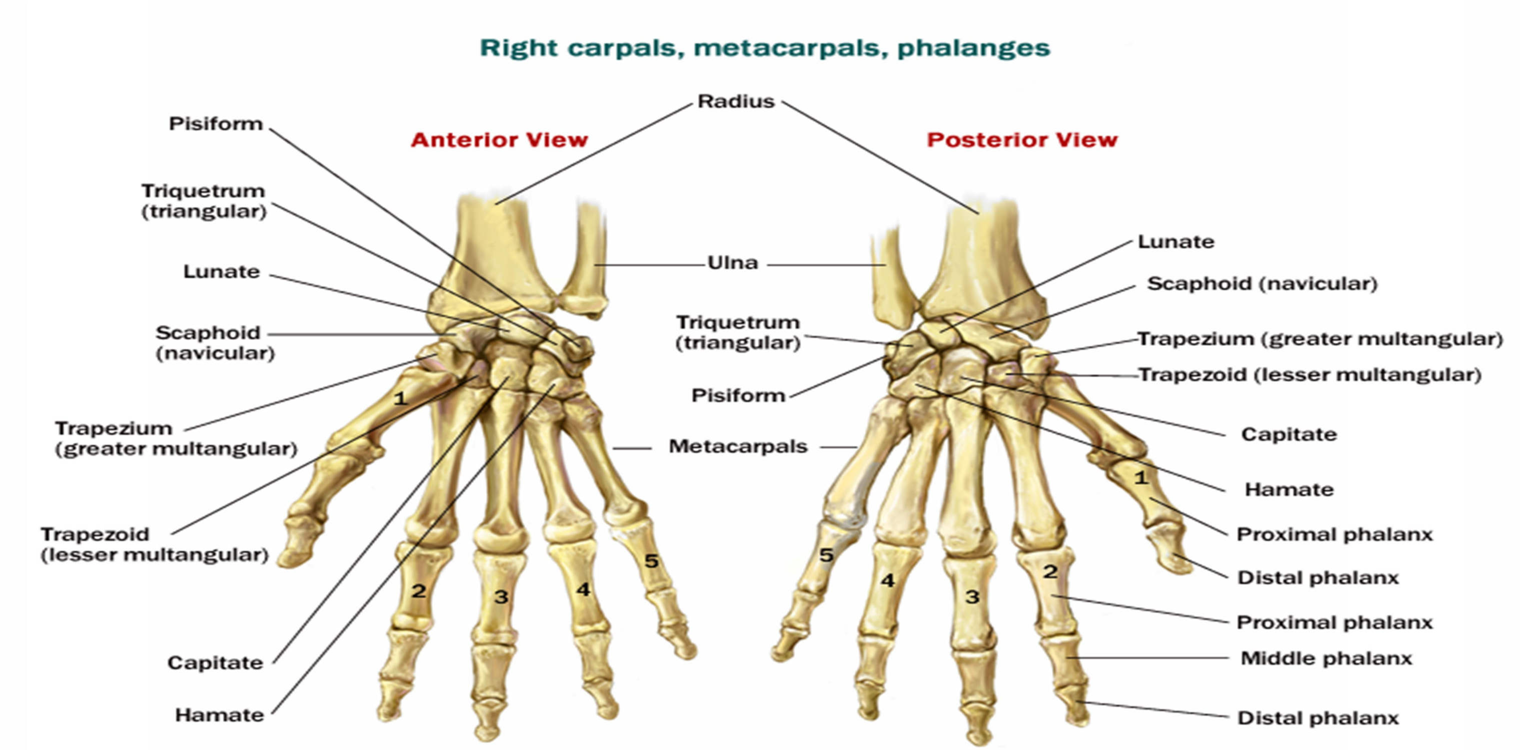


Figure 2: Skeletal anatomy of the human hand. Source: (“ Human hand and wrist bones,” 2015, July 27).

2.3 The architecture and composition of bone

Bone is a specialized and mineralized connective tissue which together with cartilage, makes up the skeletal system (Baron, 2008). This author describes bone as having protective, mechanical, supportive and metabolic functions. According to Augat and Schorlemmer (2006), bone is a composite material made of about 70% minerals (hydroxyapatite), 22% proteins (type I collagen) and about 8% water. Based on porosity, there are primarily two types of osseous tissue: cortical bone and cancellous bone. In the human body, it is approximated that 80% of the skeleton is made of cortical bones (Compston, 2002). The latter author explains that cortical bones are denser than cancellous bone and exist in the shaft of long bones as well as the surfaces of flat bones (Parks, 2009). Cancellous bone which is the lighter of the two is found in the diaphyseal regions of long bones and flat bones. It is characterized by interconnecting plates and bars in which hematopoietic cells can be found (Compston, 2002).

Saladin, (2011), describes four types of bone cells: (1) *Osteoprogenitor cells* – stem cells derived from embryonic mesenchyme located in the endosteum, inner layer of the periosteum and within the central canals which give rise to osteoblasts; (2) *Osteoblasts* – non-mitotic bone-forming cells that produce the organic matter of the matrix and help to mineralize bone; (3) *Osteocytes* – former osteoblasts trapped in the organic matrix they previously deposited, residing in tiny cavities called lacunae and are linked by channels called canaliculi; and, (4) *Osteoclasts* – bone-dissolving macrophages that are found on the surfaces of bone and are derived from the same bone marrow stem cells that give rise to blood cells. The mediated equilibrium between the formation of bone by osteoblasts and bone resorption by osteoclasts helps in preservation of bone turnover and maintenance (Kawamura et al., 2007).

2.4 Primary Sex Hormones that affect bone structure

2.4.1 Testosterone

Testosterone (T) is a primary sex hormone produced in males. This sex hormone is an anabolic steroid (Mooradian, Morley, & Korenman, 1987) which is derived from cholesterol (Waterman & Keeney, 1992) and synthesized mainly by the Leydig cells in testes. Mooradian et al. (1987) describe the function of testosterone in males as playing a key role in development of reproductive tissues and promoting secondary sexual characteristics. It also promotes the synthesis of proteins and growth tissues that possess androgen receptors (ARs) since it is an androgen (Sheffield-Moore, 2000). It is secreted in relatively smaller amounts in females by the placenta and thecal cells of the ovaries. In both sexes, some amount of the hormone is produced by the zona reticularis of the adrenal cortex. In a study which involved 50 male and 50 female young Ghanaian adults, it was reported that the mean total testosterone serum concentrations were 4.25 ng/mol and 0.32 ng/mol respectively (Boateng, 2011).

Testosterone has either anabolic or androgenic effects on the human body. Anabolic effects of testosterone include stimulating muscle protein synthesis (Ferrando, Sheffield-Moore, Paddon-Jones, Wolfe, & Urban, 2003) and increase in body mineral density and strength (Borst et al., 2007). Handelsman (2016) indicated that the promotion of secondary sexual characteristics, development of sperm cells and development and functioning of male accessory sex glands are the androgenic roles played by the hormone.

After the testes secrete testosterone a small amount of it is activated to two bioactive metabolites, oestradiol and dihydrotestosterone (DHT). A greater proportion of it is inactivated to inactive oxidized and conjugated metabolites to be excreted through urinary and/or biliary mechanisms (Van Eenoo & Delbeke, 2006). The testosterone is converted to DHT by the 5α-reductase enzyme which gives it a greater binding affinity to ARs and makes it 3 to 10 times more potent than testosterone itself (McRobb et al., 2008). When testosterone binds directly to specific nucleotide sequences of chromosomal deoxyribonucleic acids (DNA), the areas of binding influence transcriptional activity of certain genes that produce the androgenic effects noticeable in humans (Gao, Bohl, & Dalton, 2005).

2.4.2 Oestrogen

Oestrogen (E) is another hormone responsible for sexual dimorphism in humans. It is a group of steroid hormones which functions as the primary sex hormone in females. Oestrogens are synthesized mainly from cholesterol in the ovaries, corpus luteum, and placenta (Cui, Shen, & Li, 2013). These authors also stress that small but significant quantities of the hormone can be produced by nonreproductive organs such as the liver, heart, skin, and brain. They listed major forms of physiological eostrogens that are present in females: oestrone (E1), oestradiol (E2, or 17β-oestradiol), and oestriol (E3). The most potent oestrogen during the premenopausal period is E2. It is the main product of the entire biosynthesis process (Emaus et al., 2008).

The synthesis of oestrogen occurs in the theca interna cells in the ovary (Coad & Dunstall, 2005). Before ovulation, a pre-ovulatory dominant ovarian follicle is responsible for synthesizing and secreting oestrogen (Hillier, 1994). The largest follicle in the ovary is stimulated to produce oestrogen by gonadotropic hormones (Moor, 1973).

At the molecular level, 17β-oestradiol diffuses through the plasma membrane in order to bind with oestrogen receptor alpha (ERα) and oestrogen receptor beta (ERβ), in the target cells. Once binding occurs there is dissociation of heat shock proteins and then the receptor experiences a conformational change as well as dimerization (Jensen, 1996; MacGregor & Jordan, 1998). The transcriptional activation and modulation of gene expression occurs when the ligand-receptor complex binds to the promoter region of the target genes.

Oestrogen plays an important role in promoting the development of female secondary sexual characteristics. These include the regulation of female menstrual cycle, thickening of the endometrium and development of breasts. According to Lee and Howell (2006), the hormone also functions in the deceleration of height growth, acceleration of metabolism, reduction of muscle mass and bone resorption.

2.4.3 The action of testosterone and oestrogen on bone and bone maturation.

Androgens and oestrogens exert powerful influences on the shape and size of the skeletal structure during growth. In addition to this function, these hormones also contribute to skeletal homeostasis in adult life (Manolagas, 2002; Riggs, Khosla, & Melton, 1998) which takes place in both cancellous bone and cortical bone sections.

At physiological concentrations and binding affinity in both osteoblasts and osteoclasts, androgen and oestrogen receptors can be found (Boateng, 2011). Boateng adds that homodimerization or heterodimerization may occur when these hormones bind to their receptor proteins which lead to conformational changes. The conformational changes permit coactivator proteins to interact with the receptor dimers. The author explains that, steroid hormone receptors may block transcription resulting in the prevention of interactions with their target gene promoters.

Increase in the production of osteoblast-like cells in culture and the stimulation of osteoblast differentiation is caused by testosterone, DHT and nonaromatizable androgens (Gray et al., 1992). According to Seeman (1997), boys acquire 10% greater body weight and 25% greater peak bone mass as compared to girls due to the late onset of puberty. Consequently, teenage boys tend to be 10% taller than girls since the accelerated growth phase lasts longer in males (Riggs et al., 2002). These authors note that linear growth is experienced until age 18 in males as compared to age 16 in females. This is because, testosterone supports the growth of long bones, chondrocyte maturation, elevated calcium retention and incorporation into bone. Metaphyseal ossification as well as periosteal new bone formation are also processes that are affected by testosterone.

At basal levels, the growth hormone (GH) – insulin-like growth factor I (IGF-I) axis modulates a slow but constant bone growth before puberty. Puberty is triggered by the cascade effect that begins with the increased pulsatile secretion of gonadotropin-releasing hormone (GnRH) by the hypothalamus. This leads to increases in serum gonadotropins and subsequently increases in gonadal secretion of sex steroids which trigger puberty (Terasawa & Fernandez, 2001). The rise in serum oestrogen, amplifies pulsatile GH secretion in both sexes by 1.5 - to 3.0-fold. The consequence of the increaments are the heightened levels of circulating and possibly osteoblastic concentrations of IGF-I by 1.5- to 3.0-fold (Giustina & Veldhuis, 1998; Grumbach, 2000). Thus, pubertal growth spurt is supported by the synchronized increases in levels of GH, IGF-I, and especially the increase in serum oestrogen. Giustina and Veldhuis (1998) added that males who have homozygous mutations in ER or aromatase genes do not undergo rapid adolescent growth.

Frost (1992, 1998 & 1999) described the mechanism of oestrogen interaction with biomechanical strain to regulate bone mass as follows:

The internal mechanostat in bone senses strain that is generated by contraction of muscles skeletal loading. The mechanostat then offers a cybernetic response by activating bone cells that induce either bone gain or bone loss until a new steady state is attained. Low strain signals is associated with high bone mass while low bone mass is associated with high strain signals. Nevertheless, the ability of the mechanostat to sense strain is modulated by ambient E concentrations in the bone microenvironment. At menopause, there is impaired sensing due to low E levels. Because of the resultant low strain signals, the mechanostat erroneously senses that bone mass is increased which leads to rapid bone loss. This phenomenon continues until strains are sensed as being the same as those present before menopause, at which point bone loss ceases.

According to Smith et al. (1994), during puberty, the continued rise in serum E levels is the likely cause of epiphyseal closure in both sexes. This they explained is as a result of open epiphyses in young adult males who are unable to respond to E because of homozygous mutations of the ER gene. A mutation of the aromatase gene in young adult males also produces a similar effect (Bilezikian, Morishima, Bell, & Grumbach, 1998; Caranic et al., 1995; Morishima et al., 1995). On the other hand men with testicular feminization due to null mutations of AR achieve epiphyseal closure (Marcus et al., 2000; Zachman et al., 1986). Thus oestrogen does not only initiate pubertal growth spurt but also ends it by inducing epiphyseal closure.

2.5 Sexual dimorphism in anthropometric variables

Sexual dimorphism refers to all the sex related variations that exist between males and females at either morphological or nuclear level. It is not only observable from the differential development of internal and external genitalia but also from extragenital features such as body size, appendages and specific cellular components (Kanchan & Krishan, 2011). Fairbairn (2016) also describes sexual dimorphism as traits that occur in two distinct morphs or forms between and females within a given species. In most animal species, sexual dimorphism exists in body size (Samal, Subramani, & Marx, 2007).

According to Fairbairn (2016), some other sexually dimorphic features may differ so strongly that they can be reliably used to predict or differentiate sexes in a given species. Pascalis (2002), wrote that it is very easy for human beings to tell males apart from females just by looking at the faces. This human ability is intuitive and makes it easy to recognize the faces. It has been established that sexual dimorphism is strongly demonstrated in the face (Samal et al., 2007). These authors demonstrated that about 85% of facial features showed significant sexual differences.

In a research conducted by Igiri, Ekong and Odey (2008), 500 male and 500 female young adult Nigerians in Calabar Metropolis were recruited and some anthropometric features assessed for sexual dimorphism. These researchers measured neck circumference, waist circumference, bioacromial diameter, height and weight. At a significance level of $p < 0.01$, all the parameters showed a significant difference between males and females. Mean height for males was found to be 170.83 ± 0.24 cm while that for females was recorded as 162.44 ± 0.26 cm. These authors drew the conclusion that height and all anthropometric features observed were sexually dimorphic.

Nor et al., (2013) carried out anthropometric investigations in one 100 deceased human bodies in Malaysia. The bodies were aged between 20 and 40 years. The sample for this investigation represented a mixture of major races specifically, the Malay, Chinese, Indian as well as the minorities. Height and six lower limb parameters were measured: thigh length (TL), lower leg length (LLL), leg length (LL), foot height (FH), foot breadth (FB) and foot length (FL). The researchers reported that the mean values of lower limb parameters together with their standard deviations were significantly higher in males than in females ($p < 0.05$). For instance mean foot length for males was 24 ± 1.6 cm while that of females was 21.29 ±1.3 cm. Height which was also sexually dimorphic was 164.8 ± 7.2 cm in males and 152.6 ± 6.3 cm at $p < 0.05$.

Boateng (2011) also studied sexual dimorphism of some anthropometric variables among students in a teaching hospital in Accra. The scientific inquiry involved 50 male volunteers and 50 female volunteers. Since Accra is a cosmopolitan area, the sample included participants who belonged to different ethnic groups in the country. The means of the variables that showed statistical differences between males and females were waist to hip ratio (WHR), right foot length to height ratio and lower limb length. The mean WHR was 0.83 ± 0.042 for males and 0.75 ± 0.043 ($t = 10.45$, $p < 0.001$), while mean right foot length to height ratio was 0.16 ± 0.0057 and 0.15 ± 0.0073 ($t = 2.44$, $p = 0.016$). However, no statistical differences were found between males and females when mean body mass indices (BMIs) ($t = 0.06$, $p = 0.553$), mean torso length ($t = 0.37$, $p = 0.715$) and 2D:4D ($t = 0.41$, $p = 0.686$) were compared.

Fink, Neave, Brewer and Pawlowski (2007), studied height and mate selection preferences in three European populations: Germany, Austria and United Kingdom (UK). The sample comprised 286 men and 310 women from Germany, 119 men and 184 women from Austria, and, 51 men and 152 women from UK, with a mean age of 26.34 ± 9.11 years. The range of height in men of all three the countries (n = 1102) was from 155 cm to 205 cm with a mean of 181.08 ±7.90 cm and in women 147 cm to 192 cm with a mean of 167.40 ± 6.82 cm. In a one-way ANOVA, sex as factor produced a significant main effect of ($F_{1.1102} = 691.25$, $p < 0.001$) on height.

2.6 Determination of sex from hand measurements

Quite a number of studies have also been able to predict sex from hand measurements due to sexual dimorphism in hand anthropometric parameters (Ishak, Hemy, & Franklin, 2012; Kanchan, Krishan, Sharma, & Menezes, 2010; Kanchan & Rastogi, 2009; Krishan, Kanchan, & Sharma, 2011). Kanchan and Rastogi (2009), revealed that hand breadth, palm lengths as well as hand length showed 87%, 85.7%, and 83% predictive accuracies for males, and 91%, 89.6%, and 88.5% for females respectively. The pair studied 500 males and females aged between 20 years and 30 years in North and South Indians. Subjects' sexes were predicted by using sectioning point analysis of hand and palm lengths which produced these accuracy measures. The mean values of all hand dimensions were significantly larger in males than in females for both hands ($p < 0.001$). The study could not show any significant differences between hand dimensions between North and South Indians.

Aboul-Hagag et al. (2011) reported that the mean right hand lengths and breadths in a selected sample of Egyptians were so statistically significant that they were used as estimators of sex. Mean right hand length was 19.47 ± 0.92 cm and 18.13±0.90 cm for males and females respectively ($p \leq 0.05$). Mean right hand breadth was 8.13 ± 0.39 cm and 7.16 ± 0.40 cm for males and females respectively ($p \leq 0.05$). When hand index was calculated for this sample, the following results were obtained: mean right hand index for males –41.78 ± 1.51, and mean right hand index (HI) for females –39.54 ± 1.50 ($p \leq 0.05$). After calculating hand index and employing sectioning point analysis, a cut-off index point of 40.55 and less was is suggestive of females while and index greater than 40.55 was suggestive of males. The index was able to accurately determine sex in 80% males and 80% females using the right hand. The sex determination accuracies were 81.2% in males and 78% in females when using the left hand.

In a study where 123 men and 123 women were sampled from a Rajput population in North India, Krishan et al. (2011) attempted to predict sex from dimensions of hand length, hand breadth and hand index. The study group comprised 100 males and hundred females while the remaining 46 individuals made up male and female test groups. With reference to right-left asymmetries, HB was significantly larger on the right side in both men (t = 5.606, $p < 0.001$) and women (t = 5.493, $p < 0.001$), while right hand length (RHL) was significantly larger than the left in men only (t = 2.455, p = 0.01). RHL predicted sex with an accuracy 76% in males and 83% in females as compared with left hand length (LHL) with corresponding values of 78% and 81% in the study groups. Right hand breadth (RHB) produced accuracies of 91% in males and 81% in females in the study groups while left hand breadth (LHB) predicted sex to 79% and 89% respectively. All predictions from hand indices were below 60%. In the test groups however, accuracies were 69.9% and 82.6% for RHL; 82.6% and 78.3% for LHL; 87.0% and 95.7% for RHB; and 69.6% and 91.3% for LHB in males and females respectively.

In the same study using the Rajput sample, Krishan et al. (2011) employed linear regression methods to discriminate between sexes. The equations of hand length produced values of r = 0.645 (R^2 = 0.416) from the right and r = 0.633 (R^2 = 0.401) for the left. r = 0.710 (R^2 = 0.504) from the right and r = 0.683 (R^2 = 0.467) for the left were associated with models of hand breadth. All p-values from these models were statistically significant ($p < 0.001$). These authors found that multiple regression models produced better results for sex differentiation: r = 0.727 (R^2 = 0.528) from the right hand model with significant p-values (RHL = 0.002, RHB < 0.001) and r = 0.714 (R^2 = 0.510) from the left hand model having significant p-values (LHL < 0.001, LHB < 0.001).

Jee, Bahn and Yun (2015) obtained data on several hand dimensions from a Korean population and attempted to predict sex using discriminant analysis. The subjects included 167 males and 154 females aged between 20 years and 70 years. In addition to hand length, hand breadth and several other hand dimensions, the researchers included hand circumference and maximum hand circumference. The measured variables showed an average sex prediction accuracy of 70%. The maximum hand circumference showed the highest accuracy in both males (88.6%) and females (89.6%) with significance of $p < 0.001$.

2.7 Estimation of sex from foot measurements

Generally men are thought to have longer and broader feet than women of similar stature. Contrary to common thought, Wunderlich and Cavanagh (2001) demonstrated that female foot sizes are not merely scaled down versions of male foot sizes. These authors proved that females have a higher medial longitudinal arch and shallower first toe than males of comparative foot length. Similarly females were reported to have a shorter ankle length and smaller instep circumference than men of similar foot length.

Some researchers have attempted to produce sex predictive modules from foot and foot print dimensions in different populations (Jasuja, Harbhajan, & Anupama, 1997; Jasuja & Manjula, 1993; Kanchan, Krishan, Prusty, & Machado, 2014).

Ozden et al. (2005) found significant differences in the mean foot length and breadth between males and females examined ($p < 0.01$). In this research, 294 males and 275 females over 19 years were assessed. These researchers found no significant difference between left foot/shoe measurements and right foot/shoe measurements. The correlation coefficients were $r = 0.552$ for RFB, $r = 0.778$ for RFL, $r = 0.568$ for LFB and $r = 0.769$ for LFL. Concerning shoe length (SL) and shoe breadth (SB), the correlation coefficients were $r = 0.580$ RSB, $r = 0.825$ for RSL, $r = 0.579$ for LSB and $r = 0.818$ for LSL. All the coefficients were significant as they all corresponded to values of $p < 0.001$. Using logistic regression analysis, the authors were able to develop formulae for sex from left and right foot measurements with predictive accuracy between 86-89%. This is consistent with findings made by Smith (1997).

Zeybek, Ergur and Demiroglu (2008) predicted sex using several foot measurements obtained from a sample of 249 (113 females and 136 males) subjects in a health institution in Turkey. Logistic regression analysis was performed in order to estimate sex from right or left foot measurements. 0.50 was the limit value for the evaluation model. The values less than 0.50 were evaluated as female and values more than 0.50 were evaluated as male. The developed model, estimated the gender 93.8% correctly in females and 97.1% correctly in males with right foot measurements; and 96.5% correctly in females and 96.3% correctly in males with left foot measurements.

Ahmed (2013) was also able to assign sex correctly using demarking point and cross-validation on data obtained from a Sudanese population. The results for foot length and breadth in this study showed discrimination, with a study group accuracy rate of 86.5% and 87.5% for the test group. The findings of this study are inconsistent with finding by Ozden et al. (2005), who proposed that sex estimation from foot and shoe lengths were better discriminators of sex than breadth. The current research established that foot breadth was a better sex discriminator when used alone or together with foot length. The findings of Ahmed agreed with that of Krishan et al. (2011) who found foot breadth to be a better discriminator of sex than length in North Indians.

2.8 Estimation of height from foot measurements

For many decades, scholars have studied the relationship between long bones and height (Geetha et al., 2015; Jasuja & Singh, 2004; S. Kumar, Srivastava, & Sahai, 2010; Rao, 2010; Shintaku & Furuya, 1990). Recent studies have established that the dimensions of the bones of the lower extremities have greater association with height than those of the upper extremities (Fessler et al., 2005; Nor et al., 2013).

Patel et al. (2007) studied the relationship between foot length and height in 278 male and 224 female medical students in the Gujarat region of India. Students were from 17 to 22 years in age. The mean height and foot length for males were 170.96 ± 5.13cm and 24.44 ± 0.99cm respectively, while females measured 156.14 ± 5.15 cm and 22.34 ± 1.12 cm. These results of the means showed significant differences between males and females ($p < 0.05$). Correlation coefficients (r) of 0.65 for males and 0.80 for females were obtained for this research ($p < 0.001$). Regression equations for both males and females were developed for this population as a predictor of height in this region. However, the research neither produces any predictive accuracy values nor any cross-validation results.

In a study that involved Rajbanshi 175 males and 175 females from North Bengal, Sen & Ghosh (2008) attempted to produce an equation to predict height from length and breadth of bilateral feet. It was observed that stature significantly correlated with overall FL ($r = 0.813$, $p < 0.01$) and overall FB ($r = 0.693$, $p < 0.01$). The correlation coefficient between stature and foot length in males was $r = 0.626$, while that for foot breadth was $r = 0.522$, which were statistically significant ($p < 0.01$). Conversely, the correlation coefficient between stature and FL in females was +0.696, while that for FB was +0.319, which were statistically significant ($p < 0.01$). By producing linear regression modules fitted to height from FL and FB (which were all significant; $p < 0.05$), these established that height is dependent on both FL and FB. The accuracy rates of estimating stature from FL and FB for Rajbanshi males and females showed accuracy between 99.00% and 99.99% in almost all the cases. The authors of this research noted that when similar equations were obtained for other Indian populations (e.g. from the Gujjars, Kanchan et al. (2008)) were fitted on the Rajbanshis, the accuracy rate varied widely (95.00% – 101.80%). It is therefore wise to develop such equations on a population specific basis. This is primarily due to widespread variations among different ethnic groups (Bharati, Demarchi, Mukherji, Vasulu, & Bharati, 2005).

Efforts by Uhrova, Benu and Masnicova (2011) to produce regression equations for height from foot and footprint dimensions also yielded significant results in a Slovakian population. The study involved 49 females and 36 male students. The measurements of foot length, foot breadth, footprint length and footprint breadth were higher on the left side than on right side in both sex groups. Bilateral differences were not statistically significant as was assumed ($p > 0.05$) and this was consistent with result reported by Zeybek et al., (2008); Ozden et al. (2005); Kanchan et al., (2008). On the contrary, Sen & Ghosh (2008) obtained significantly different bilateral measurements for foot length. Moreover, statistically significant differences between right and left side were also found by Agnihotri et al. (2007) for foot length and by Kanchan et al. (2008) for foot breadth.

All the measurements recorded by Uhrova et al. (2011) exhibited significant correlation coefficients with height. The highest correlation was observed for foot length in males ($r = 0.716$), in females ($r = 0.728$). Footprint length showed higher correlation than footprint breadth in males (r = 0.644) and in females (r = 0.680). Linear regression models fitted for height showed that regression coefficients for all parameters were statistically significant ($p < 0.05$). According to these authors, foot length and footprint length yielded the lowest standard errors of estimate, SEE = 4.601 and SEE = 5.144 respectively. The corresponding R-squared values were 0.740 and 0.678, meaning that foot length explained 74% while footprint length explained 67.8% of variation in height of the study sample. Therefore, foot length was the optimal variable for height prediction.

Grivas et al. (2008) also demonstrated a high linear relationship between foot length and height in a Greek sample. The correlation coefficients in males were r = 0.898 and r = 0.903 in the left and right feet respectively. In females, r = 0.856 was obtained for the left foot while 0.855 was obtained for the right foot. The standard errors of estimates from the univariate regressions with unknown sex were 7.603 ($R^2 = 0.765$) for RFL and 7.721 ($R^2 = 0.757$) for LFL.

Sanli et al. (2005) established that foot length from a Turkish sample was significantly associated with height. The authors found good correlations between foot length and height (i.e. r = 0.716 in males and r = 0.699). After producing linear regression models, the standard errors of estimates were SEE = 43.04 in males and 35.45 in females. The corresponding R-squared values were 0.513 and 0.489.

2.9 Determination of height from hand measurements.

It has been established that lower limb measurements have a greater correlation with stature than upper limb dimension in some situations (Fessler et al., 2005; Nor et al., 2013; Ozaslan, Iscan, Ozaslan, Tugcu, & Koc, 2003), it is crucial to find the association of parts of the upper limb with stature due to possible loss of lower limbs in mass disasters**.**

Jasuja and Singh (2004) undertook a study to determine height from hand length, palm length and phalange lengths. The research included 30 male and 30 female Jat Sikhs (a peasant tribe of northern India and erstwhile Punjab now part of Pakistan) aged between 18 years and 60 years. It was ascertained that all variables had a positive and statistically significant correlation with height ($p < 0.001$). These anthropologists were able to formulate regression equations for height using all the measurements taken. These equations were tested by putting in the actual values and it was found that the error of estimation of stature existed within the calculated range. The regression equations were formulated with the standard error ranging from 4.033 cm to 4.82 cm in case of the males and 5.061 cm to 5.127 cm in case of females. It is evident from this study that various dimension of length in the hand and phalanges can be used as reliable predictors of height in this population. These equations may not be accurate for other populations.

Geetha et al. (2015) attempted to estimate height from hand length and hand breadth using a sample of Indian tribals aged between 20 years and 30 years. The dimensions of hand breadth and hand length showed significant positive correlations with height. The higher positive correlations were seen in right hand length ($r = 0.479$, $p < 0.001$) and left hand breadth ($r = 0.39$, $p < 0.001$) for males and both hand lengths ($r = 0.949$, $p < 0.001$) and right hand breadth ($r = 0.470$, $p < 0.001$) in females. The authors proposed that hand length was the best single predictor of height in a linear regression model as it exhibited lower SEEs in both males (SEE = 5.66) and females (SEE = 2.39). They however concluded that a combination of both dimensions in multiple regression models offered more reliable estimates in both males (SEE = 5.24) and females (SEE = 2.29).

Mahakizadeh, Moghani, Moshkdanian, Mokhtari and Hassanzadeh (2016), undertook a study with the aim of assessing the relationship between stature and upper limb and hand length. The study was to help develop regression formulae for height estimation in Iranian adults. Height, upper limb length (ULL) and hand length were taken on 142 male subjects (18-25 years) using standard measuring instruments. The results indicated a positive significant correlation between height and upper limb and hand measurements. The correlation coefficient of height with hand length was $r = 0.78$; $p = 0.0001$. Other "*r*" values produced in other researches of a similar manner are $r = 0.696$ (Akhlaghi, Hajibeygi, Zamani, & Moradi, 2012), $r = 0.58$ (Ilayperuma, Nanayakkara, & Palahepitiya, 2009), $r = 0.697$ (Habib & Kamal, 2010), $r = 0.829$ (Mulla, Kulkarni, & Gangane, 2014) and $r = 0.60$ (Ahmed, 2013a). From the results of that study, upper limb length ($R^2 = 0.791$; SEE = 2.66) can be used as a better logical predictor of height in males compared to hand length ($R^2 = 0.609$; SEE= 3.634).

Pal, De, Sengupta, Maity and Dhara (2016) undertook a study to set up standard formulae to estimate height from hand dimensions in the Bengalese population. Different measurements of hand dimensions and height were taken from 1662 adult Bengalese women aged from 20 years to 40 years. There was no statistically significant bilateral variation of the measurements. All hand measurements were positively and significantly correlated with height ($p < 0.001$). As seen in other populations, the hand length and palm length showed a better correlation with height than all the remaining variables. Simple linear regression and multiple linear regression models developed were derived and applied to the control group. The study showed that the percentage difference between true stature of the control and the estimated stature ranged from 0.01% to 0.15%. Due to lower standard error of estimate and higher multiple correlation coefficient, the multiple regression equations were more reliable than simple linear regression equations. Many researchers have advocated for multiple regression equations in estimating height from explanatory variables (Altayeb, 2013b; Geetha et al., 2015; Sanli et al., 2005; Sen, Kanchan, & Ghosh, 2011).

2.10 Handedness and its association with hand and foot variables

2.10.1 Introduction

Many people generally tend to favour one side of their body than the other, in everyday activities. This is referred to as laterality. Laterality is the scientific term for "sidedness," which is a natural feature of many bipedal animals where there is an asymmetry between one side of the body and the other (Denny & O'Sullivan, 2007). Research has proven that laterality is a consequence of brain hemisphere dominance (Elneel, Carter, Tang, & Cuschieri, 2008) with handedness being the most obvious human behavioural lateralization.

Handedness as defined by Corey et al. (2001) refers to a person's preference to use one hand predominantly in performing unimanual tasks and/or the individual's ability to perform tasks more efficiently with one hand. Trivers et al. (2015), stated that handedness is likely controlled by many variant genetic factors. Some of these are sex-dependent genes that influence body asymmetry. Handedness is highly heritable (Llaurens, Raymond, & Faurie, 2009). Its heritability is estimated at around 25%, possibly involving a minimum of 40 loci (McManus, Davison, & Armour, 2013).

Determination of handedness is usually not straight forward and as a result researchers have resorted to describing handedness either based on hand preference (Corey et al., 2001; Oldfield, 1971) or hand performance (Elneel et al., 2008; Scharoun & Bryden, 2014; Trivers et al., 2015). Though handedness indices are commonly used, some researchers prefer performance tests due to the subjective nature of the questionnaires (Scharoun & Bryden, 2014). The hand preference questionnaires may not be ideal for assessing laterality due to its inherent limitations but it provides sufficient means of assessing handedness (Oldfield, 1971). Barut et al. (2007) classified human handedness under five major categories: strong right-handers, weak right-handers, strong lefties, weak lefties and ambidextrous.

Right-handedness is an ancient universal trait which is found in all societies (Marchant & McGrew, 1998; Raymond & Pontier, 2004). Papadatou-pastou (2011), states that right-handedness develops early in ontogeny and is sex-dependent with females more likely right-handed than males. According to Holder (1997), all human populations are biased towards right-handedness (i.e. 70% - 90% of individuals in every population are right handed). Just like right-handedness, left-handedness has been linked to asymmetry in the brain hemispheres (Jackson, 2008). It is a more complex phenomenon to understand and it was earlier linked with hemispheric injury during birth and genetics in more recent times (Denny & O'Sullivan, 2007). Handedness research points to the fact that men are more prone to left-handedness than females (Oldfield, 1971; Scharoun & Bryden, 2014).

In humans, the use of hand preference as an indirect indicator of hemispheric asymmetry is a reflection of the brain itself (Bishop, Ross, Daniels, & Bright, 1996). Genetic research has established that expression of the members of the TGF-3 gene family is asymmetric in the bulbus during the formation of the asymmetry (Meno et al., 1996). The same gene is involved in bone development and modelling. This underpins the idea that an intimate relationship exists between hand preference, which is an indirect indicator of brain asymmetry, and various dimensions of the hand (Moore & Persaud, 1998).

2.10.2 Association of handedness with hand and foot anthropometric variables

In a study by Levy and Levy (1978) using standardized foot lengths, it was observed that right-handed males had larger right feet than left while right-handed females had larger left feet than right. Contrastingly, the reverse was observed in non-right-handed subjects where asymmetry favoured the left foot in males and the right foot in females.

Mascie-Taylor and McManus (1981) studied the relationship between foot-length asymmetry, sex and handedness in a sample of 146 undergraduate students. In this research, handedness was determined by hand performance and classified as either right-handedness or left-handedness. The results from the study indicated that there was a significant difference between the means of bilateral foot lengths (left = 257.76 mm ± 1.48, right = 256.99 mm ± 1.42) ($t = 2.62$, $p < 0.01$) of the total sample. The difference between the mean absolute foot length and standardized foot length (0.014 ± 0.057) was significant ($t = 2.46$, $p < 0.02$). Their results showed that in right-handed subjects, foot asymmetry favoured the left foot in males and the right foot in females. In left handed subjects on the other hand, foot asymmetry favoured the left foot in both males and females. According to these authors, there was no main effect of handedness on standardized foot length ($F = 0.112$, $p = 0.738$). Sex on the contrary showed significant effect on standardized foot length ($F = 3.934$, $p = 0.049$).

In a study carried out on a Jamaican sample, there was only a weak tendency for left feet to be longer than that of the right feet. In this study, Trivers et al. (2015) found that there was a left foot bias in asymmetry but this difference was not significant ($t = 0.96$, $p = 0.34$). The sex difference between foot asymmetry was also not significant ($t = 0.33$, $p = 0.74$). This research was able to show that right hand performance and right foot length in boys were significantly positively correlated ($r = 0.23$, $p < 0.01$). Left hand performance and left foot length in boys were also significantly positively correlated ($r = 0.21$, $p < 0.05$). There were no significant correlations between foot asymmetry and hand performance in females.

Garn et al. (1976) studied bilateral asymmetries in bone size and bone mass of the hands or chronic renal patients. It was revealed that even in left-handed patients, the measurements were larger on the right side than on the left. The extent of the statistical significance of this finding was inconclusive but the researchers were able to ascertain that handedness did not significantly influence the bilateral differences.

Kulakslz and Gozil (2002) studied the effect of hand preference on hand anthropometric measurements in 394 undergraduate students. In this study, hand preference was determined using the Geschwind score in five groups. The researchers reported that the bilateral asymmetries in hand length and hand breadth were both significant in the 394 students. In strong right-handed and weak right-handed subjects, asymmetry significantly favoured the left hand in terms of length ($p < 0.05$), and the right hand in terms of breadth ($p < 0.001$). The right hand biases were not significant in terms of length and breadth for ambidextrous participants. Strong lefties were found to have insignificant left hand width and right hand length biases. The asymmetry significantly favoured left hand length while the left bias was not significant in weak left handed subjects. According to this research, the heterogeneity observed in the left-handers could be due to the differing etiology of left-handedness while hand dominance could account for observations in the right-handers.

Krishan et al. (2011) found that in both males and females studied, the foot and hand breadths were significantly larger on the right side than on the left. This research sampled only right-handed volunteers and as a result, the researchers attributed this finding to hand dominance.

2.11 Forefoot types

According to Correa (2016), three kinds of feet based on toe arrangement in the forefoot can be identified. The commonest is the Egyptian type which has the great toe longest with the following four arranged in descending order at an angle of 45degrees. The second is the Greek type (also known as Morton's type (Morton, 1927)) which has the second toe longer than the first. The Roman type (also called Square type) has the great, second toes and third toes being of same length. Depending on how narrow the tip of the toes is, the Greek and Egyptian foot types can be described as either tapered of wide.

Correa explains that while the Egyptian type denotes royalty, the Roman foot represents a well-balanced personality. On the other hand, individuals with Greek type feet are said to be sporty and creative but with impulsive tendencies that could lead to stress.

The Egyptian feet have been closely associated with hallux valgus (Orzechowski & Wall, 1999), hallux rigidus (Calvo, Viladot, Giné, & Alvarez, 2009) and ingrowing toe nails (Ogawa & Hyakusoku, 2006). Kurup, Clark and Dega (2012) associated the Greek type feet with higher risk of metatarsalgia, hammer-toes and Morton's neuroma.

CHAPTER THREE

3 MATERIALS AND METHODS

3.0 Ethical approval

The Ethical and Protocol Review Committee of the University of Ghana, College of Health Sciences approved and provided ethical clearance for this research. After carefully scrutinizing the research proposal and recommending vital modifications to the protocol, a written approval was issued and referenced CHS-Et/M.2 – P 4.10/2016/2017. All participants signed a consent form (Appendix I) that was designed for this study after which they responded to a questionnaire (Appendix II).

3.1 Methodology

3.1.1 Study Design

This is a cross-sectional study of young adult Ghanaians. The participants were recruited by the convenience sampling method from the College of Health Sciences, Korle-Bu. Questionnaires were then administered to each research subject in order to gather data that was relevant to the study. The data obtained was used to determine whether subjects met the inclusion criteria for the study.

3.1.2 Study Site / Study Population

The study site for this research was the Korle-Bu campus of the University of Ghana. The participants were recruited from the College Of Health Sciences within the campus. Two hundred participants were recruited to participate in the research; one hundred males and one hundred females.

3.1.3 Inclusion and exclusion criteria

Subjects were indigenous young adult Ghanaians aged between eighteen (18) years and thirty (30) years. The age range was informed by Agnihotri, Shukla and Purwar (2006) who explained that maximum growth and elongation of bones is attained by 24 years. However, humans can put on weight, increasing measurements of breadth and circumference. Volunteers who were unhealthy or had apparent deformities in the hands and feet were excluded. All subjects were not on any hormonal treatment. Subjects also confirmed that they had not suffered any fractures previously. Volunteers that are naturally ambidextrous or have been forced to change their natural hand preference for everyday activities due to injury or culture were also excluded.

3.1.4 Sample size determination

Considering the nature of the study and population to be studied, the minimum sample size for each independent group (male and female) was determined by the formula below (Daly & Bourke, 2000)

$$N > 2K\sigma^2 / \Delta^2$$

K is a constant and σ^2 (4.84) represents the variance in each group (equal variances are assumed). Δ (1.24) is the magnitude of the difference between two groups which is needed to detect α (Type I error) and β (Type II) values. N represents the minimum sample size required in each study group. K (7.8) was obtained from a table of two-sided significance test at a 5% level an 80% (power of test) chance of determining an effect. Computing the values, a sample size of 49.12 was obtained for each group. However, for predictive models, a small representative test sample is selected at random from the study sample to demonstrate accuracy and reliability of the equations during analysis. As a result, the minimum sample size for this research was doubled. The study thus comprised 100 male volunteers and 100 female volunteers.

3.2 Measurements of anthropometric variables

Subjects were recruited into the study after they had provided written consent and satisfied all the inclusion criteria by responding to the administered questionnaire. The measurements of anthropometric variables for this research were taken between 10:00am and 1:00pm each day. This was done to avoid any diurnal variations that occur in body sizes. To prevent or reduce the level of personal error in the research, all the anthropometric data was collected by the research investigator alone**.**

3.2.1 Foot Anthropometry

All foot measurements were taken using the direct method while the subjects were standing in an upright position. Subjects stood barefooted on a flat wooden board with their body weight evenly distributed on both feet (Uhrova et al., 2011). These measurements were taken in both feet, one after the other using a foot measuring device (see figure 3) specially designed for this research by Joseph Akyeampong and a tape measure. The foot measurements were recorded to the nearest 0.1 cm.

Foot length (FL)

Foot length was measured as the straight line between the most posterior projecting point of the heel (pternion) and the most anterior projecting toe, using the measuring device. Subjects placed their heel against the rear board of the device with the lateral side of the foot touching the side board so that the foot was perpendicular to the rear board. The sliding front board was then adjusted till it just touched the longest toe. The length of the foot was then read off the metric scale of the device (distance between front board and rear board).

Foot Breadth (FB)

The foot breadth was measured as the distance between the most medially projecting point of the head of the first metatarsal and the most laterally projecting point of the fifth metatarsal, using the measuring device. Subjects placed the lateral foot against the rear board and the sliding from board was adjusted till it just touched the first metatarsal in the medial foot. The breadth of the foot was then read off the device (distance between front board and rear board) to the nearest millimeter and later converted into centimeters.

Foot circumference (FC)

Foot circumference was determined as the distance round the plantar surface and dorsum of the foot (Yamaner, Karacabey, Kavlak, & Sevindi, 2011). A tape measure was used to measure the circumference as described by these authors.

Forefoot type determination: In this study, the forefoot refers to the distal part of the foot from the metatarsophalangeal joints to the tips of the five toes. The forefoot type of each subject was classified as either Egyptian (tapered or wide), Grecian (tapered or wide) or Roman (square) (Mariposa & Sand, 2016). The Egyptian type has the big toe being longest than all the other toes. The second toe is the longest in the Grecian forefoot type while the big toe is approximately the same length as the second, third and fourth toes in the Roman type (see figure 6 & Appendix V).

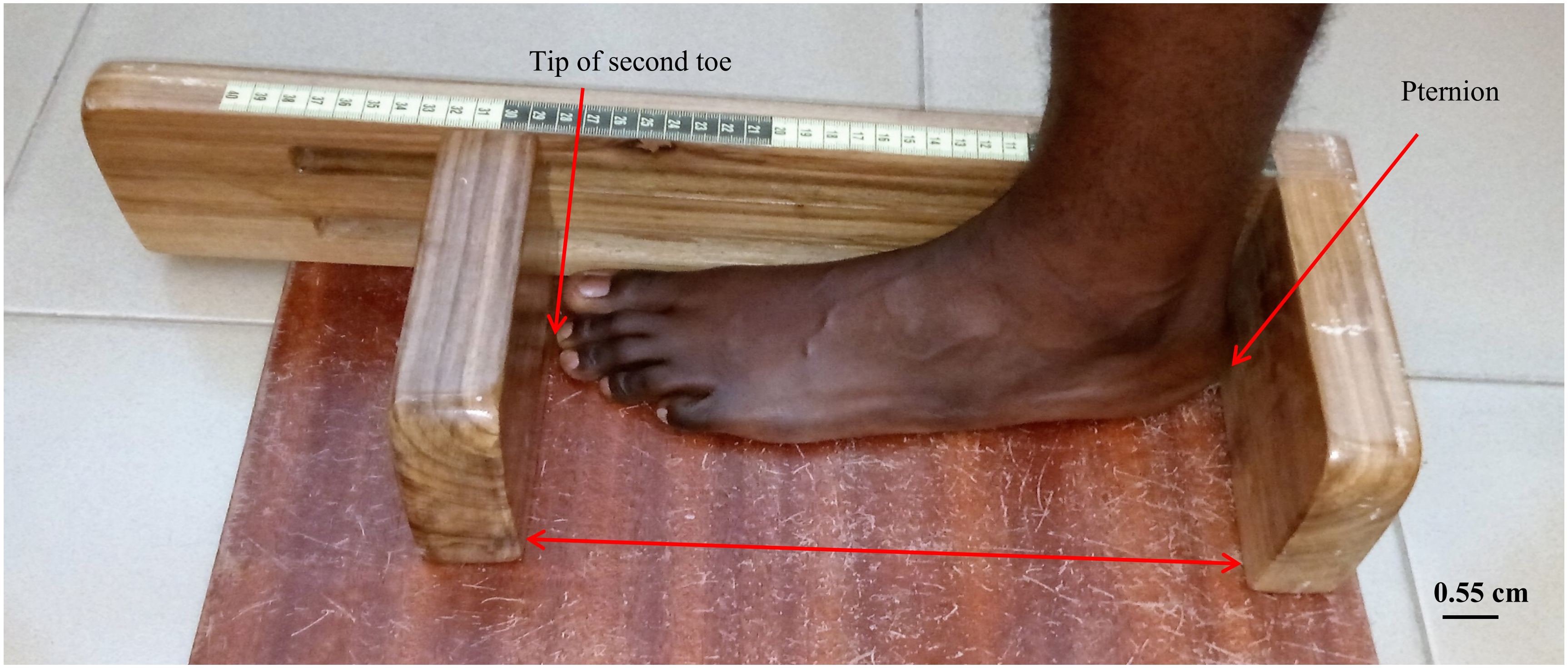


Figure 3: A photograph of the measurement of the right foot length of a subject using the specially designed foot measuring device. The measurement which is indicated by the double- arrowed line was taken from the tip of the longest toe (second toe) to the pternion (rearmost part of the foot).

3.2.2 Hand anthropometry

To measure the hand variables, subjects were asked to place their hands on the top of a flat table, exposing the palmar surface. All measurements were taken from the palmar surface. The measured hand variables were recorded to the nearest 0.1 cm.

Hand length (HL): Hand length was measured while all the fingers were adducted. It was determined as the straight line between the tip of the middle finger and the midpoint of the distal wrist crease, using a pair of sliding calipers (Jowaheer & Agnihotri, 2011) (figure 4).

Hand breadth (HB): Hand breadth was measured while the fingers were slightly abducted as the distance between the most medially projecting point of the head of the fifth metacarpal and the most laterally projecting point of the second metacarpal (Jee et al., 2015). The measurement was taken using a pair of sliding calipers

Hand circumference (HC): The distance round the palmar surface and dorsum of the hand was measured for hand circumference abducted (Jee et al., 2015). A tape measure was used to measure this distance round the hand (figure 5).

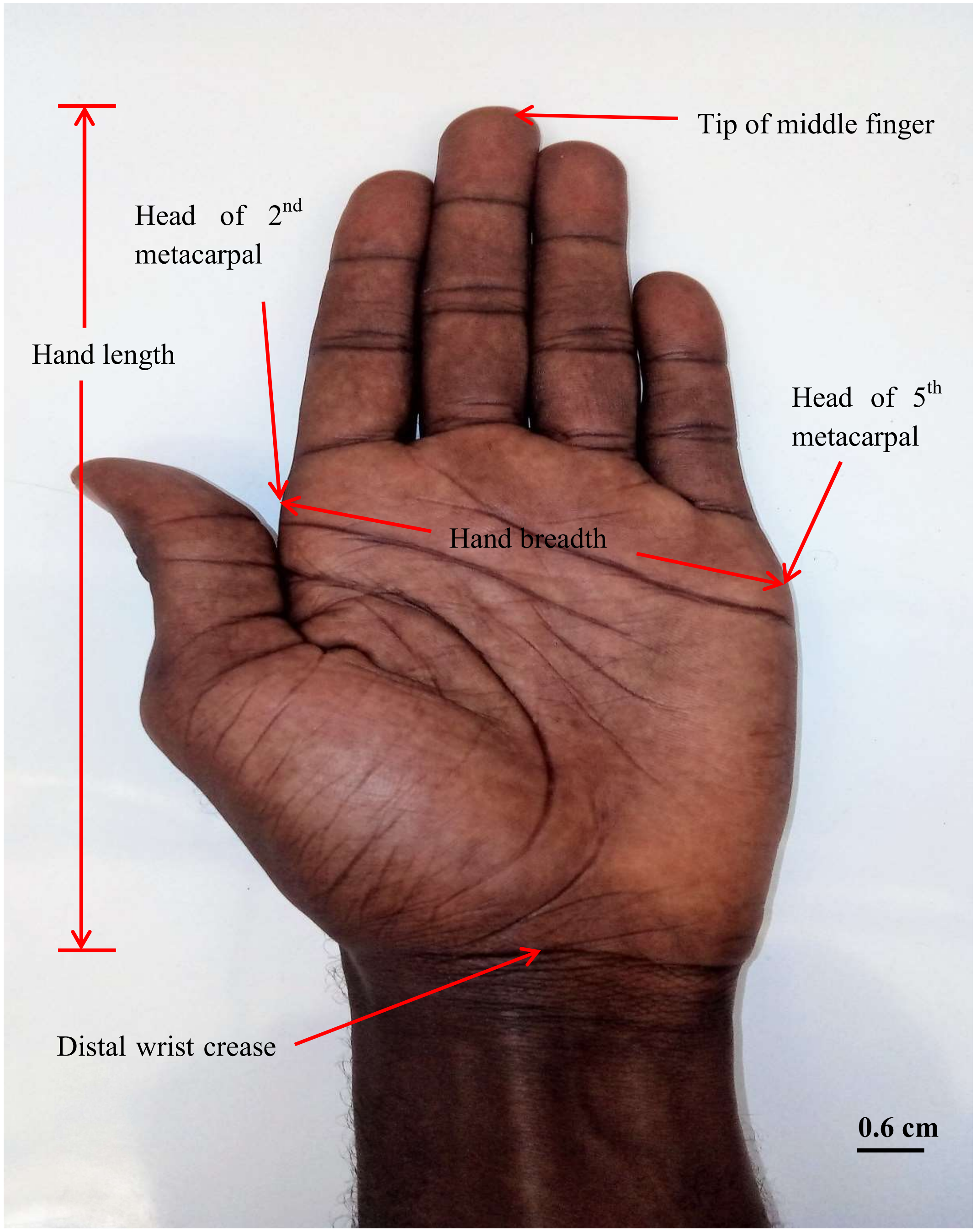


Figure 4: A photograph of a subject's left hand showing the reference points for hand length (HL – from tip of middle finger to distal wrist crease) and hand breadth (HB – from head of 5th metacarpal to head of 2nd metacarpal).

3.3 Determination of Handedness

In order to determine handedness, participants were asked to complete the twelve item Edinburgh Handedness Inventory (EHI) in the research questionnaire (Appendix II) (Oldfield, 1971). Subjects were required to place a **(+)** under either right hand, left hand or both depending on hand preference for each activity on the inventory. The research participants were obliged to place a **(++)** under either left hand or right hand for activities that were so strong in one hand that they would never use the other hand. Each **(+)** was assigned a numeric value of one (1).

Handedness was then determined by the formula:

{Sum of right (+) – Sum of left (+)} / {Sum of right (+) + Sum of left (+)}

The research participants with scores $-1 \leq x < 0$ were classified as left handed. Conversely, the classification for right handedness included participants with a score $0 < x \leq 1$ (Oldfield, 1971).

Measurement of standing Height

It was measured as the vertical distance from the vertex of the skull to the floor with the subject standing in anatomical position on bare feet (Altayeb, 2013b). Each subject was made to stand erect on the floor board under a wall-hang stadiometer with both feet touching at the base of the vertical wall. The feet pointed outward and the trunk braced the vertical board. The face was adjusted to the Frankfort horizontal plane and all excess hair on the crown of the head was pushed aside. The horizontal bar was lowered to the vertex of the head of the subjects and measurement taken.

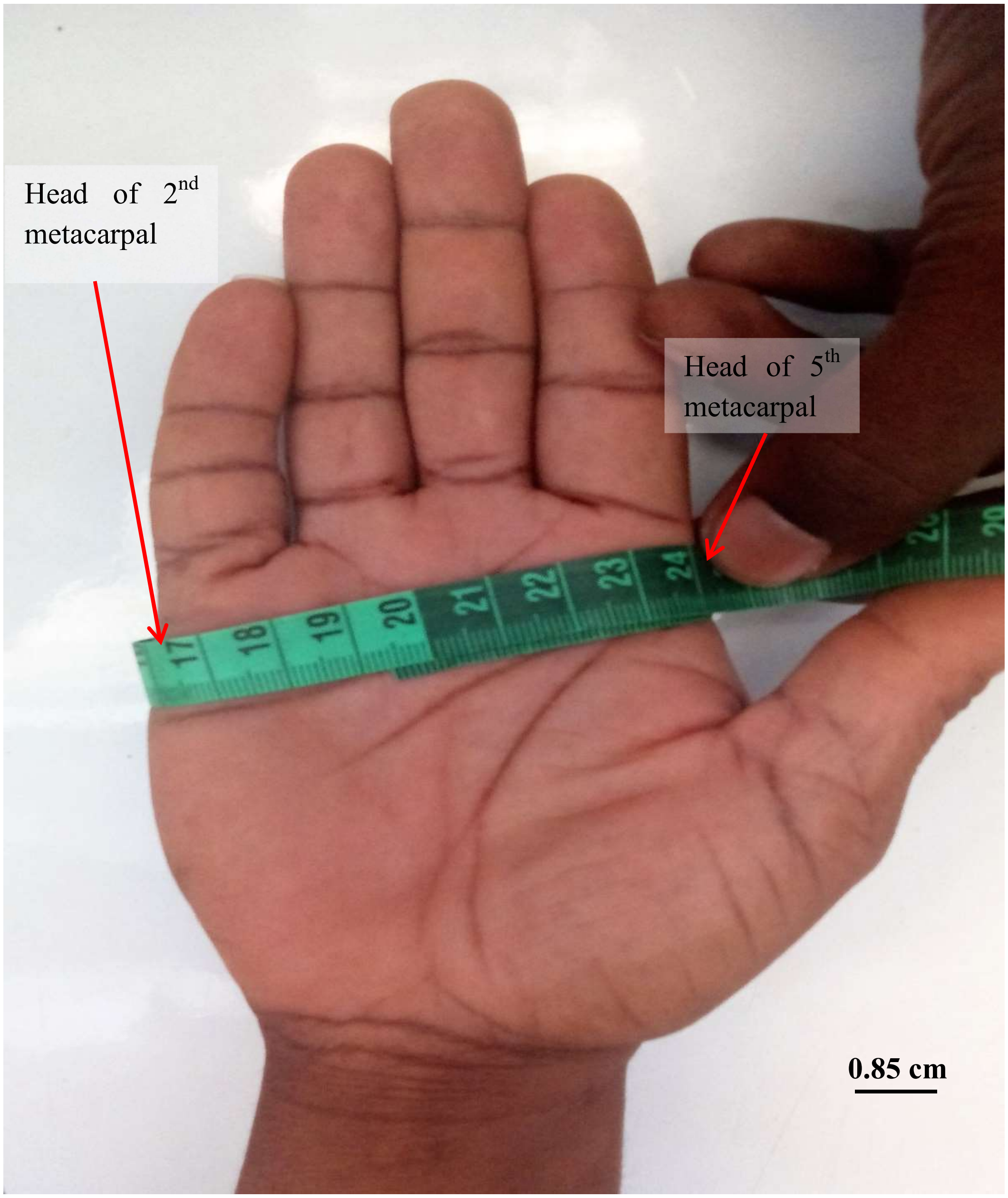
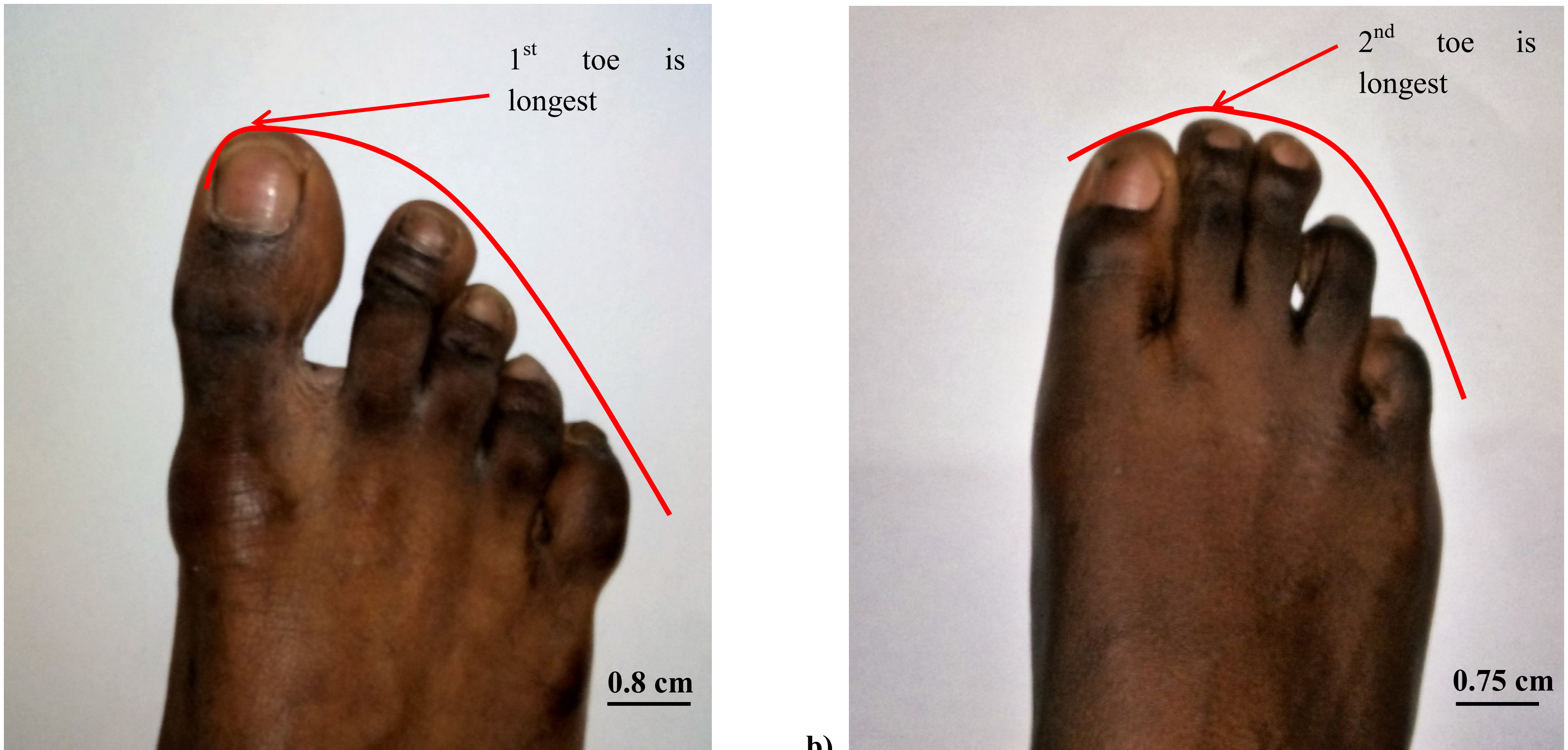


Figure 5: A photograph of a subject's right hand circumference being measured by the investigator.

Egyptian forefoot **Grecian forefoot**



a) b)

Figure 6: Two photographs showing the Egyptian (a) and Grecian (b) forefoot types based on the arrangement of the toes.

3.4 Statistical Analysis

The R Project for statistical computing software (version 3.4.0) for Windows was used to analyse data. The technical error of the measurements (TEM) and relative TEM (%TEM) were calculated to determine the accuracy of measurements. The coefficient of reliability (R) was calculated to evaluate the level of reliability of the data. The Shapiro-Wilk's test for normality of data was used to assess distribution of the data. The data was then split into study and test/control groups by randomly selecting the data of seventy (70) male and seventy (70) female participants to represent the study groups. The male test group (n=30) and female study group (n=30) comprised the remaining data on which the derived equations were tested. Descriptive statistics were generated for each data set. All parametric data results were expressed as means and standard deviations (SD). Paired t-test was used to assess the bilateral differences between the means of all variables while the independent t-test was used to assess the sex differences in height. Pearson's correlation coefficient (r) was calculated for dependent variables. Linear regression equations were derived for height and handedness. Sex was determined by sectioning point method and also by deriving multiple regression equations. Two-way ANOVA was used to determine the main effects of handedness and sex on standardised hand and foot lengths. Significance level was set at $p < 0.05$ for all tests with 95% confidence interval (CI).

CHAPTER FOUR

4 RESULTS

Table 1: Summary of descriptive statistics of age of males and females in study and test groups.

Sex	Min. Age (years)	Max. Age (years)	Mean (years)	Standard Deviation of mean (SD)	Variance	95% Confidence Interval (CI)
Male study group (n=70)	18	30	22.37	3.13	9.80	21.6 - 23.11
Male test group (n=30)	18	30	22.33	3.75	14.09	20.93 - 23.73
Female study group (n=70)	18	30	22.12	2.94	8.69	21.42 - 22.83
Female test group (n=30)	18	29	22.66	2.91	8.50	21.57 – 23.75

Table 2: Summary of descriptive statistics of height of males and females in study and test groups.

Sex	Min. Height (cm)	Max. Height (cm)	Mean (cm)	Standard Error of Mean (SE)	Standard Deviation (SD)	Variance (cm^2)	95% C.I.
Male study group	154.65	191.65	175.13	0.93	7.82	61.24	173.26 – 176.99
Male test group	163.05	190.15	174.73	1.15	6.30	39.77	172.32 – 177.08
Female study group	150.10	182.75	164.23	0.73	6.18	38.22	162.75 – 165.70
Female test group	149.90	175.75	162.61	1.01	5.56	30.91	160.54 – 164.69

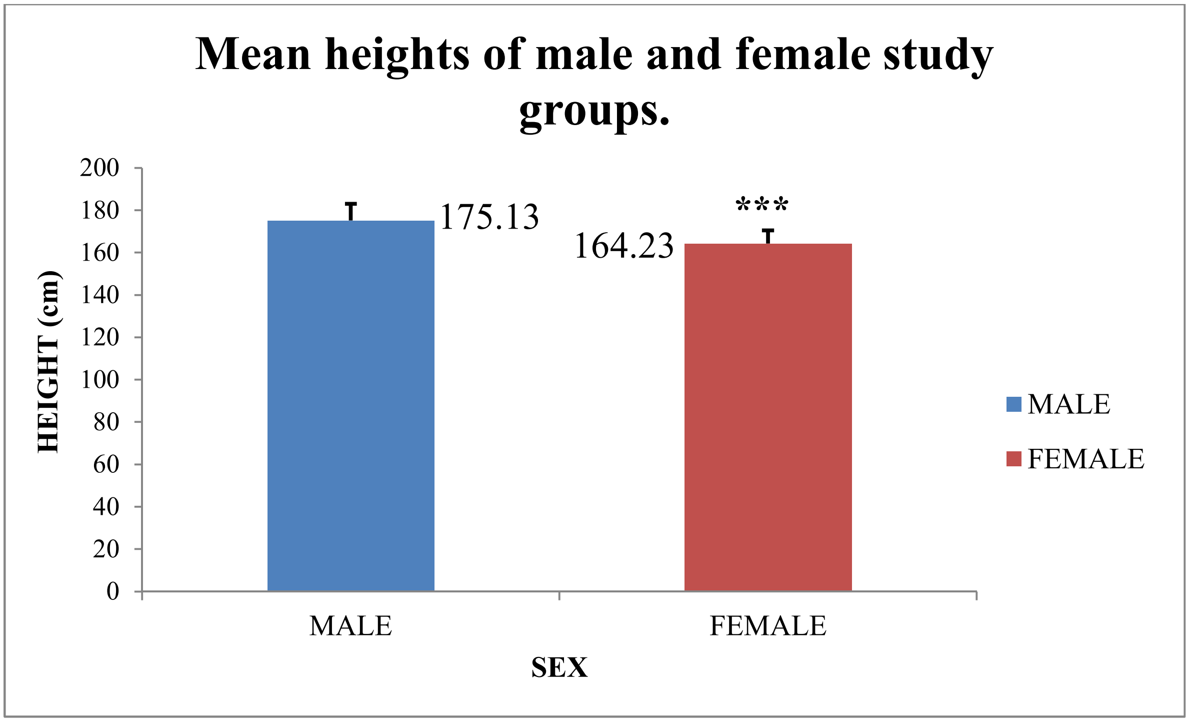


Figure 7: Bar chart showing the difference between the mean heights of the male and female study groups. Error bars represent the standard deviations from the means.

*** means difference is significant at $p \leq 0.001$.

Table 3: Summary of descriptive statistics on foot length of males and females in study and test groups.

Sex	Variable	Min. (cm)	Max. (cm)	Mean ± SD (cm)	SE (cm)	Variance (cm^2)	95% C.I.
Male study group	**RFL**	24.40	30.95	27.41 ± 1.51	0.18	2.30	27.05 – 27.77
	LFL	23.00	30.90	27.39 ± 2.42	0.18	2.42	27.02 – 27.76
Male test group	**RFL**	24.95	30.05	27.37 ± 1.68	0.23	1.68	26.89 - 27.86
	LFL	25.00	30.00	24.47 ± 1.18	0.21	1.40	27.03 - 27.91
Female study group	**RFL**	23.45	28.40	25.11 ± 1.01	0.12	1.03	24.87 - 25.36
	LFL	23.25	28.10	25.13 ± 1.02	0.12	1.04	24.88 - 25.37
Female test group	**RFL**	23.10	27.05	24.75 ± 1.09	0.20	1.20	24.34 - 25.16
	LFL	23.10	27.05	24.75 ± 1.11	0.20	0.17	24.33 - 25.17

RFL: right foot length   LFL: left foot length

Table 4: Summary of descriptive statistics on foot breadth of males and females in study and test groups.

Sex	Variable	Min. (cm)	Max. (cm)	Mean ± SD (cm)	SE	Variance	95% C.I.
Male study group	**RFB**	9.00	12.10	10.12 ± 0.75	0.09	0.57	9.94 - 10.30
	LFB	9.20	12.10	10.17 ± 0.67	0.08	0.45	10.01 - 10.33
Male test group	**RFB**	9.10	12.05	10.22 ± 0.70	0.12	0.50	9.95 - 10.48
	LFB	9.35	11.80	10.25 ± 0.56	0.10	0.31	10.04 - 10.46
Female study group	**RFB**	7.95	10.10	9.22 ± 0.47	0.05	0.22	9.10 – 9.33
	LFB	8.4	10.30	9.23 ± 0.37	0.04	0.14	9.14 - 9.32
Female test group	**RFB**	8.05	10.00	9.14 ± 0.45	0.08	0.20	8.96 – 9.31
	LFB	8.05	9.85	9.09 ± 0.41	0.07	0.17	8.93 – 9.24

RFB: right foot breadth   LFB: left foot breadth

Table 5: Summary of descriptive statistics on foot circumference of males and females in study and test groups.

Sex	Variable	Min. (cm)	Max. (cm)	Mean ± SD (cm)	SE	Variance	95% C.I.
Male study group	**RFC**	23.4	31.2	26.12 ± 1.52	0.18	2.31	25.76 - 26.49
	LFC	23.45	31.2	26.19 ± 1.45	0.17	2.1	25.84 - 26.53
Male test group	**RFC**	24.6	30.1	26.74 ± 1.03	0.18	1.08	26.35 - 27.13
	LFC	24.45	30.105	26.51 ± 1.11	0.2	0.23	26.09 – 26.92
Female study group	**RFC**	21.45	25.55	23.78 ± 1.02	0.12	1.04	23.54 – 24.03
	LFC	21.1	26	23.80 ± 1.09	0.13	1.2	23.53 – 24.06
Female test group	**RFC**	21.1	25.55	23.90 ± 0.92	0.16	0.56	23.56 – 24.25
	LFC	20.9	25.8	23.93 ± 1.02	0.18	1.05	23.55 – 24.32

RFC: right foot circumference   LFC: left foot circumference

The mean age for males was 22.36 ± 3.31 years and 22.29 ± 2.93 years for females. The minimum age recorded for both males and females in the study was 18 years while the maximum ages was 30 years. In the male study group, the mean age recorded was 22.37 ± 3.13years as opposed to 22.33 ± 3.75 years in the test group. The mean age was 22.12 ± 2.94years in the female study group while the mean age in the test sample was 22.66 ± 2.91 years (table 1).

The mean height of males in the study group was 175.13 ± 7.82 cm and 174.73 ± 6.30 cm in the test group. In the female study group, the mean height was 164.23 ± 6.18 cm while 162.61 ± 5.56 cm was the mean recorded for the test group. The remaining descriptive statistics have been summarised in table 2.

The mean RFLs as shown in table 3 were 27.41 ± 1.51 cm and 27.37 ± 1.68 cm corresponding to the male study group and male test sample. In the female study group, an average of 25.11 ± 1.01 cm was yielded for RFL whereas an average of 24.75 ± 1.09 cm was obtained for the test group. Table 3 provides a brief on other descriptive statistics related to RFL.

With regards to LFL, the mean was 27.39 ± 2.42 cm and 24.47 ± 1.18 cm for the male study group and male control group respectively. A mean of 25.13 ± 1.02 cm was derived for the female study group and 24.75 ± 1.11 cm for the test group. All other descriptive statistics on LFL are summarised in table 3.

On average, the RFB of males in the study group was 10.12 ± 0.75 cm and 10.22 ± 0.70 cm in the test group. The mean RFB was 9.22 ± 0.47 cm in the female study sample while a mean of 9.14 ± 0.45 cm was attained for the control group. A brief on SEs and variances of RFB have been provided in table 4.

The average LFBs were 10.17 ± 0.67 cm in male study group and 10.25 ± 0.56cm in the control group. In females, a mean of 9.23 ± 0.37cm was attained for the study group and 9.09 ± 0.41 cm for the test group. Table 4 shows a more comprehensive report on descriptive statistics related to LFB.

The mean RFC for the male study sample as summarised in table 5 was 26.12 ± 1.52 cm and 26.74 ± 1.03cm for the test group. In the female study sample, a mean of 23.78 ± 1.02 cm was derived for RFC and 23.90 ± 0.92 cm in the test sample. Other descriptive statistics on RFC have been detailed in the table mentioned.

The mean LFCs were 26.19 ± 1.45 cm and 26.51 ± 1.11 cm for the male study group and male test group respectively. The average LFC in the female study group was 23.80 ± 1.09 cm while 23.93 ± 1.02 cm was obtained for the test group. Table 5 reports on the remaining descriptive statistics of LFC.

For RHL, the means obtained were 19.84 ± 1.14 cm for the male study group and 19.79 ± 1.08 cm for the male test group (Table 6). In females, the means were 18.10 ± 0.72 cm for the study group and 17.81 ± 0.80 cm for the test group. The corresponding SEs and variances have been listed in the table.

Table 6 also shows 19.94 ± 1.11 cm as the mean LHL in the male study group and 19.87 ± 0.99 cm as the average in the control sample. The mean LHL in the female study group was 18.10 ± 0.72 cm and 17.80 ± 0.78 cm in the control sample. The respective SEs and variances of LHL have also been tabled.

The mean RHBs as shown in table 7 were 8.99 ± 0.54 cm and 8.90 ± 0.49 cm for the male study group and male test group respectively. In the female study group, a mean of 8.02 ± 0.39 cm was recorded for RHB while the mean was 7.90 ± 0.45 cm for the test group. The table gives a detailed report on descriptive statistics on RHB.

The mean LHBs were 8.83 ± 0.57 cm and 8.85 ± 0.54 cm for the male study group and male test group respectively. The mean LHBs were 7.97 ± 0.38 cm in the study sample of females and 7.78 ± 0.49 cm in the female test group. Further descriptive data for LHB have been summarised (table 7)

On average, the RHC of males in the study group was 21.79 ± 1.24 cm and 21.75 ± 1.13 cm in the test group. In females, the mean RHC in the study sample was 19.58 ± 1.21 cm while a mean of 19.53 ± 1.02 cm was obtained for the control group. The corresponding SEs, variances and ranges for RHC have all been listed in table 8.

The mean LHC attained by males in the study group was 21.50 ± 1.41 cm and 21.60 ± 1.21 cm in the test group. The females attained a mean of 19.32 ± 0.91cm in the study group and 19.05 ± 1.03cm in the test group. Table 8 gives a more account of descriptive statistics on LHC.

Table 6: Summary of descriptive statistics on hand length of males and females in study and test groups.

Sex	Variable	Min. (cm)	Max. (cm)	Mean ± SD (cm)	SE	Variance	95% C.I.
Male study group	**RHL**	17.22	23.80	19.84 ± 1.14	0.13	1.30	19.57 – 20.12
	LHL	17.32	23.60	19.94 ± 1.11	0.13	1.24	19.62 – 20.21
Male test group	**RHL**	17.95	22.20	19.79 ± 1.08	0.19	1.17	19.38 – 20.19
	LHL	17.95	22.05	19.87 ± 0.99	0.18	0.99	19.50 – 20.24
Female study group	**RHL**	16.15	19.45	18.10 ± 0.72	0.08	0.53	17.92 – 18.27
	LHL	16.05	19.45	18.10 ± 0.71	0.08	0.51	17.93 - 18.27
Female test group	**RHL**	16.05	19.45	17.81 ± 0.80	0.14	0.64	17.51 – 18.11
	LHL	16.05	19.45	17.80 ± 0.78	0.14	0.60	17.51 – 18.09

RHL: right hand length LHL: left hand length

Table 7: Summary of descriptive statistics on hand breadth of males and females in study and test groups.

Sex	Variable	Min. (cm)	Max. (cm)	Mean ± SD (cm)	SE	Variance	95% C.I.
Male study group	**RHB**	8.10	10.55	8.99 ± 0.54	0.06	0.30	8.86 – 9.12
	LHB	8.00	10.55	8.83 ± 0.57	0.06	0.33	8.69 – 8.97
Male test group	**RHB**	7.95	10.35	8.90 ± 0.49	0.09	0.24	8.72 – 9.08
	LHB	7.40	10.35	8.85 ± 0.54	0.09	0.29	8.64 – 9.05
Female study group	**RHB**	7.10	8.80	8.02 ± 0.39	0.04	0.15	7.93 – 8.11
	LHB	7.15	8.70	7.97 ± 0.38	0.04	0.14	7.88 – 8.06
Female test group	**RHB**	7.00	8.80	7.90 ± 0.48	0.08	0.23	7.72 – 8.08
	LHB	6.80	8.70	7.78 ± 0.49	0.09	0.24	7.59 – 7.96

RHB: right hand breadth LHB: left hand breadth

Table 8: Summary of descriptive statistics on hand circumference of males and females in study and test groups.

Sex	Variable	Min. (cm)	Max. (cm)	Mean ± SD (cm)	SE	Variance	95% C.I.
Male study group	**RHC**	20.00	25.60	21.79 ± 1.24	0.14	1.55	21.49 – 22.08
	LHC	19.50	25.55	21.50 ± 1.41	0.16	2.00	21.16 – 21.84
Male test group	**RHC**	19.55	25.60	21.75 ± 1.13	0.20	1.28	21.33 – 22.17
	LHC	18.95	25.50	21.60 ± 1.21	0.22	1.47	21.14 – 22.05
Female study group	**RHC**	12.95	21.70	19.58 ± 1.21	0.14	1.47	19.28 – 19.87
	LHC	17.40	21.70	19.32 ± 0.91	0.11	0.83	19.10 – 19.53
Female test group	**RHC**	17.45	21.70	19.53 ± 1.02	0.18	1.04	19.15 – 19.92
	LHC	16.95	21.70	19.05 ± 1.03	0.18	1.07	18.66 – 19.4

RHC: right hand circumference   LHC: left hand circumference

Bilateral differences in anthropometric hand and foot measurements in the study groups.

In males, there were no significant differences between bilateral foot lengths ($t = 0.194$, $p = 0.846$), bilateral foot breadths ($t = 1.075$ $p = 0.286$) and bilateral foot circumferences ($t = 0.908$, $p = 0.366$). The differences between the bilateral means were however significant for hand length ($t = 2.50$, $p = 0.014$), hand breadth ($t = 4.391$, $p < 0.001$) and hand circumference ($t = 3.295$, $p = 0.001$).

In females, there was also no significant difference between bilateral foot lengths ($t = 0.725$, $p = 0.427$), bilateral foot breadths ($t = 0.271$, $p = 0.786$) and bilateral foot circumferences ($t = 0.212$, $p = 0.832$). The means of hand length ($t = 0.087$, $p = 0.930$) and hand breadth ($t = 1.289$, $p = 0.201$) showed no significant difference. Hand circumference on the contrary, showed that the difference between the bilateral means was significant ($t = 2.468$, $p = 0.015$).

Correlation of hand and foot variables with height

Foot length, foot breadth, foot circumference, hand length, hand breadth and hand circumference all showed significant positive correlation with height. The strongest correlation with height in males was attained by LFL ($r = 0.753$, $p < 0.001$) for foot measurements and RHL ($r = 0.710$, $p < 0.001$) for hand measurements (figures 9 & 10 respectively).

Just as in males, foot length, foot breadth, foot circumference, hand length, hand breadth and hand circumference in females all showed significant positive correlation with height. The coefficients of correlation for all the variables were significant except for RHC ($r = 0.186$, $p = 0.122$) (figure 14). The strongest correlation with height in females was attained by RFL ($r = 0.680$, $p < 0.001$) for foot measurements and RHL ($r = 0.504$, $p < 0.001$) for hand measurements (figures 12 & 14 respectively).

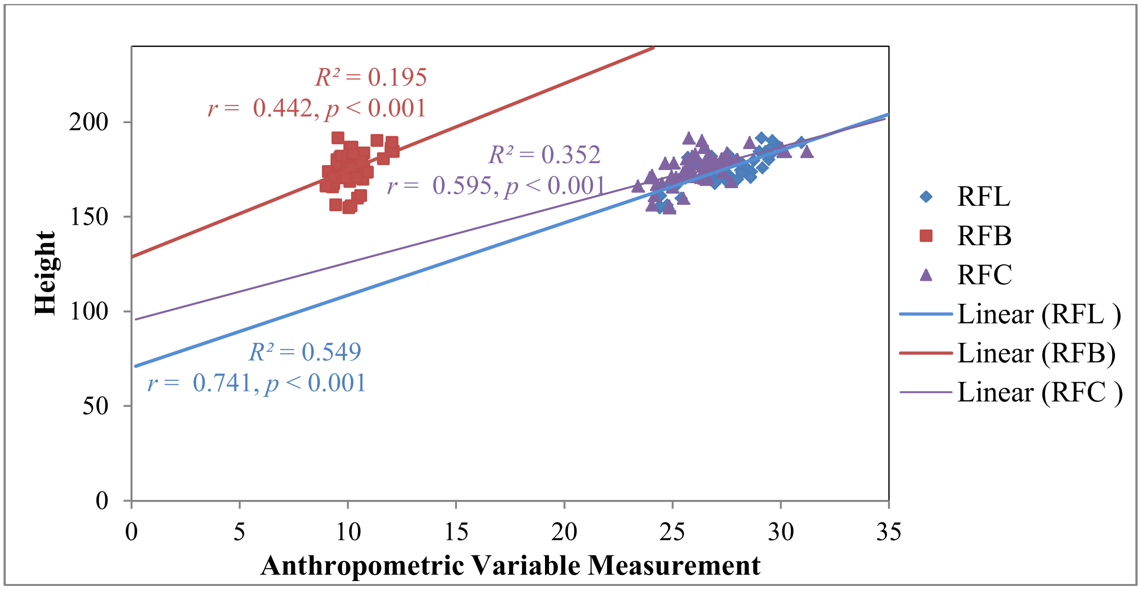


Figure 8: Scatter plot of correlation between height and RFL, RFB and RFC in male study group. r is the Pearson's correlation coefficient and R^2 is the coefficient of determination. $p \leq 0.05$ is significant.

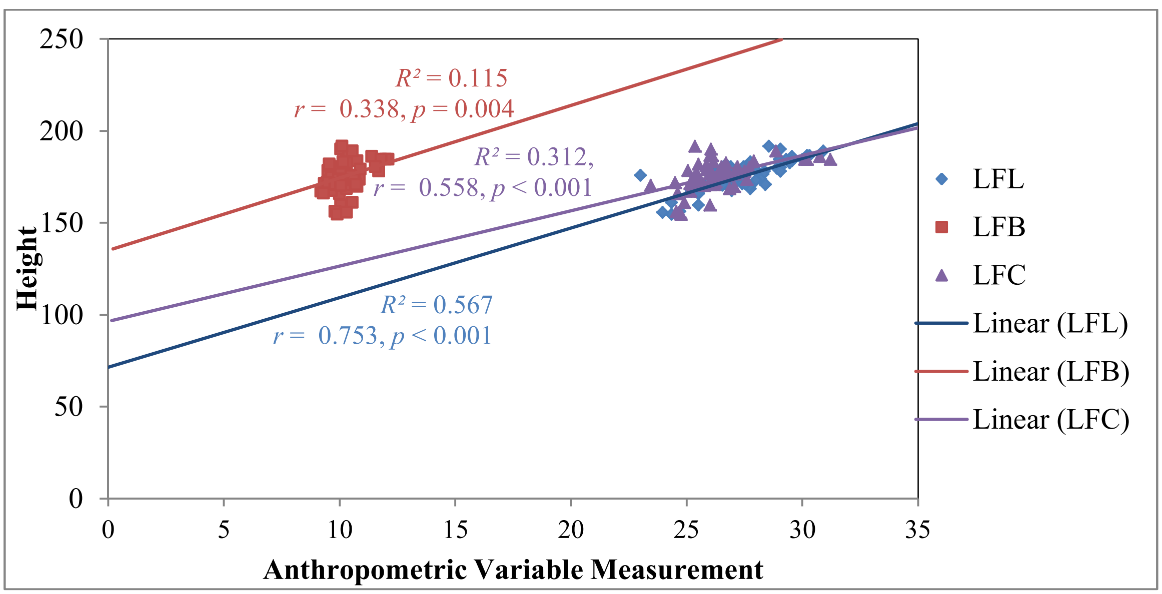


Figure 9: Scatter plot of correlation between height and LFL, LFB and LFC in male study group. r is the Pearson's correlation coefficient and R^2 is the coefficient of determination. $p \leq 0.05$ is significant.

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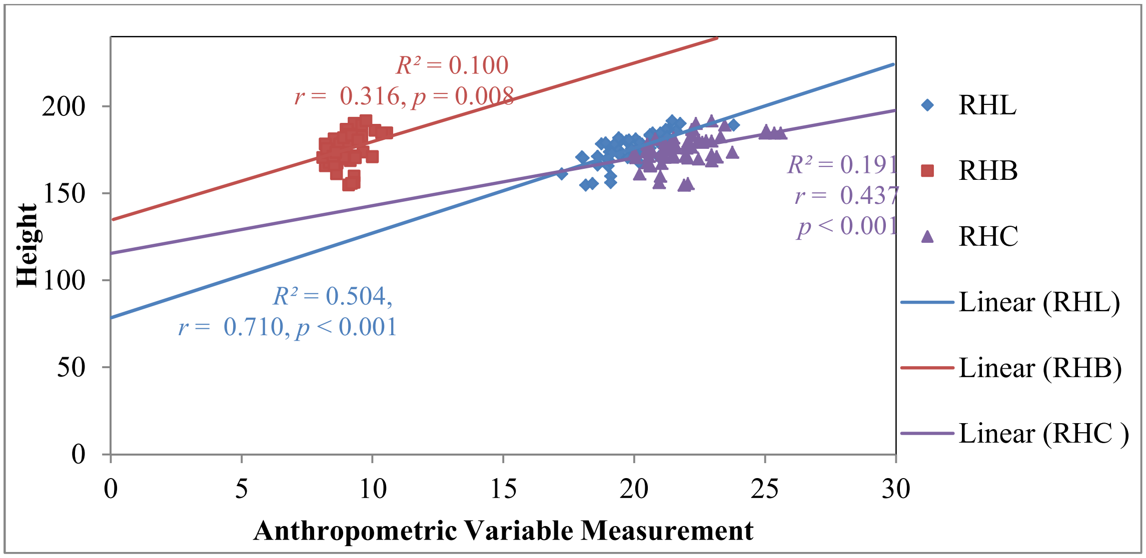

Figure 10: Scatter plot of correlation between height and RHL, RHB and RHC in male study group. r is the Pearson's correlation coefficient and R^2 is the coefficient of determination. $p \leq 0.05$ is significant.

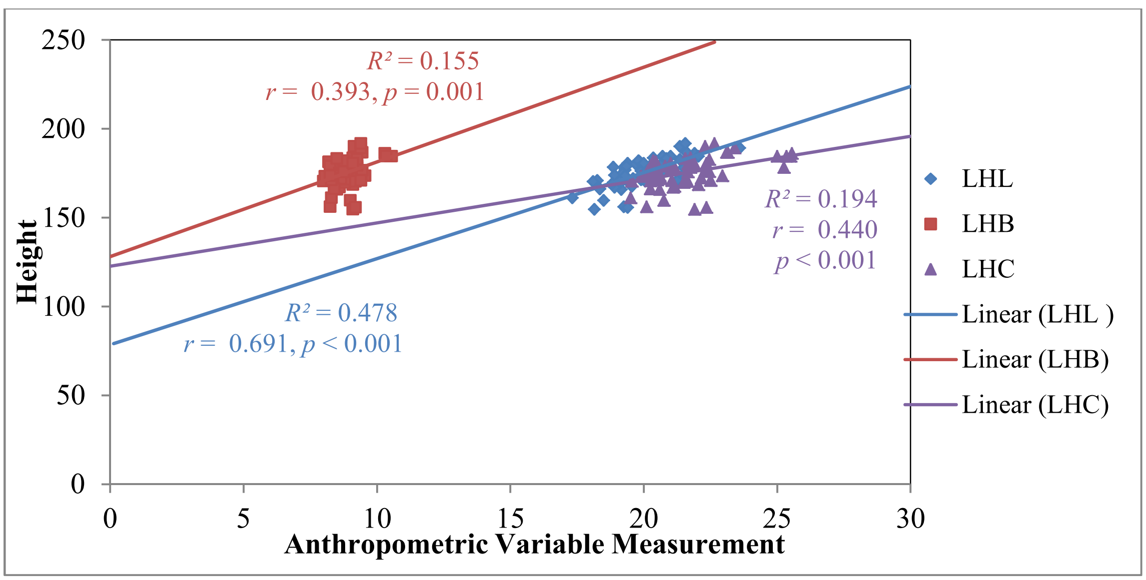

Figure 11: Scatter plot of correlation between height and LHL, LHB and LHC in male study group. r is the Pearson's correlation coefficient and R^2 is the coefficient of determination. $p \leq 0.05$ is significant.

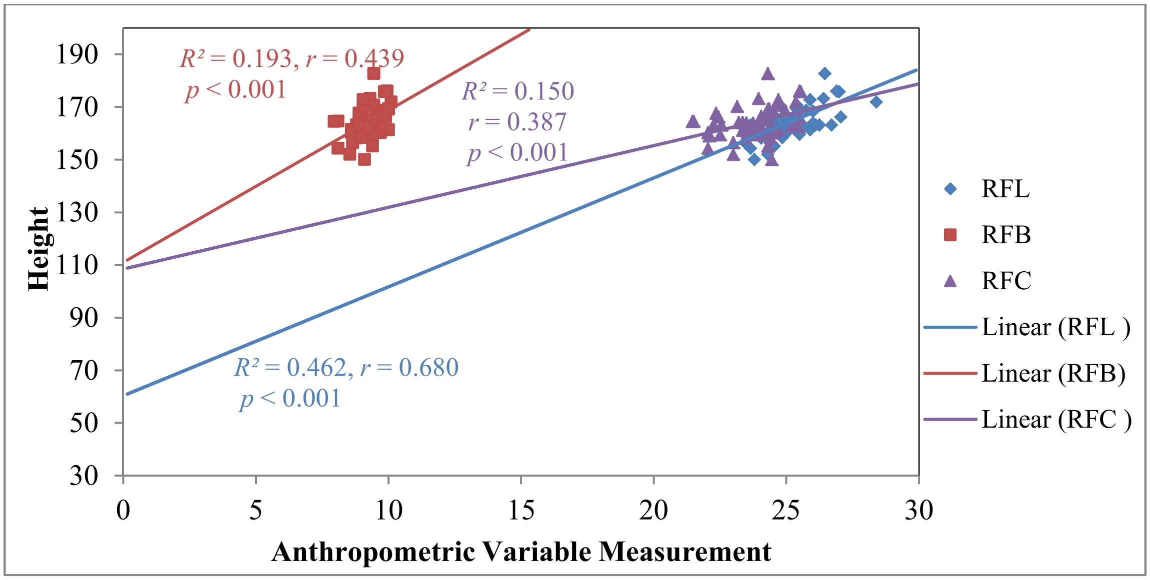

Figure 12: Scatter plot of correlation between height and RFL, RFB and RFC in female study group. r is the Pearson's correlation coefficient and R^2 is the coefficient of determination. $p \leq 0.05$ is significant.

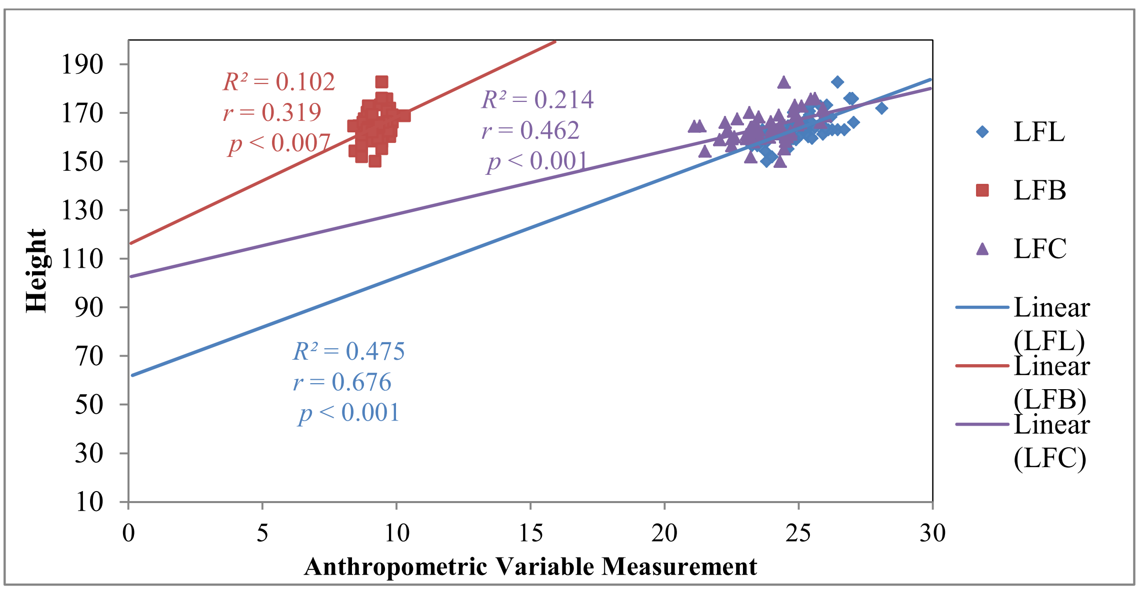

Figure 13: Scatter plot of correlation between height and LFL, LFB and LFC in female study group. r is the Pearson's correlation coefficient and R^2 is the coefficient of determination. $p \leq 0.05$ is significant.

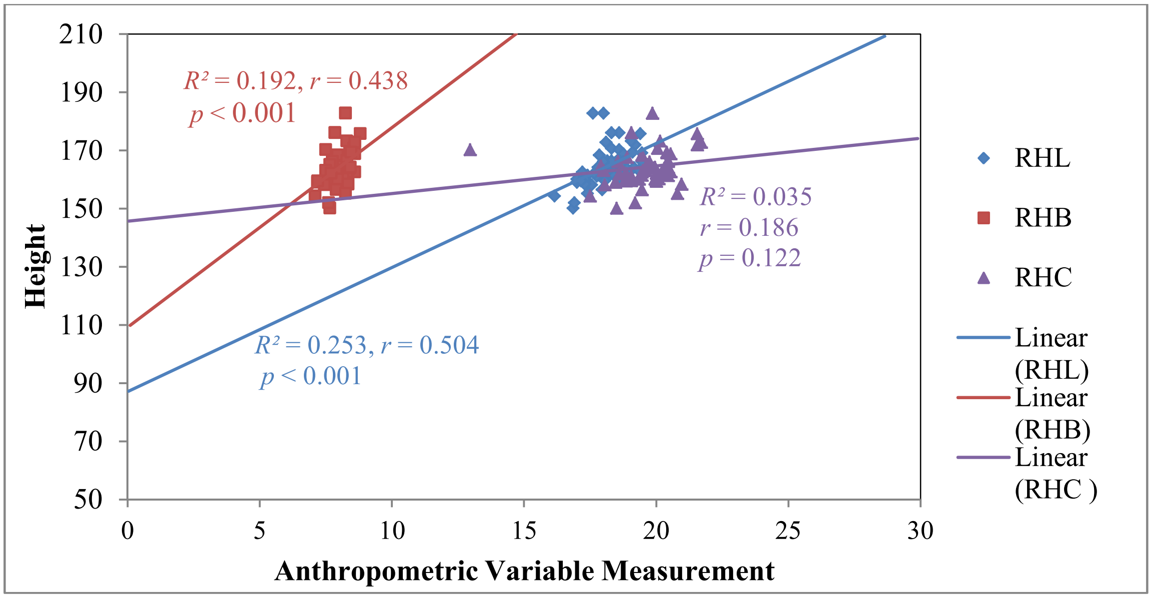

Figure 14: Scatter plot of correlation between height and RHL, RHB and RHC in female study group. r is the Pearson's correlation coefficient and R^2 is the coefficient of determination. $p \leq 0.05$ is significant.

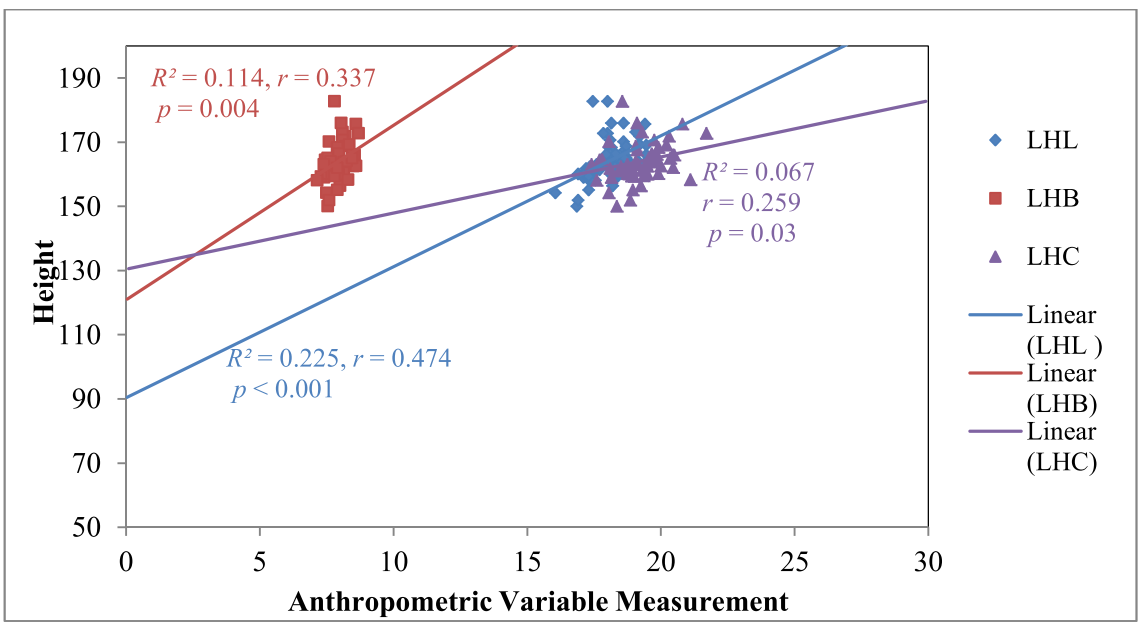

Figure 15: Scatter plot of correlation between height and LHL, LHB and LHC in female study group. r is the Pearson's correlation coefficient and R^2 is the coefficient of determination. $p \leq 0.05$ is significant.

Height prediction from explanatory variables.

There was a significant difference (t = 12.779, p < 0.001) between the mean height of males (175.13 ± 7.82 cm) and that of females (164.23 ± 6.18 cm) (refer to figure 7).

The predictive equations for height from foot measurements using linear regression have been summarised in table 9. The slope coefficients for the formulae derived were all significant. The model with the least standard error of estimate in males was obtained when LFL was used (SEE = 11.52, R^2 = 0.549). The same equation yielded the highest determination coefficient. In females, the least standard error of estimate was attained with RFB (SEE = 13.20, R^2 = 0.193) while RFL produced the highest determination coefficient (R^2 = 0. 0.462, SEE = 13.58).

The linear equations for height derived with the individual hand variables have been summarised in table 10. The slope coefficients for the formulae derived were all significant. In males, the equation obtained with RHL reported the least standard error of estimate (SEE = 11.60, R^2 = 0.505). The same equation yielded the highest determination coefficient. . In females, the least standard error of estimate was attained with RHC (SEE = 11.88, R^2 = 0.034) while RHL produced the highest determination coefficient (R^2 = 0. 0.254, SEE = 16.08)

The results for multiple regressions of hand and foot explanatory variables on height have been detailed in table 11. The slope coefficients for the formulae derived were all significant. The model equations from the right feet in both males and females returned the least standard error of estimates; (SEE = 12.17, R^2 = 0.577) for the former and (SEE = 15.65, R^2 = 0.476) for the latter. The determination coefficient was highest with the right left foot (R^2 = 0.594, SEE = 12.32) in males while the highest determination coefficient was maintained by the right foot in females.

Table 9: Formulae for height estimation from univariate linear regression analysis using foot variables.

Sex	Variable	Regression model	SEE	R^2	r	p-value
Male	**RFL**	(3.822 × RFL) + 70.354	11.52	0.549	0.741	<0.001***
	LFL	(3.785× LFL) + 71.456	11.00	0.567	0.753	<0.001***
	RFB	(4.578× RFB) + 128.797	11.42	0.195	0.442	<0.001***
	LFB	(3.940× LFB) + 135.046	13.54	0.114	0.338	<0.001***
	RFC	(3.062 × RFC) + 95.118	14.06	0.352	0.595	<0.001***
	LFC	(3.009× LFC) + 96.310	14.24	0.311	0.558	<0.001***
Female	**RFL**	(4.133× RFL) + 60.409	13.58	0.462	0.680	<0.001***
	LFL	(4.090× LFL) + 61.426	13.58	0.457	0.676	<0.001***
	RFB	(5.769× RFB) + 111.034	13.20	0.193	0.439	<0.001***
	LFB	(5.248× LFB) + 115.786	13.28	0.102	0.319	<0.001***
	RFC	(2.342× RFC) + 108.496	14.10	0.150	0.387	<0.001***
	LFC	(2.597× LFC) + 102.411	14.40	0.213	0.462	<0.001***

SEE: standard error of estimate R^2: determination coefficient r: correlation coefficient
RFL: right foot length LFL: left foot length RFB: right foot breadth
LFB: left foot breadth RFC: right foot circumference LFC: left foot circumference
*** means slope coefficient is significant at $p \leq 0.001$

Table 10: Formulae for height estimation from univariate linear regression analysis using hand variables.

Sex	Variable	Regression model	SEE	R^2	r	p-value
Male	**RHL**	(4.868× RHL) + 78.499	11.60	0.505	0.710	<0.001***
	LHL	(4.844× LHL) + 78.502	12.28	0.477	0.691	<0.001***
	RHB	(4.511× RHB) + 134.556	14.76	0.100	0.316	<0.001***
	LHB	(5.332× LHB) + 128.028	13.36	0.155	0.393	<0.001***
	RHC	(2.739× RHC) + 115.442	14.92	0.191	0.437	<0.001***
	LHC	(2.437× LHC) + 122.723	12.98	0.194	0.440	<0.001***
Female	**RHL**	(4.266× RHL) + 86.988	16.08	0.254	0.504	<0.001***
	LHL	(4.085× LHL) + 90.2655	16.66	0.224	0.474	<0.001***
	RHB	(6.864× RHB) + 109.147	13.72	0.192	0.438	<0.001***
	LHB	(5.436× LHB) + 120.876	14.72	0.113	0.337	<0.001***
	RHC	(0.947× RHC) + 145.677	11.88	0.034	0.186	<0.001***
	LHC	(1.752× LHC) + 130.382	15.32	0.067	0.259	<0.001***

SEE: standard error of estimate R^2: determination coefficient r: correlation coefficient RHL: right hand length LHL: left hand length RHB: right hand breadth LHB: left hand breadth RHC: right hand circumference LHC: left hand circumference

*** means slope coefficient is significant at $p \leq 0.001$

Table 11: Formulae for height estimation from multivariate linear regression analysis using hand and foot variables.

	Regression equation	SEE	R^2	r	p-value
	Male				
Right foot	61.731 + 3.209(RFL) - 1.587(RFB) + 1.588(RFC)	12.17	0.577	0.759	< 0.001***
Left foot	64.188 + 3.227(LFL) - 1.887(LFB) + 1.593(LFC)	12.32	0.594	0.771	< 0.001***
Right hand	77.185 + 4.601(RHL) - 6.171(RHB) + 2.850(RHC)	12.93	0.539	0.734	< 0.001***
Left hand	77.341 + 4.759(LHL) + 0.466(LHB) – 0.058(LHC)	13.30	0.478	0.691	< 0.001***
	Female				
Right foot	51.944 + 3.712(RFL) + 1.098(RFB) + 0.378(RFC)	15.65	0.476	0.690	= 0.001***
Left foot	55.829 + 3.645(LFL) – 0.422(LFB) + 0.869(LFC)	16.33	0.474	0.686	< 0.001***
Right hand	80.216 + 3.022(RHL) + 5.101(RHB) – 0.595(RHC)	17.20	0.301	0.549	< 0.001***
Left hand	81.439 + 3.537(LHL) + 1.641(LHB) + 0.293(LHC)	19.08	0.240	0.490	< 0.001***

SEE: standard error of estimate R^2: determination coefficient r: correlation coefficient
RHL: right hand length LHL: left hand length RHB: right hand breadth
LHB: left hand breadth RHC: right hand circumference LHC: left hand circumference
RFL: right foot length LFL: left foot length RFB: right foot breadth
LFB: left foot breadth RFC: right foot circumference LFC: left foot circumference
*** means slope coefficient is significant at $p \leq 0.001$

Percentage of difference between means of estimated height and actual height of the test/control groups.

The statistics regarding percentage of difference between means of actual height and estimated height from individual foot measurements are detailed in table 12. In the male test group the true height was 174.73 ± 6.30 cm while the mean was 162.61 ± 5.56 cm in the female test group. There were no significant differences between the means of true height in the test groups and estimated height except for RFC (177.00 ± 3.18, $p = 0.05$) in males. The minimum percentage mean difference between estimated height and the true height of males from single foot variables was 0.04 percent (from LFL & LFB) while that of females was 0.03 percent (from LFL).

Table 13 summarises the statistics on percentage of difference between means of actual height and estimated height from hand measurements. No significant differences between the means of true height in the control groups and estimated height were observed. The minimum percentage mean difference between estimated height and the true height of males from single hand variables was 0.01 percent (from LHL & RHB) while that of females was 0.23 percent (from RHL & LHL).

The percentage of difference between means of actual height and estimated height from multiple regression analyses using hand and foot variables have been described in table 14. The results showed no significant differences between the means of true height in the control groups and estimated height. The left hands of males and right hands of females yielded the least percentages of difference which were 0.03 percent and 0.08 percent respectively.

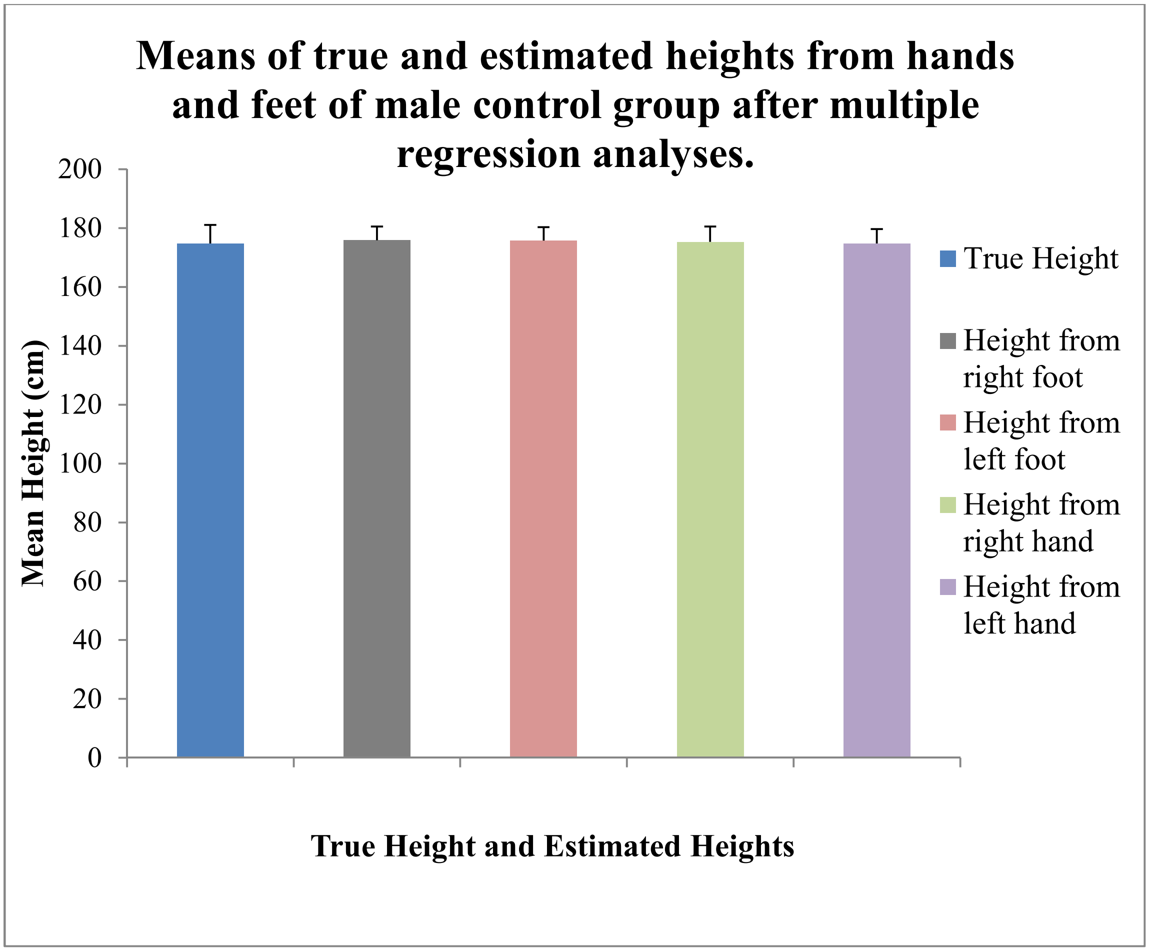

Figure 16: A bar chart comparing the means of true height and estimated heights derived from the hands and feet of the male test group using the multiple regression equations. Error bars represent the standard deviations from the means.

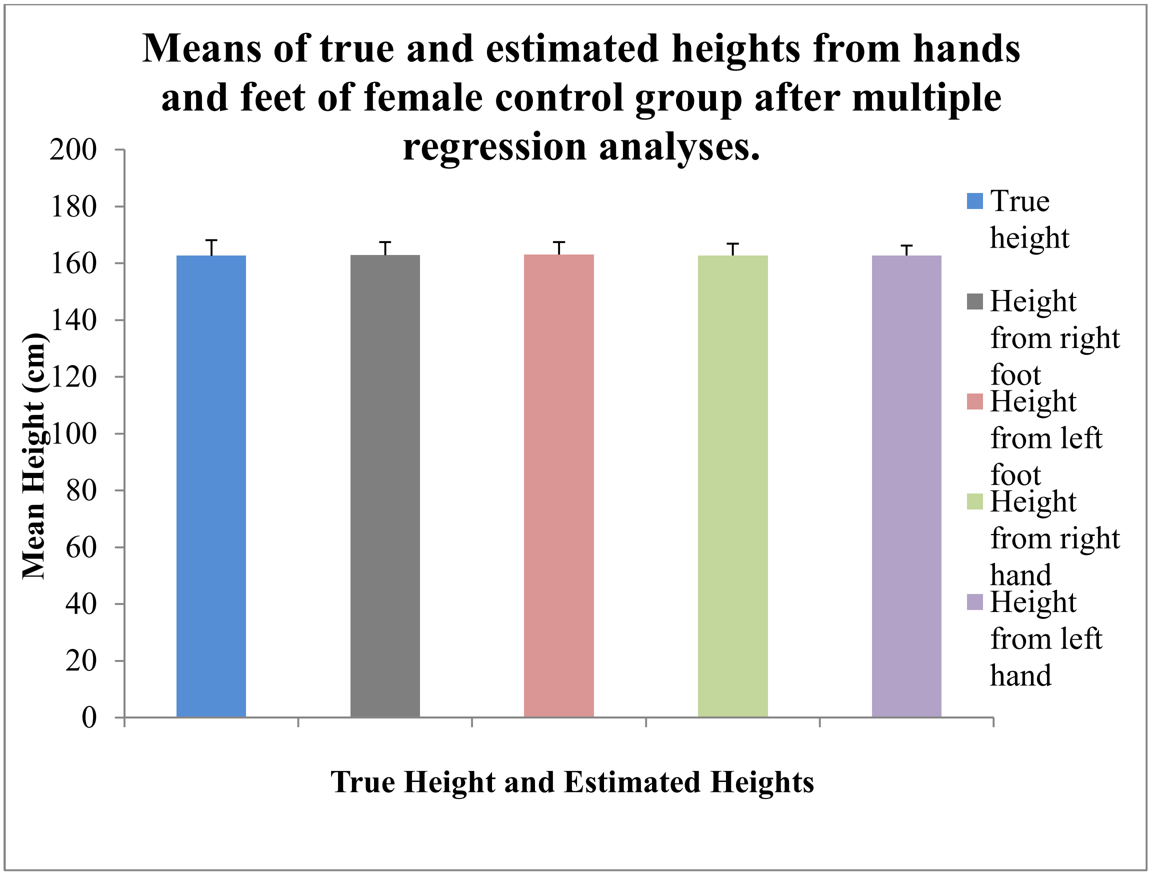

Figure 17: A bar chart comparing the means of true height and estimated heights derived from the hands and feet of the female test group using the multiple regression equations. Error bars represent the standard deviations from the means.

Table 12: Percentage of difference (%), mean difference and *p*-value of paired t-test between true stature and estimated stature from foot dimensions in test groups (linear regression analyses).

	Variable	Mean ± SD	% Diff	Mean Diff. ± SD	*p*-value
True Male Height		174.73 ± 6.30	-	-	
Estimated Height	**RFL**	174.98 ± 4.96	0.14	- 0.25 ± 4.96	0.769
	LFL	175.44 ± 4.48	0.40	-0.70 ± 4.48	0.371
	RFB	175.59 ± 3.23	0.48	-0.86 ± 3.23	0.433
	LFB	175.43 ± 2.21	0.40	-0.70 ± 2.21	0.535
	RFC	177.00 ± 3.18	1.29	-2.27 ± 3.18	0.050*
	LFC	176.08 ± 3.34	0.77	-1.35 ± 3.34	0.231
True Female Height		162.61 ± 5.56	-	-	
Estimated Height	**RFL**	162.70 ± 4.52	0.05	-0.09 ± 4.52	0.898
	LFL	162.67 ± 4.54	0.03	-0.05 ± 4.54	0.935
	RFB	163.76 ± 2.63	0.69	-1.14 ± 2.63	0.242
	LFB	163.08 ± 2.18	0.54	-0.88 ± 2.18	0.393
	RFC	164.48 ± 2.17	1.13	-1.87 ± 2.17	0.060
	LFC	164.57 ± 2.66	1.19	-1.96 ± 2.66	0.049

% Diff: percentage difference between true mean and estimated mean
RFL: right foot length LFL: left foot length RFB: right foot breadth
LFB: left foot breadth RFC: right foot circumference LFC: left foot circumference
* means difference is significant at $p \leq 0.05$

Table 13: Percentage of difference (%), mean difference and *p*-value of paired t-test between true stature and estimated stature from hand dimensions in test groups (linear regression analyses).

	Variable	Mean ± SD	%Diff	Mean Diff. ± SD	*p*-value
True Male Height		174.73 ± 6.30	-	-	
Estimated Height	**RHL**	174.84 ± 5.27	0.06	-0.11 ± 5.27	0.891
	LHL	174.76 ± 4.83	0.01	-0.03 ± 4.83	0.969
	RHB	174.72 ± 2.23	0.01	0.01 ± 2.23	0.993
	LHB	175.21 ± 2.90	0.28	-0.52 ± 2.90	0.687
	RHC	175.03 ± 3.10	0.17	-0.30 ± 3.10	0.798
	LHC	175.36 ± 2.95	0.36	-0.63 ± 2.95	0.596
True Female Height		162.61 ± 5.56	-	-	
Estimated Height	**RHL**	163.00 ± 3.42	0.23	-0.39 ± 3.42	0.605
	LHL	163.00 ± 3.18	0.23	-0.39 ± 3.18	0.620
	RHB	163.39 ± 3.32	0.47	-0.77 ± 3.32	0.363
	LHB	163.18 ± 2.70	0.34	-0.56 ± 2.70	0.524
	RHC	164.17 ± 0.96	0.95	-1.56 ± 0.96	0.111
	LHC	163.76 ± 1.82	0.69	-1.15 ± 1.82	0.208

% Diff: percentage difference between true mean and estimated mean

RHL: right hand length LHL: left hand length RHB: right hand breadth LHB: left hand breadth RHC: right hand circumference LHC: left hand circumference

Table 14: Percentage of difference (%), mean difference and p-value of paired t-test between true stature and estimated stature from hand dimensions in test/control groups (multiple regression analyses)

	Variable	Mean ± SD	% Diff	Mean Diff. ± SD	*p*-value
True Male Height		174.73 ± 6.30			
Estimated Height	**Right foot**	175.82 ± 4.73	0.62	-1.09 ± 4.73	0.242
	Left foot	175.73 ± 4.51	0.57	-1.00 ± 4.51	0.236
	Right hand	175.30 ± 5.17	0.32	-0.57 ± 5.17	0.529
	Left hand	174.78 ± 4.84	0.03	-0.05 ± 4.84	0.950
True Female Height		162.61 ± 5.56			
Estimated Height	**Right foot**	162.89 ± 4.59	0.17	-0.28 ± 4.59	0.703
	Left foot	163.03 ± 4.49	0.25	-0.42 ± 4.49	0.558
	Right hand	162.75 ± 4.11	0.08	-0.14± 4.11	0.860
	Left hand	162.77 ± 3.44	0.09	-0.15 ± 3.44	0.835

% Diff: percentage difference between true mean and estimated mean

Sex differences in anthropometric hand and foot variables.

An independent *t*-test showed significant sex differences between the means of corresponding variables in the opposite sex. The test statistics between the means of males and females were ($t = 13.815$, $p < 0.001$) for RFL, ($t = 10.204$, $p < 0.001$) for RFB, ($t = 10.200$, $p < 0.001$) for RFC, ($t = 13.672$, $p < 0.001$) for LFL, ($t = 12.822$, $p < 0.001$) for LFB and ($t = 1.936$, $p < 0.001$) for LFC.

With regard to hand measurements the values obtained were ($t = 14.185$, $p < 0.001$) for RHL, ($t = 8.96$, $p < 0.001$) for RHB, ($t = 10.263$, $p < 0.001$) for RHC, ($t = 15.026$, $p < 0.001$) for LHL, ($t = 12.919$, $p < 0.001$) for LHB and ($t = 11.017$, $p < 0.001$) for LHC.

Sex determination by sectioning point method

The sectioning points for hand and foot variables together with their accuracies of predictions have been summarized in table 15. The highest accuracies from hand variables were yielded by RHL (92.85%, SP = 18.92) in females and RHB (88.57%, SP = 8.47) in males. With regards to foot variables, the highest accuracies were returned by LFC (85.71%, SP = 24.95) in males and LFB (88.57%, SP = 9.69) in females.

Sex determination using multiple regression analyses

The multiple linear regression analyses using hand and foot explanatory variables for sex estimation have been summarised in table 16. The equations that incorporated only length and breadth dimensions produced results in which both dimensions were significant contributors to the equations (i.e. $p < 0.05$).

The percentage accuracies of sex prediction from the multiple regression analysis tested on the study groups of males and females have been listed in table 16. Right feet in females and left feet in males produced the comparatively higher accuracies of prediction (92.85% and 82.85% respectively). Also, Right hands in females and left hands in males produced the comparatively higher accuracies of prediction (92.85% and 88.57% respectively).

Table 15: Percentage accuracy of sectioning points derived in the study samples

Variable	SP	Male (*n*=70)	Female (*n*=70)
RFL	26.20	80.00%	81.42%
LFL	26.22	80.00%	81.42%
RFB	9.67	67.14%	81.42%
LFB	9.69	77.14%	88.57%
RFC	24.95	80.00%	87.14%
LFC	24.99	85.71%	84.28%
RHL	18.92	80.00%	92.85%
LHL	18.96	82.85%	87.14%
RHB	8.47	88.57%	91.42%
LHB	8.37	74.28%	81.42%
RHC	20.69	78.57%	90.00%
LHC	20.41	80.00%	88.57%

SP: Sectioning point n: number of subjects in the group
RHL: right hand length LHL: left hand length RHB: right hand breadth LHB: left hand breadth RHC: right hand circumference LHC: left hand circumference RFL: right foot length LFL: left foot length RFB: right foot breadth LFB: left foot breadth RFC: right foot circumference LFC: left foot circumference

Table 16: Summary of formulae for sex prediction based on multiple linear regression analysis

	Regression equations for Sex	R^2	r	*p*-value
Right foot	6.764 - (0.148 × RFL) - (0.141 × RFB)	0.467	0.684	RFL < 0.001*** RFB < 0.001***
	7.096 - (0.108 × RFL) + (0.041 × RFB) - (0.126 × RFC)	0.507	0.712	RFL < 0.001*** RFB = 0.598 RFC = 0.001***
Left foot	7.151- (0.112 × LFL) - (0.278 × LFB)	0.516	0.718	LFL < 0.001*** LFB < 0.001***
	7.195 - (0.091 × LFL) - (0.186 × LFB) - (0.059 × LFC)	0.524	0.723	LFL < 0.001*** LFB = 0.025* LFC = 0.132
Right Hand	6.839 - (0.124 × RHL) - (0.349 × RHB)	0.556	0.746	RHL < 0.001*** RHB < 0.001***
	6.906 - (0.122 × RHL) - (0.270 × RHB) - (0.037 × RHC)	0.559	0.747	RHL < 0.001*** RHB = 0.009** RHC = 0.341
Left Hand	6.932 - (0.180 × LHL) - (0.238 × LHB)	0.536	0.732	LHL < 0.001*** LHB < 0.001***
	6.925 - (0.166 × LHL) - (0.064 × LHB) - (0.084 × LHC)	0.545	0.738	LHL < 0.001*** LHB = 0.607 LHC = 0.101

*** means variable is significant contributor to the equation at $p \leq 0.001$

** means variable is significant contributor to the equation at $p \leq 0.01$

* means variable is significant contributor to the equation at $p \leq 0.05$

Table 17: Percentage accuracies of sex predictive equations from multiple regression analysis tested on the study groups of males and females.

	Regression equations for Sex	% Accuracy		*p*-value
		Male (*n* = 70)	**Female (*n* = 70)**	
Right foot	6.764 + (-0.148 × RFL) + (-0.141 × RFB)	80.00	92.85	RFL < 0.001*** RFB < 0.001***
Left foot	7.151+ (-0.112 × LFL) + (-0.278 × LFB)	82.85	91.42	LFL < 0.001*** LBL < 0.001***
Right Hand	6.839 + (-0.124 × RHL) + (-0.349 × RHB)	84.28	92.85	RHL < 0.001*** RHB < 0.001***
Left Hand	6.932 + (-0.180 × LHL) - (0.238 × LHB)	88.57	91.42	LHL < 0.001*** LHB < 0.001***

n: number of subjects in the group.

RHL: right hand length LHL: left hand length RHB: right hand breadth

LHB: left hand breadth RFL: right foot length LFL: left foot length

RFB: right foot breadth LFB: left foot breadth

*** means variable is significant contributor to the equation at $p \leq 0.001$

Handedness in male and female samples

A total of 179 participants in the sample were right-handed, representing 89.5% of the total sample. This consisted of 90 males and 89 females. The remaining 21 participants were left-handed, representing 10.50%. Out of this number, 10 were males while 11 were females.

In left-handed females, the handedness scores obtained ranged from -1.00 to -0.63 while the range for left-handed males was between -1.00 and -0.27. In right-handed females, handedness scores ranged between +0.25 and +1.00 with that of males spread between +0.20 and +1.00.

Mean foot length and hand length asymmetry (L-R) in both left-handed and right-handed males and females.

The mean foot length asymmetry in right-handed males was +0.009 cm while that of right-handed females was -0.027cm. In left-handed males, mean foot asymmetry was +0.060 cm and +0.032 cm in left-handed females. The values of the mean hand length asymmetries were +0.092 cm and <0.0001 cm in right-handed males and right-handed females respectively. Similarly, the means for left-handed males and females were +0.100 cm and +0.010 cm respectively (table 18).

Absolute and standardized foot-length and hand-length.

The mean left foot length of the total sample (*n* = 200) was 26.22 ± 1.74 cm while that of the right foot was 26.21±1.74cm with no significant difference between them (*t* = 0.305, *p* = 0.761). The mean difference between LFL and RFL which was 0.013 ± 0.603 cm also did not differ significantly from the mean standardized foot length which was 0.024 ± 1.147 (*t* = 0.291, *p* = 0.771) (see table 19).

With regards to hand measurements, the mean left hand length of the total sample (*n* = 200) was 18.96 ± 1.33cm while that of the right foot was 18.92 ± 1.31cm. There was however a significant difference between the means of hand length (*t* = 2.529, *p* = 0.01). The mean difference between LHL and RHL which was 0.045 ± 0.250 cm also differed significantly from the mean standardized hand length which was 0.116 ± 0.647 (*t* = 2.535, *p* = 0.011).

Association of handedness with standardised foot length and standardised hand length.

The results from the ANOVA did not show any significant main effect of handedness on standardised foot length (*F* = 0.068, *p* = 0.794). There was also no significant influence of sex on the standardised foot length (*F* = 0.000, *p* = 0.988). Ultimately, the sex-handedness interaction was not significant for standardised foot length (*F* = 0.041, *p* = 0.840) (see table 20).

The results showed that sex had a significant main effect on standardised hand length ($F = 7.378$, $p = 0.007$). The standardised hand length was not statistically influenced by handedness ($F = 0.400$, $p = 0.527$). The sex-handedness interaction was not significant for standardised hand length ($F = 0.007$, $p = 0.934$).

Table 18: Left-right asymmetry (L-R) in right-handed and left-handed subjects

SEX	Right-handed		Left-handed	
	Hand-Asymmetry (cm)	Foot-Asymmetry (cm)	Hand-Asymmetry (cm)	Foot-Asymmetry (cm)
Male	+0.092 (n = 90)	+0.009 (n = 10)	+0.100 (n = 90)	+0.060 (n = 10)
Female	<+0.0001 (n = 89)	-0.027 (n = 11)	+0.010 (n = 89)	+0.032 (n = 11)

(+) means left length is larger than right (-) means right length is greater than left

n = number of subjects

Table 19: The mean differences between standardised measurements and absolute/actual measurements of hand and foot lengths.

Mean actual left ft. length (cm)	**Mean actual right ft. length (cm)**	**Mean difference**	**SFL**	***t*-test**	***p*-value**
26.22±1.74	26.21±1.74			0.305	0.761
		0.013±0.603	0.024±1.147	0.291	0.771
Mean actual left hd. length (cm)	**Mean actual right hd. length (cm)**	**Mean difference**	**SHL**	***t*-test**	***p*-value**
18.96±1.33	18.92±1.31			2.529	0.01**
		0.045±0.250	0.116±0.647	2.535	0.01**

SFL: standardised foot length SHL: standardised hand length

** means difference is significant at $p \leq 0.01$

Table 20: Association of handedness with standardised foot length and standardised hand length.

	Standardised foot length		
	Df	***F* – value**	***p* – value**
Handedness	1	0.068	0.794
Sex	1	0.000	0.988
Handedness + Sex	1	0.041	0.840
	Standardised hand length		
Handedness	1	0.400	0.527
Sex	1	7.378	0.007**
Handedness + Sex	1	0.007	0.934

df: degree of freedom *F*-value: ANOVA test value

** means difference is significant at $p \leq 0.01$

Table 21: Percentage of forefoot types among males and females

Foot type	`Male (*n* = 100)		Female (*n* = 100)		Total %
	Wide	Tapered	Wide	Tapered	*n* = 200
Grecian	11%	11%	11%	8%	20.5%
Egyptian	22%	55%	16%	63%	78%
Square	1%		2%		1.5%

Out of the 100 males sampled 22 (22%) possessed the Grecian type, 77 (77%) possessed the Egyptian type and 1 (1%) possessed the Roman type. Within the Grecian type 11 (50%) out of the 22 males had the wide variant while the remaining 11 (50%) were of the tapered variant. A total of 55 (71.43%) out of the 77 males with the Egyptian type possessed the tapered form while the remaining 22 (28.57%) were of the wide form.

Out of the 100 females sampled 19 (19%) possessed the Grecian type, 79 (79%) possessed the Egyptian type and 2 (2%) possessed the Roman type. Within the Grecian type 11 (57.89%) out of the 19 females had the wide variant while the remaining 8 (42.11%) were of the tapered variant. A total of 63 (79.75%) out of the 79 females with the Egyptian type possessed the tapered form while the remaining 16 (20.25%) were of the wide form. In all 41 (20.25%) subjects out of the total sample of 200 had the Grecian foot type while 156 (78%) possessed the Egyptian type with 3 (1.5%) subjects bearing the Roman type.

CHAPTER FIVE

5 DISCUSSION

5.0 Bilateral differences in anthropometric hand and foot measurements

In both males and females, the bilateral differences between the lengths, breadths and circumferences of the feet were not significant as has been reported earlier by Hemy et al. (2013). Trivers et al. (2015) recorded similar results in their research in which the left bias in foot length was not significant. Kanchan et al. (2014) also observed no statistical variation between the breadths of footprints except for heal-ball breadth. The studies that reported significant foot asymmetries attributed such differences to foot dominance. The preferential use of the feet in balancing, kicking and initiating walking and running motions are linked with the dominant foot and therefore is expected to have more elaborated anthropometric features. In this study nonetheless, the significant effect of foot dominance in foot asymmetry was not observed.

With regards to hand measurements, there were no significant bilateral differences between hand length and hand breadth in females. Pal et al. (2016) also reported no statistical variation in bilateral hand dimensions for a Bengalee population. The variations were conversely significant for length, breadth and circumference in males and circumference in females. Kulakslz and Gozil (2002) reported some related significant bilateral differences in hand length and hand breadth based on hand preference. The latter researchers attributed their findings to hand dominance and brain lateralization. It is likely that handedness could have influenced the differences observed for length, breadth and circumference in males and circumference in females. It however does not seem to sufficiently explain why there were no significant bilateral differences between hand length and hand breadth in females.

5.1 Sexual dimorphism

The difference between the male and female mean heights were statistically significant (figure 7). Height was found to be significantly greater in males than females in this study. Earlier studies showed significant sex differences in height of subjects (Fessler et al., 2005; Jasuja & Singh, 2004; Nor et al., 2013). The sex difference in height suggests that among the young adult Ghanaian sample, males are generally taller than females as shown by earlier researches (Jakhar et al., 2012; Kanchan et al., 2008). Even though boys were significantly taller than girls in this study, the percentage difference in mean height was only 6.64%. This was not as high as 10% as reported by Riggs et al. (2002). The difference could be due to the fact that this study focused on a young adult sample whereas Riggs et al. (2002) was referring to teenagers.

Linear growth is experienced until 18 years in males as compared to age 16 in females (Seeman, 1997). This is due to the fact that testosterone supports long bone growth, chondrocyte maturation, elevated calcium retention and incorporation into bone. During pubertal growth, the rise in serum oestrogen levels is the likely cause of closure of epiphyseal plates in both sexes (E. P. Smith et al., 1994); earlier in females and then later in males. This accounts for the major sex differences observed in body height after puberty.

The results of this study also showed significant sex differences between males and females with regard foot length and foot breadth. Previous anthropometric studies have shown similar results in different populations. Ozden et al. (2005) found significant differences in the mean foot length and breadth between males and females from a Turkish population. Sen and Ghosh (2008) also established parallel results for foot breadth. The measurements of all anthropometric variables of this study were larger in males than in females, just as was observed by Ozden et al. (2005) and the latter authors. Though foot circumference also showed significant sexual dimorphism in this study, this is the first time to the best of my knowledge that this has been estimated. The results obtained for length, breadth and circumference of the feet suggest that these dimensions are good sex discriminants and can be used to predict sex.

There were significant sex differences with respect to the means of hand length and hand breadth. These results are consistent with the findings of Ishak et al. (2012) and Krishan et al. (2011). Unlike foot circumference, research by Jee et al. (2015) documented the sex discriminating capabilities of hand circumference. Thus, the results obtained for hand length, hand breadth and hand circumference depict that of good sex discriminants and it is plausible to use them to predict sex.

5.2 Correlation of hand and foot variables with height

All the correlation coefficients (r) achieved significant positive correlation with height except for the dimension of RHC in females. The coefficient of reliability (R) for RHC in females was 0.629 (see Appendix III). This was far below the required minimum of 0.950 and this likely accounted for its insignificant correlation coefficient.

With regards to hand dimensions, hand length was shown to have the highest significant positive correlation with height in both males and females as expected. In both sexes, it was also observed that RHL correlated stronger with height than LHL. The correlation was stronger in males than females and this could be explained by the longer period of linear growth in males during adolescence (Riggs et al., 2002). These findings support the earlier study by Geetha et al. (2015). The correlation between RHL and height in males (r = 0.710) was observed to be stronger than that from hand lengths reported by Akhlaghi et al. (2012) (r = 0.696), Ilayperuma et al (2009) (r = 0.58), Habib and Kamal (2010) (r = 0.697) and Ahmed (2013a) (r = 0.60). On the other hand, it fell short of r = 0.829 reported by Mulla et al. (2014). This puts forward that correlation between hand length and height could be stronger in the Ghanaian population compared to the other populations in which the above listed researchers conducted their studies.

The dimensions of hand breadth and circumference demonstrated weak correlations with height in both sexes. The finding for hand breadth is also consistent with that of Geetha et al. (2015). The finding for hand circumference in this study could however not be compared to any other study as none was found to have examined its relationship with height.

The foot dimensions measured in this study also showed significant positive correlations with height in both sexes. Foot length correlated strongest with height both sexes. In another study, Patel te al. (2007) reported similar results as this study. This study observed that RFL had a greater association with height than LFL. While foot length was strongly correlated with the dependent variable in males, its correlation with height was moderate in females. As explained earlier, this could be as a result of the longer period of linear growth in males during adolescence (Riggs et al., 2002).

The correlations with regards to foot breadth dimensions were moderate in the two sexes. As anticipated, the values of the coefficients were greater in males than females. The role of androgens and oestrogens in maintaining skeletal homeostasis in adult life could be linked to this sexually dimorphic pattern due the higher levels of androgens in males and higher levels oestrogens in females (Manolagas, 2002). Though Sen and Ghosh (2008) reported an identical trend, the values of this study are greater than those reported by the latter authors. This trend also supports the study by Uhrova et al. (2011) even though the correlations in this study were comparatively weaker.

Foot circumference was also positively correlated with height at a moderate level. The correlation coefficients were higher in males than females as has been observed as the trend for all coefficients in this study that have already been discussed. Previous studies have not focused on the relationship between height and foot circumference and as a result there is no standard for comparison.

Admittedly, this study supports the theory that correlation between foot dimensions and height is stronger than between hand dimensions and height (Ozaslan et al., 2003).

5.3 Height prediction from explanatory variables

This research was successful in deriving equations for predicting height from linear regression analysis. This indicated that the estimated variable is associated with foot length and foot breadth (Nor et al., 2013) as well as foot circumference. From the earlier analyses on correlation, foot lengths in both sexes were reported to have the highest coefficients and as a result these dimensions returned the best statistics.

The coefficients of determination (R^2) were highest for foot length in both males and females. These values suggest that foot length explains between 45.70% - 56.7% of variances in the models. Body dimensions are influenced by age, nutrition, exercise and other environmental and genetic factors (Pal et al., 2016). Though Patel et al. (2007) did not directly report values of R-squared, it can be deduced from their correlation coefficients (0.65 in males and 0.80 in females) that they would have obtained a better range of values than in this study. The R^2 values of the linear regression models obtained from foot length in this study were higher in males than females, consistent with findings of Sanli et al. (2005).

The standard errors of estimates in this study showed that there was some moderate variation between the estimated and true values of height. The errors were lowest for foot length, consistent with findings of Uhrova et al., (2011). This can be explained by the fact that foot length comparative to breadth and circumference, explained the highest level of variation in height. The SEEs were however, lower in the earlier study (Grivas et al., 2008). Those from the linear regression models derived by Sanli et al. (2005) were much higher than those reported in this study.

The significant association with height demonstrated by the regression equations of foot breadth and foot circumference was not as high as that of foot length. They both yielded higher SEEs than foot length and lower R^2. Their individual R^2 values could not explain up to 40% model variances. It was interesting to note that comparatively, foot circumference performed better than foot breadth in both sexes. It has been reported that foot circumference is more closely related to foot length than breadth and in many cases, the difference between foot length and foot circumference is not more 5% of foot length (Atherley, 2012). This could explain why foot circumference correlated better with height than foot breadth, since measurements of foot circumference are closely related to those of foot length.

The multiple regression analysis using all foot explanatory variables yielded better results for R-squared than linear regression from single variables (table 11). This finding is parallel to the finding of Kanchan et al. (2008). In the current study, the R-squared coefficient was higher in the left foot in males and higher in the right foot in females due to their higher multiple correlation coefficients obtained. This finding in females was a replicate of the findings of the latter authors.

The SEEs obtained from the multiple regression analyses were lower in males than in females. Zeybek et al. (2008) reported a similar finding. This indicates the likelihood of lower error levels in predicting height in males than in females. The SEEs for both feet of the two sexes however exceeded the least SEE recorded for foot length which could be accounted for by the greater variation in foot breadth and probably foot circumference (table 9). The errors in the latter study were still higher than those returned in this study.

When both the linear and multiple regression models were applied to the study group, the differences between the means of true height and estimated height as well as the percentage differences (tables 12 & 14) were not significant (figure 10). This gives some hint of success from the foot estimators using regression models with their related accuracies.

This research was also successful in obtaining univariate and multivariate regression equations for predicting height from hand dimensions which indicated that the estimated variable is associated with hand length and hand breadth (Geetha et al., 2015) as well as hand circumference. Similar to the trend observed in the foot, hand length proved to have a better significant positive correlation with height than hand breadth and hand circumference.

The values of R-squared coefficients were highest for hand length as expected (Tandon, Yunus, Faruqi, & Asghar, 2016). According to this research, between 47.7% - 50.5% of the variances in the male height model can be explained by hand length while 22.2% - 25.4% of the variances in the female height model can be explained by hand length. This gives an indication that researchers stand a better chance of obtaining more accurate height estimates in young adult males than females in Ghana, when these linear models are employed. Geetha et al. (2015) also noted higher coefficients of determination in males than females. The values of the coefficients of determination for hand breadth and hand circumference were very low, indicating very low determination accuracies.

The SEEs for hand lengths were lower in males than in females which were inconsistent with the findings of Geetha et al. (2015). This confirms the greater accuracy for hand length in the male model than with the equation for females. Comparatively, while the errors for hand length models obtained in this study were higher than in the study by Pal et al. (2016), they were still lower than those reported by Sanli et al. (2005).

The results from multivariate analyses in height estimation from all hand variables gave a better account for the variations in height than the linear models. In both sexes the right hands yielded the best accuracy in comparison with the left hands and all others produced by the univariate regression models. These were as a result of the higher multiple correlation coefficients obtained for the right hands. Rastogi, Nagesh and Yoganarasimha (2008) proved that multiple variables presented better explanations for the variations in the dependent variable as shown in this study. Similarly, higher accuracy was realised in height prediction when using more than one variable in South Africans (Dayal, Steyn, Kevin, & Kuykendall, 2008). Though the multivariate regression analysis returned better R-squared values, they still fall short of a 0.50 (i.e. 50%) mark in females which may arguably not be enough for forensic investigations.

When comparing the standard errors of estimates, those from the multiple linear regression analyses were surprisingly higher than the most accurate linear model. This contradicts what was previously reported by Krishan and Sharma (2007). Altayeb (2013) also recorded lower standard errors of estimates in height prediction from multiple regression methods than from the univariate regression methods. This unexpected finding can however not be explained.

5.4 Sex estimation

5.4.1 Sectioning point accuracy in sex prediction.

One key finding of this research was that hand circumference recorded high sex discriminating accuracies in both males and females. This is in agreement with the work of Jee et al. (2015) who reported that maximum hand circumference showed the highest predictive accuracy (88.6%) in Korean males. The sectioning point predictive accuracies from hand measurements were comparatively higher in females than in the males (refer to table 15). These findings are similar to the findings of Kanchan and Rastogi (2009). When considering hand measurements alone, RHL and RHB in this study showed the highest determination accuracies in females (92.85%) and males (88.57%) respectively.

Based on hand length the determination accuracies were greater as compared with the study by Krishan et al. (2011). The possible reason is that the mean hand lengths of Ghanaian males in this present study were 1.63 cm (RHL) and 1.74 cm (LHL) greater than those belonging to the Rajput sample. The hand lengths of female Ghanaians were greater by 1.23cm for RHL and 1.33cm for LHL. The longer hand lengths reduced the overlapping of measurements from sectioning points of males and females in this study which resulted in the higher accuracies (Jee et al., 2015).

Another novel finding was that on the average foot circumference (i.e. RFC and LFC) performed better as a sex discriminator than foot breadth and foot length in both sexes. All literature on sectioning point analysis reviewed in this study did not include dimensions of foot circumference. The results obtained for foot circumference therefore could not be compared. Foot circumference nevertheless could be used as a reliable sex discriminant; at least for young adult samples in Ghana.

In agreement with the study by Abledu et al. (2015), the foot sex discriminants were more accurate on the left side except for left foot circumference in this study. The prediction accuracies were remarkably higher in this research than in that project. This could be due to the fact that the earlier research used footprints rather than direct measurements used in this investigation. Also their research was carried out in the eastern region which tends to be cooler than the Accra metropolis. In cold weather, blood flow to the extremities and skin is reduced in order to keep the body core warm which leads to shrinking of hands and feet (Gupta, 2015). As a result, body measurements are reduced in cooler weather conditions. These factors could have led to the lesser overlapping in measurements from sectioning points in males and females and consequently higher accuracies obtained in this study. That notwithstanding, the finding of these authors and that of this study so far depict a fairly consistent predictive pattern in Ghanaians.

The comparison between foot breadth and foot length accuracies of this research contradicted those of Krishan et al. (2011). The latter reported that foot breadth was a better sex discriminant than foot length while the opposite was true for the former. The findings from the Indian study ultimately complement the outcomes of this Ghanaian based research even when the contradictions are considered. In the long run, foot length, foot breadth and foot circumference could be acceptable parameters for sex differentiation in Ghanaians.

5.4.2 Sex determination based on regression analyses.

The multiple correlation coefficients were significant when only dimensions of length and breadth were used ($p < 0.001$) (table 17). This research finding is congruent with the findings of Sen et al. (2011) with regard to foot dimensions. The coefficient was significantly higher for the right foot for the earlier study while the coefficient was significantly higher for the left foot in this study. This means that the regression models developed in the earlier study fitted better using the right foot while the models for the Ghanaian study fitted better using the left foot. The reason(s) for this observation was not apparent but could be a population related factor. Among males the prediction accuracies from both feet were higher in the earlier research, while among females the accuracies were higher in this study.

Also, the theoretical correlations were comparatively higher in the work of Krishan et al. (2011). The findings of this research with respect to regression models are also consistent with the reports by these researchers. This is to say that both studies portrayed reasonable levels of sex determination using multiple regressions, even though there were no specific accuracies mentioned in the earlier study.

The percentage accuracies demonstrated by the work of Zeybek et al. (2008) in a Turkish population are comparable to the current study. In males, the predictive accuracies in this study were not as high as those recorded in the Turkish study. These differences could be due to environment, population specific sexual dimorphisms and the different measuring tools used since special foot measuring devices were developed in both studies (Ahmed, 2013; Albanese et al., 2016; Fessler et al., 2005; Wells, 2007). The parallel nature of findings revealed in the two researches still emphasises the possible use of isolated foot measurements in sex prediction with reasonable accuracy; even in Ghanaians this research established the sexual dimorphism of the feet.

The regression equations for sex determination using hand measurements were significant when hand breadth and hand length were used. When hand circumference was incorporated into the models, at least one other variable lost significant contribution to the equation. The coefficient obtained for the significant equations was higher with the right hand than with the left hand. This is in agreement with the finding of Krishan et al. (2011). It appears that only the work of Krishan et al. (2011) predicted sex using multiple regression equations from hand measurements as other researches reviewed, seemed to prefer sectioning point method (Jee et al., 2015; Kanchan & Rastogi, 2009).

The predictive accuracies were higher in females than males in this study as has been the usual trend recorded for sex determination using sectioning points (Ishak et al., 2012; Ozden et al., 2005; Sen et al., 2011). This is likely due to the wider range of measurements in males than females. This allows for more measurements of females than males to lie closer to the fitted line of regression. Though Krishan et al. (2011) obtained high correlation coefficients, unfortunately, they failed to demonstrate the accuracy of the models and as a result accuracy cannot be compared between the two studies. It could be inferred from their regression coefficients that the accurary of their models would have been similar to what was found in this study. Regardless, the findings of this study gives credence to the possible use of hand length and breadth in multiple regression equations for sex determination of young adult Ghanaians.

The equation developed from hand measurements in males had a higher accuracy than that of the right. In females on the other hand, the accuracy was higher when right hand measurements were used. The reason(s) for these observations are not immediately clear. The predicive accuracies were still with females as expected.

5.5 Determination of handedness.

The handedness of all subjects was determined by hand preference. The hand preference scores obtained for each subject from the Edinburgh Handedness Inventory (EHI - Appendix II) classified left handed preference and right handed preference successfully. Though handedness indices are frequently used, some studies prefer hand performance tests due to the subjective nature of the questionnaires (Scharoun & Bryden, 2014). The EHI provides a sufficient means of assessing handedness and has been used successfully in some relevant studies (Corey et al. 2001; Oldfield, 1971).

Though the inventory is used to determine the magnitude of hand preference (i.e. strong or weak), this current study was only interested in whether subjects were right handed or left handed. This was because the study sample was not large enough to examine the extent of handedness. Thus, this research assessed only bilateral differences between anthropometric variables between the left and right hand preference groups without regard to the extent of handedness.

The right-handedness bias was very evident from the results of this study. The percentage of the left-handed minority in this current project was within the 5% - 30% range specified by Corey et al. (2001). It was realised from this study, that one more female than males was left-handed. This, does not agree with the distribution of handedness reported by Kulakslz and Gozil (2002), Levy and Levy (1978) and Trivers et al. (2015). These authors recorded more left-handed (non-right-handed) males than females. This could be explained by the fact that in all the three studies, more males than females were sampled while an even number of males and females were recruited in this study. It is common knowledge that in every population, there are more males than females which explained the ease in recruiting males for the previous studies. This finding could be a basis for further investigation as it may represent the true distribution of left-handedness comparative to males in a Ghanaian population.

5.6 Association of handedness with standardised foot length and standardised hand length.

There was no significant main effect due handedness on standardised foot length (table 20). The results also showed that the mean difference between LFL and RFL and SFL was not significant. This implied that handedness had no significant association with foot asymmetry. Since foot asymmetry and handedness were not significantly related, it could offer an explanation for the non-association between handedness and standardised foot length. This finding on handedness agrees with the report by Mascie-Taylor and McManus (1981). On the contrary, it disagrees with the finding of Levy and Levy (1978). The finding gives reason to further investigate foot asymmetry and its association with handedness and other factors.

Sex also showed no significant main effect on standardised foot length. This failed to replicate the results reported by Mascie-Taylor and McManus (1981). There was also no significant sex-handedness interaction with regard to standardised foot length, contrary to what was reported in the pioneering study by Levy and Levy (1978). The latter authors used foot sizes to measure foot length whereas this study measured foot length directly. This could account for the failure to obtain similar results. The difference in sample sizes could also account for the varying outcomes. As a result, further investigations may be imperative.

There was also no main effect of handedness on standardised hand length was not significant. The mean left hand length was statistically different from the mean right hand length. As a result it was not surprising that the mean left-right hand asymmetry differed significantly from SHL. Consequently, this creates a gap in the logic that once the mean hand length asymmetry is comparable with SHL, then association of handedness with one parameter implies association with the other and vice versa. Kulakslz and Gozil (2002) speculated that the significant hand asymmetry detected for right-handed subjects could be linked to hand dominance. The handedness-hand-asymmetry interaction could neither be confirmed nor disproved by the present study. It is probable that some factors other than handedness may be significantly associated with standardised hand length.

Sex was found to have a significant main effect on standardised hand length unlike in the feet. This supports the finding of Means and Walters (1982). An agreeable conjecture hypothesised by these authors was that different sex-related body asymmetry factors could be evident at varying detectable magnitudes in different parts of the body; in this case in the hands more than in the feet. There was also no proof of sex-handedness interaction with SHL in this study just as was reported by latter scientists. The pair studied children aged between 4years and 9 years and proposed that the association of sex and handedness with SFL could be detectable with maturation. Since this present study replicated the results of these authors in young adults, it provides a foundation to possibly re-evaluate their maturation based assumption.

5.7 Forefoot types among males and females.

All the three major forefoot types were found in both the male and female samples. Comparatively, the majority of volunteers were found to possess the Egyptian forefoot type followed by the Grecian type with as little as 1.5% of subjects having the Roman forefoot type. The same trend was found in the male and female groups when considered separately. These findings are in agreement with the distribution of forefoot types as described by Correa (2016). The author described the Egyptian forefoot type as the commonest, followed by the Morton's forefoot with the Square forefoot being the least common.

Within both sexes of the Egyptian type, a greater number of the subjects possessed the tapered variant (males = 55, females = 63) as compared with the wide variant (males = 22, females = 16). The trend was quite different within the Grecian type. In males, both Greek tapered and Greek wide had an equal number of subjects (n = 11) while more females were found in the Greek wide type (n = 8) than Greek tapered type (n = 8). It is difficult to compare these results with any other because no research with details of this type of information has been found. It is likely that no previous studies have been conducted in any population with respect to this area. Even though Correa (2016) provided some pointers as to which types were more common than others, this author failed to provide data to support that information.

Relevance of this study to science and implications for social life

It is evident from this study that there are clear relationships and correlations between hand measurements, foot measurement, sex and handedness; some of which are more significant than others. Also, some variable showed better predictive value than others while a few variables demonstrated just about average predictability and accuracy especially with regards to height estimation; which is not the best theoretically. However, in a practical sense, humans are social beings and are most likely to employ any meaningful mechanism to find a loved one or relative even when the chances are only slight. A year after the June 3rd gas explosion disaster in Ghana, some bodies had to be exhumed after they were claimed by different families (Ghana Crusader, 2015). This only means that 3 families have not been able to account for their relatives and therefore do not have closure. So far this counts as one of the few research studies in this area in Ghana. Since forensic experts have very little to go on. Pertinent details from the study could be employed even in the minutest way to make a huge difference in person identification in cases of mass disasters which are inevitable.

5.8 Summary of findings.

1. All significant bilateral differences were observed in only hand dimensions: hand length and hand breadth in males and hand circumference in both sexes.
2. All anthropometric variables measured in the study were found to be sexually dimorphic. The measurements were significantly higher in males than females.
3. Dimensions of length showed the strongest positive correlations with height with the relationships being stronger with the feet than with the hands. Right foot length demonstrated the strongest positive correlation with height in females while in males this was demonstrated by left foot length.
4. The multiple correlation coefficients returned by the multiple regression analyses for height were comparatively stronger than all the univariate analyses.
5. The equations produced for height were moderately accurate as there were no significant differences between mean true height and mean estimated heights using the test group.
6. The sectioning point method of sex prediction seemed to estimate sex more accurately in females than in males.
7. In estimating sex from multivariate regression analyses, at least one variable was not a significant contributor to the equation when circumference was incorporated. Therefore dimensions of length and breadth were the most consistently significant contributors to the equations produced by the multivariate analyses. These equations also estimated female sex more accurately than male sex.

8. Right-handers represented 89.5% while left-handers represent 10.5% of the sample.
9. In both right-handed and left handed subjects, the foot length and hand length asymmetries favoured the left except for right handed females where the mean right foot length was greater than the left.
10. Only sex was found to be significantly associated with standardised hand length. The influence of handedness on standardised hand and foot lengths was not statistically significant.
11. More than three quarters of the sample possessed the Egyptian forefoot type.

5.9 Conclusion

In the present study, height and sex were positively significantly correlated with hand and foot dimensions of length, breadth and circumference. Subsequently, these variables were able to predict height and gender successfully for the Ghanaian sample. The equations obtained from regression analyses were specific for this sample and require further modifications and verifications on other samples in order to be generalised for the population of young adults in Ghana. The asymmetry between the hand lengths and that between foot lengths was observed to mostly favour the left, regardless of subjects' handedness. It was observed that sex rather than handedness influenced standardised hand length. It is important that these models are not applied to citizens of other countries since these analyses were population specific and would yield erroneous outcomes when applied to samples from other countries. This study ultimately provides a good theoretical basis for larger national studies as well as improves forensic identification of Ghanaians from hand and foot anthropometric features.

5.10 Limitations

1. The stadiometer used in this research was a wall-hung stadiometer which did not allow the setup to be moved around on a daily basis. This resulted in a longer data collection period than expected as some volunteers were initially not willing to take a walk from their lecture rooms and departments to the research setup.
2. The scarcity of literature on hand circumference and foot circumference was a major challenge and subsequently it was difficult to compare the results obtained from this research.

5.11 Recommendations

1. Larger sample sized studies should be conducted to obtain enough data to standardise and generalise for the Ghanaian population.
2. Future studies should include anthropometric variables such as upper arm length and leg length – the usual predictive variables of height.
3. In the future, studies of this kind should include practical ways of incentivizing volunteers to make data collection easier and faster.
4. From the larger studies, shoe manufacturers should be educated on the differences between bilateral foot measurements.

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APPENDIX I

RESEARCH CONSENT FORM

Name of researcher: Joseph Gyamera Akyeampong

Name of organisation: Department of Anatomy, School of Biomedical and Allied Health Sciences, College of Health Sciences, University of Ghana, Korle-Bu, Accra.

Project title: Correlation of Sex, Height and Handedness with Anthropometric Foot and Hand Measurements of Young Adult Ghanaians.

Supervisory Team: Professor Frederick K. Addai & Prof. Clifford N. B. Tagoe. Department of Anatomy School of Biomedical and Allied Health Sciences, College of Health Sciences, University of Ghana, Korle-Bu, Accra.

I ……………………………………………......... have been invited to take part in the above titled research. The purpose of the research I have been told is: to determine if foot shape, foot and hand measurements are good predictors of sex, stature and handedness of young adult Ghanaians. Participation in the study involves students and workers of the College of Health Sciences, University of Ghana, Korle-Bu.

I am informed that the nature of procedure such as the method of data collection chosen and its subsequent analysis will not expose me to serious risks or hazards neither will it cause undue pain to me. My only involvement in the research will be to allow measurements of my feet, hands and height to be taken as well as determine my handedness. I have been told that the essence of the research is to provide data in the areas forensic research and ergonomics.

I will not by my participation in this study, derive any personal benefits but help in generating data that will be useful to researchers. I do have the right to refuse participation in this research if I wish to without being affected in any way. I may ask questions now or later for clarification on issues pertaining to the research.

I may contact the addresses below to ask questions or make complaint later:

1. The Supervisors (Prof. F. K. Addai & Prof. Clifford N. B. Tagoe) Department of Anatomy, School of Biomedical and Allied Health Sciences, College of Health Sciences, Korle-Bu. Tel: 0302672020

2. The Ethical and Protocol Review Committee, School of Biomedical and Allied Health Sciences, College of Health Sciences, University of Ghana, Korle-Bu, Accra, who have the task to ensure that no harm is made to research participants.

3. Joseph Gyamera Akyeampong (the researcher), Department of Anatomy, School of Biomedical and Allied Health Sciences, College of Health Sciences, Korle-Bu, Accra.
Tel: 0302672020/ 0207221514

I have read the information contained herein, or it has been read to me. I have had the opportunity to ask questions about it and have received satisfactory answers to them. I give my voluntary consent to participate in this study as a subject with the understanding that I can withdraw anytime from the study without being affected any way.

Signed by …………………………........... Date …………………………................

APPENDIX II

RESEARCH QUESTIONNAIRE

DEPARTMENT OF ANATOMY
SCHOOL OF BIOMEDICAL AND ALLIED HEALTH SCIENCES
COLLEGE OF HEALTH SCIENCES, UNIVERSITY OF GHANA

CORRELATION OF SEX, HEIGHT AND HANDEDNESS WITH ANTHROPOMETRIC FOOT AND HAND MEASUREMENTS OF YOUNG ADULT GHANAIANS

RESEARCH QUESTIONNAIRE

This questionnaire solicits for information, and subsequently your foot and hand dimensions will be measured for use in the research mentioned above. This is solely for academic and health research purposes. Your identity would be kept anonymous (never to be disclosed) as your name is not required on the form. The information you provide on this form will treated as highly confidential. Please answer the under-listed questions as accurately as possible.

Age: _______________ Sex: Male ☐ Female ☐

A. Please Tick the appropriate option

1. Institution: University of Ghana College of Health Sciences ☐
   Other ☐

2. Are you Ghanaian? ☐ Yes ☐ No

3. Are any of your parents, grandparents or great-grandparents non-Negroid Ghanaians?

☐ Yes ☐ No

4. Have you recently been diagnosed with any chronic illness? ☐ Yes ☐ No

If yes, please specify:……..………………………………………………………………

5. Have you had a bone fracture in any part of your body before? ☐ Yes ☐ No

If yes, please specify: …………………………………………………………………

6. Are you currently on any hormonal treatment? ☐ Yes ☐ No

7. Have you ever been forced to switch your hand preference for any activity?

☐ Yes ☐ No

If yes, please specify: ☐ From left to right ☐ From right to left

EDINBURGH HANDEDNESS INVENTORY (ABRIGDED VERSION)

Please indicate your preference in the use of hands for the following activities by putting + in the appropriate column. Where the preference is so strong that you would never try to use the other hand **unless absolutely force to,** put **++.** If in any case you are really indifferent, put + in both columns.

Some of the activities require both hands. In these cases the part of the task, or object, for which hand preference is wanted is indicated in brackets.

Please try to answer all the questions, and only leave a blank space if you have no experience at all of the object or task.

No.	**Activity**	**Preference**	
		LEFT	RIGHT
1	Writing		
2	Drawing		
3	Throwing		
4	Scissors		
5	Toothbrush		
6	Knife (without fork)		
7	Spoon		
8	Broom		
9	Striking Match (hand that holds the match)		
10	Opening a box (lid)		
I	Which foot do you prefer to kick with?		
II	Which eye do you use when using only one?		
TOTAL			

Anthropometric Measurements

Body Dimension (cm)	1st Reading	2nd Reading
Height		
Right foot length		
Right foot breadth		
Right foot circumference		
Right foot length to height ratio		
Right foot breadth to height ratio		
Right foot circumference to height ratio		
Left foot length		
Left foot breadth		
Left foot circumference		
Left foot length to height ratio		
Left foot breadth to height ratio		
Left foot circumference to height ratio		
Right hand length		
Right hand breadth		
Right hand circumference		
Left hand length		
Left hand breadth		
Left hand circumference		

Fore foot Type

☐ Grecian ☐ Egyptian ☐ Square

Fore foot Toe arrangement: ☐ Wide ☐ Tapered

APPENDIX III

Summary of technical error of the measurements (TEM), percentage TEM (%TEM) and percentage of coefficient of reliability (R) of all variables in males and females.

	Males			Females		
Variable	**TEM**	**%TEM**	**R**	**TEM**	**%TEM**	**R**
Height	0.129	0.073	0.999	0.129	0.079	0.999
RFL	0.098	0.358	0.995	0.080	0.321	0.994
RFB	0.116	1.150	0.973	0.103	1.127	0.950
RFC	0.305	1.161	0.953	0.093	0.393	0.991
LFL	0.080	0.295	0.996	0.082	0.331	0.993
LFB	0.101	0.992	0.974	0.116	1.268	0.911
LFC	0.107	0.409	0.993	0.067	0.282	0.996
RHL	0.078	0.397	0.995	0.086	0.478	0.987
RHB	0.090	1.004	0.971	0.091	1.135	0.954
RHC	0.060	0.277	0.997	0.703	3.597	0.629
LHL	0.088	0.445	0.993	0.079	0.440	0.986
LHB	0.117	1.333	0.956	0.093	1.184	0.951
LHC	0.507	2.356	0.859	0.094	0.491	0.990

%TEM: percentage technical error of measurement R: coefficient of reliability
%TEM ≤ 5% is acceptable R ≥ 0.950 regarded as reliable.

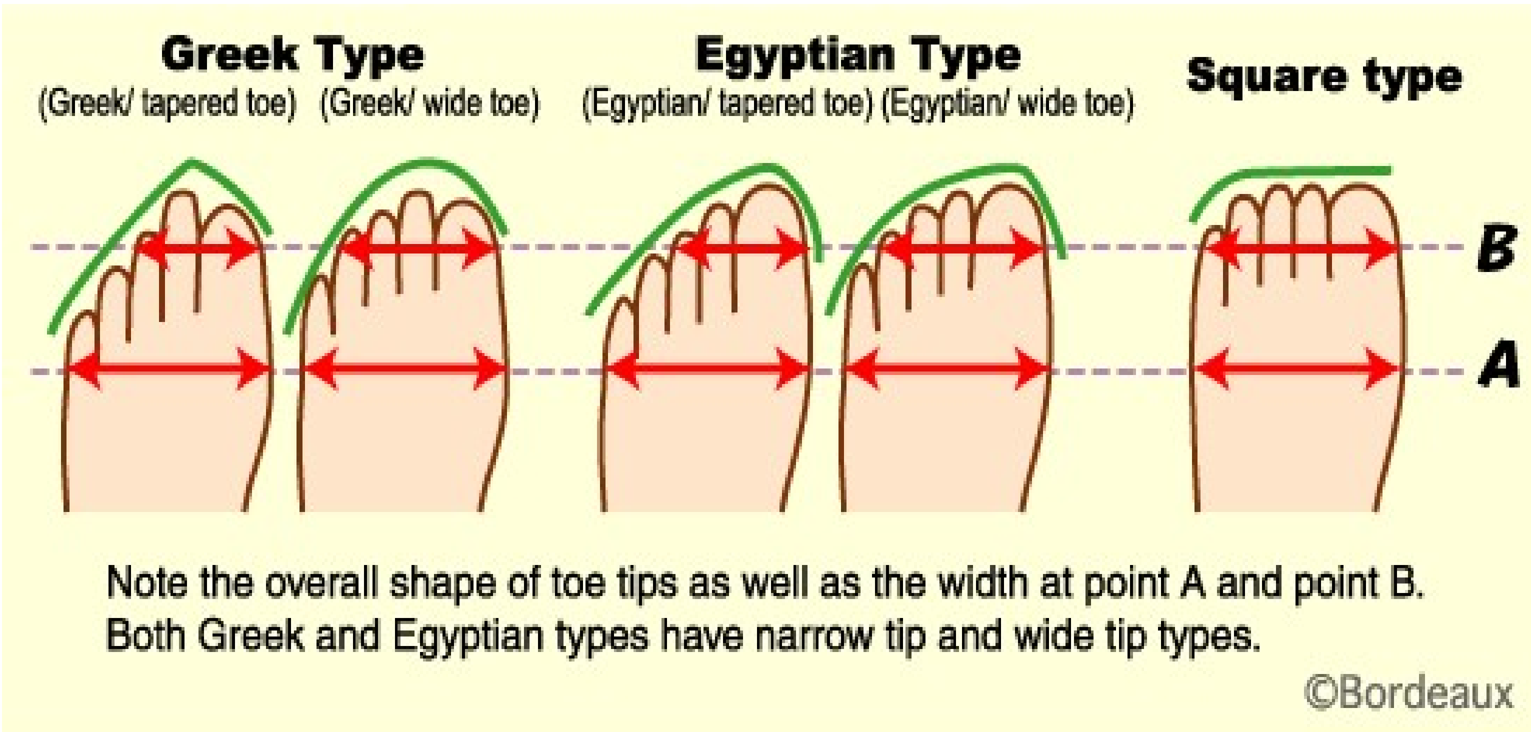
APPENDIX 1V

Pictures of some measuring tools used in the study.

a) Wall-hang stadiometer

b) Vernier (Sliding) Caliper

APPENDIX V



An image showing the three major forefoot types and subtypes based on the arrangement of the toes. Source: (Bordeaux, 2011)