The importance of complex anthropometrics in the assessment of cyclists

BULLAS, Alice May

Published version

BULLAS, Alice May (2017). The importance of complex anthropometrics in the assessment of cyclists. Doctoral, Sheffield Hallam University.

The importance of complex anthropometrics in the assessment of cyclists.

Alice May Bullas

A thesis submitted in partial fulfilment of the requirements of Sheffield Hallam University for the degree of Doctor of Philosophy

July 2017

Abstract

The description and analysis of body dimensions is vital, not merely to monitor training, performance and talent identification, but to understand the evolution and development of sport. Recent literature suggested that complex anthropometrics, such as volume and area, can identify changes in body size and shape that might otherwise go unnoticed by simple anthropometrics as well as providing a more realistic representation of the body. The aim of this programme of doctoral study was to determine the importance of complex anthropometrics in the kinanthropometric assessment of cyclists.

Stereo photogrammetry imaging was identified as the most suitable method of acquiring simple and complex anthropometrics. Validation of a stereo photogrammetry imaging system - 3dMDbody5 - was conducted using validation objects (precision engineered cylinders) and human participants, to determine the system's accuracy, repeatability and agreement with manual measurement methods. These investigations suggested the 3dMDbody5 system to be capable of detecting differences greater than 0.67 cm in girths, 0.48 cm^2 in cross sectional areas, 67.85 ml in volumes and 0.99 cm^2 in surface areas. In addition, the system demonstrated strong agreement with manual measurements, within that required by established industry standards (ISAK and ISO). Consequently, the 3dMDbody5 system was deemed suitable for use in subsequent investigations.

Using the 3dMDbody5 imaging system a series of investigations were conducted to examine the importance of complex anthropometrics in the lower body kinanthropometric assessment of cyclists. First, in a descriptive context, an investigation into the extent to which simple and complex anthropometrics can distinguish between non-cyclists and cyclists from different disciplines was conducted. Second, in an applied context, the extent to which simple and complex anthropometrics explained the variance in peak power output was investigated. Third, in a longitudinal context, the anthropometrics and peak power output of a group of cyclists were monitored over the course of a power based training phase. This was to assess if changes in peak power output related to changes in anthropometrics and the extent to which simple and complex anthropometrics identified morphological change. The findings of these investigations provide a more detailed understanding of the lower body anthropometrics of cyclists. Moreover, demonstrating that in descriptive, applied and longitudinal kinanthropometric assessment of cyclists complex anthropometrics complement simple anthropometrics, and in some cases distinguished differences / changes that are unidentifiable through simple anthropometrics alone.

Acknowledgements

I would like to express my sincere gratitude to my supervisors: Professor Jon Wheat, Dr Ben Heller and Dr Simon Choppin. You have provided an unending supply of knowledge, guidance and patience. I would like to extend this thanks to all the members of the Centre for Sports Engineering Research - past and present, in particular Dr Heather Driscoll, Terry Senior, Dr John Hart, Carole Harris and Amanda Brothwell.

Thank you to those that so generously volunteered their time and legs in the various investigations, helped to promote my research and assisted in the collection of data. Your involvement was invaluable and much appreciated.

To my fellow doctoral students in Chestnut Court, thank you for your friendship, kindness and support throughout this experience. It has bolstered my knowledge and sustained my sanity.

To my family and friends thank you for your unrelenting encouragement and love. Special thanks to Grace for the hours of spell checking and perpetual faith in my abilities and Christopher for your patience and unwavering friendship.

Personal bibliography

Journal articles:

Bullas, A. M., Choppin, S., Heller, B., & Wheat, J. 2016. Validity & repeatability of a depth camera-based surface imaging system for thigh volume measurement. Journal of Sports Sciences, 29, 1-7.

Conference proceedings:

Bullas, A.M., Choppin, S., Heller, B., & Wheat, J.,2016. ISAK & digital 3D body measurement: A longitudinal case study from elite cycling. In: Kinanthropometry XV. Merida, Mexico, 215–217.

Bullas, A. M., Choppin, S., Heller, B., & Wheat, J. 2016. The relationship between peak power and leg size in mountain bike cyclists. In: Kinanthropometry XV, Merida, Mexico, 88-89.

Bullas, A. M., Choppin, S., Heller, B., & Wheat, J. 2016. The effect of distance between anthropometric measures in geometric models of thigh volume. In: BASES Biomechanics Interest Group Conference, Liverpool, UK.

Bullas, A. M., Choppin, S., Heller, B., & Wheat, J. 2015. The validity and repeatability of a depth camera based 3D scanning system for thigh volume measurement. In: Sheffield Hallam University Health & Wellbeing Faculty Research Conference, Sheffield, UK.

Bullas, A. M., Clarkson, C., Choppin, S., Heller, B., & Wheat, J. 2014 Kinanthropometry applications of depth camera based three-dimensional scanning systems in cycling: repeatability and agreement with manual methods. In: Proceedings of 3D Body Scanning Technologies Conference, Lugano, Switzerland.

Contents page

List of tables

List of figures

Nomenclature

Abbreviations

1D	One dimensional
2D	Two dimensional
3D	Three dimensional
ACSM	American College of Sports Medicine
BMI	Body mass index
BMX	Bicycle motor cross
BM	Body mass
CSA	Cross sectional area
CT	Computed tomography
D	Dominant
ICC	Intra-class correlation coefficient
ICP	Iterative closest point
ISAK	International Society for the Advancement of Kinanthropometry
IWGK	International Working Group on Kinanthropometry
kg	Kilogram
km	Kilometre
LSD	Least significant difference
MDC	Minimal detectable change
MRI	Magnetic resonance imaging
ND	Non dominant
NUI	Natural user interface
OLP	Ordinary least products regression
OLS	Ordinary least squares regression
PCA	Principle component analysis
PLSR	Partial least squares regression
RMSE	Root mean squared error
RPE	Rate of perceived exertion
SA	Surface area
SEM	Standard error of the measurement method
TDIDT	Top down induction decision trees
TEM	Technical error of measurement
TOF	Time of flight
UCI	Union Cycliste Internationale

VIP	Variable importance in projection
WHO	World Health Organisation
XCE	Cross-country eliminator
XCM	Cross-country marathon

Symbols

ABS	Absolute
μ	Mean
σ	Standard deviation
CV	Coefficient of variation ratio
CV%	Coefficient of variation
D	Difference between measurements
k	Number of observations
m	Value of the measurement
m_D	Value of the measurement from dominant side
m_{ND}	Value of the measurement from non-dominant side
n	Number of individuals measured
S	Measurement of symmetry
SDpooled	Pooled standard deviation
X Y Z	3D real world components, comprising horizontal, vertical, and depth components

Chapter 1 - Introduction

1.0 Introduction

This thesis documents a three-year programme of doctoral study into the importance of complex anthropometrics in the assessment of cyclists. It outlines the systematic acquisition of data through original research to facilitate the creation and interpretation of new knowledge, thereby extending the scope of the kinanthropometry discipline in its understanding of complex anthropometrics. This chapter outlines the motivation for this research by introducing and reviewing anthropometry, kinanthropometry, anthropometrics and, kinanthropometry and cycling. The aims, objectives and thesis structure are given at the end of this chapter.

1.1 Motivation for the research

Anthropometry, derived from the Greek words ‘anthropos’ (human) and ‘metrein’ (to measure), is the ‘scientific procedures and processes of acquiring surface anatomical dimensional measurements such as lengths, breadths, girths, and skinfolds of the human body by means of specialist equipment’ (Stewart, 2010, p. 455). Anthropometry is believed to be one of the oldest measures of human variation (Ulijaszek & Komlos, 2010) dating back to 400 B.C. (Jones & Riouxb, 1997). Its use throughout history is prevalent in monitoring human size and shape, most attractively presented in the Vitruvian Man by Leonardo da Vinci (1452-1519). Today, anthropometrics are used to optimise equipment, product and clothing design, industrial design and ergonomics, to monitor health and lifestyle (Norton et al., 2002; Ulijaszek & Mascie-Taylor, 2005) and in kinanthropometry.

Kinanthropometry can be defined as a branch of anthropometry ‘that involves the use of anthropometric measures in relation to other scientific parameters and/or thematic areas such as human movement, physiology or applied health sciences’ (Stewart, 2010, p. 455). According to Stewart (2010), kinanthropometry is the scientific discipline, whereas anthropometry is the tool box and skill set. Although anthropometry is rich in history, kinanthropometry is relativity young. First referred to in 1972 (Ross et al., 1972), kinanthropometry was established as a discipline in 1978 with the formation of the International Working Group on Kinanthropometry (IWGK) (Beunen & Borms, 1990; Carter, 2008). The IWGK successor, the International Society for the Advancement of Kinanthropometry (ISAK) has established industry standards, guidelines, and accreditation and training courses (Stewart et al., 2011).

Kinanthropometry can be used in a variety of different contexts. In ergonomics kinanthropometry can optimise the fit between worker and workplace during movement (Olds, 2009). In health and medicine, kinanthropometry is imperative in the assessment of the relationship between exercise, nutrition and health, in the understanding of human growth and ageing on the body and to identify the evolution and characteristics of different disease processes in the body (Olds, 2009). In sport and exercise, kinanthropometry aids in understanding how size and shape can affect the external demands of a sporting performance, and how size and shape can also make it possible for an athlete to meet those demands (Olds, 2009). This information is used to optimise training to improve athletic performance, assist in the monitoring and prevention of injury, examine the impact of early training on growth and maturation and in the early identification of athletic potential (Carter, 2008; Olds, 2009). Although optimal body dimensions are not the only components necessary for an athlete to excel in sport, many believe they are important prerequisites of success (Wolstencroft, 2002a; Brunkhorst & Kielstein, 2013; Koley & Jain, 2013). Additionally, the measurement and continued assessment of body dimensions is believed to be vital in understanding the evolution of sport, as athletes' morphology adapts in response to modifications of the rules, technologies and structure of a sport (Norton & Olds, 2001).

Theoretically, an unlimited number of anthropometrics can be acquired in kinanthropometric investigations (Olds, 2009). However traditionally, kinanthropometric investigations use ‘simple’ anthropometrics acquired manually using tape measures and callipers, such as lengths, breaths, skinfolds, girths and comparisons of two or more of these measures, for example Body Mass Index (BMI) or somatotype (Olds, 2004; Stewart, 2010; Fawkner, 2013). However, recent literature has suggested that complex anthropometrics; anthropometrics typically unattainable through manual measurement such as volume and area, can identify changes in body size and shape that might otherwise go unnoticed by simple anthropometrics (Rønnestad et al., 2010; Schranz et al., 2012) as well as providing a more realistic representation of the body (Daniell et al., 2013) as they take into account the entire length of a body segment opposed to a single point. However, further research is necessary to establish a clearer understanding of the importance of complex anthropometrics.

It is suggested that complex anthropometrics are most informative for closed skilled sports (Abbott et al., 2002; Norton et al., 2002); sports in which the influence of body size and shape on performance is greater due to a reduction in the influence of the environment, such as weightlifting, athletics, canoeing and cycling (Wolstencroft, 2002a; Vaeyens et al., 2008).

Cycling is a closed sport that is heavily influenced by the size and shape of the cyclist (Wolstencroft, 2002a; Dellanini et al., 2004; Chen et al., 2011). This is not merely due to the aerodynamic benefits of a smaller frontal area, but because power, which can be associated with muscle size (Dellanini et al., 2004; Hopker et al., 2010) and thereby body size, is a core determinant of sprint cycling performance in the majority of disciplines and events (Faria et al., 2005a; Martin et al., 2007; Inoue et al., 2012). However, few investigations have explored the importance of complex anthropometrics in the kinanthropometric assessment of cyclists.

1.2 Aims and objectives

The aim of this programme of doctoral study was to determine the importance of complex anthropometrics in the assessment of cyclists. The objectives were to;

- Synthesise information from across published literature and develop a critical understanding of the topic area and anthropometric measurement methods.
- Validate the most suitable method of anthropometric measurement through assessment of its accuracy and repeatability in relation to established industry standards.
- Critically compare simple and complex anthropometrics in the descriptive kinanthropometric assessment of cyclists, by investigating the extent to which simple and complex anthropometrics can distinguish between non-cyclists and cyclists from different disciplines.
- Critically compare simple and complex anthropometrics in the applied kinanthropometric assessment of cyclists by determining which model (the ‘simple’ or the ‘simple and complex’) explains more of the variance in cycling performance.
- Critically compare simple and complex anthropometrics in the longitudinal kinanthropometric assessment of cyclists by monitoring anthropometrics and cycling performance over a period of time, and assessing if the change in cycling performance relates to changes in anthropometrics.

1.3 Thesis structure

This programme of doctoral study will be presented as a traditional thesis, comprising eight further chapters. These chapters are structured as follows:

- Chapter Two provides a critical review of the literature relevant to the programme of doctoral study. The literature review examines sports kinanthropometry, complex anthropometrics, the use of anthropometrics in cycling (by cycling discipline) and methods of anthropometric measurement. This chapter concludes with the identification of the most suitable measurement method for subsequent investigations.
- Chapter Three and Four investigate the most suitable method of anthropometric measurement, identified in Chapter Two, through assessment of its accuracy and repeatability, in relation to established industry standards, when measuring verification artefacts and human participants.
- Chapter Five presents the methods that remained consistent throughout the subsequent investigations of this thesis.
- Chapters Six, Seven and Eight critically compare simple and complex anthropometrics in the kinanthropometric assessment of cyclists in descriptive, applied and longitudinal contexts, respectively.
- Chapter Nine discusses the main findings of the programme of doctoral study, followed by the primary limitations, potential areas for further research and an overall conclusion of the research programme.

Chapter 2 - Literature review

2.0 Introduction

The aim of this programme of doctoral study was to determine the importance of complex anthropometrics in the kinanthropometric assessment of cyclists. To achieve this, the first objective was to synthesise information from across published literature and develop a critical understanding of the topic area and anthropometric measurement methods. This chapter reviews the relevant literature in three sections; the first reviews sports kinanthropometry and the use of complex anthropometrics. The second examines the use of anthropometrics in cycling, by cycling disciplines. The final section details the methods of anthropometric measurement, assessing their suitability for use and presents the anthropometric measurement method selected for use within the programme of doctoral study.

2.1 Sports kinanthropometry & complex anthropometrics

2.1.1 Kinanthropometry in sport

Descriptive kinanthropometry

There are three primary applications of kinanthropometry in sport: descriptive, applied and longitudinal. Descriptive kinanthropometry identifies the anthropometrics of population groups, based upon their sport, expertise, position or specialism. It is predominantly used as the participant descriptives in biomechanics and physiology investigations (Reilly, 2008). However, it can also be used to identify the morphology of an elite sporting population to assist in the creation of talent identification criteria. This is typically achieved by comparing the anthropometrics of a selected athletic population against that of a reference population, usually the general population, other athletic groups or levels of expertise (Norton et al., 2002; Olds, 2009). The anthropometrics that demonstrate the greatest magnitude of difference in size and variability between groups are considered relatively more important for use in distinguishing between groups (Norton & Olds, 2001; Olds, 2009; Schranz et al., 2010). Several analysis methods are used in descriptive kinanthropometry, including: statistical difference testing, frequency distribution analysis, effect sizes, and coefficient of variation ratios.

Statistical difference testing is used to determine the significance of any differences between groups. These are typically followed by post hoc testing to determine the source of any differences. Such analysis is informative when comparing two groups that demonstrate large differences in anthropometrics. However, typically, when comparing groups within kinanthropometry the magnitudes of any differences in anthropometrics are relatively small. Consequently, conservative post hoc techniques such as the Bonferroni and Tukey's corrections mask any differences identified between groups. Thus, it would be necessary to use un-conservative post hoc corrections, such as least significant difference (LSD). However, such tests fail to correct for type one error and, as such, potentially skew the degree to which the results are representative of the wider population. Consequently, the use of statistical analysis within descriptive kinanthropometry should be approached with caution.

In Kinanthropometry, frequency distribution analysis, also known as the Overlap Zone, combines assessment of the magnitude of difference in size and variability into a single index (Norton & Olds, 2001; Norton et al., 2002; Ackland, 2006; Olds, 2009). Overlap zones have a theoretical ranking, whereby '0' equates to no overlap and '100' equates to perfect overlap. The Overlap Zone is calculated using the equation of the curve for each group using the mean (μ) and standard deviation (σ) in Equation 2.1. The intersection of these curves are then calculated by iteration and converted into z-scores in Equation 2.2.

Equation 2.1:

$$P_x(V = X) = \frac{1}{\sqrt{2\pi\sigma_x}}\, exp\left[\frac{-\left(\frac{X - \mu_x}{\sigma_x}\right)^2}{2}\right]$$

Equation 2.2:

$$z = \frac{X - \mu}{\sigma}$$

However, this method is only suitable for normally distributed data of equal and medium to large sample sizes (Norton et al., 2002). Consequently, when exploring non-normal, unequally distributed or small sample sizes analysis is reliant upon exploration of differences and variability independently, through effect sizes and coefficient of variation ratios respectively.

Effect sizes are used to determine the magnitude of difference between groups. The most common method of calculating effect sizes is Cohen's d (Cohen, 1988). Cohen's d is calculated by subtracting the mean (μ) for each group from one another and dividing it by the pooled standard deviation (SDpooled) (Equation 2.3) as demonstrated in Equation 2.4.

Equation 2.3:

$$SDpooled = \sqrt{\frac{SD_x^2 - SD_y^2}{2}}$$

Equation 2.4:

$$d = \frac{\mu_x - \mu_y}{SDpooled}$$

For unequal and small sample sizes Hedges's g is calculated; a corrected version of the Cohen's d (Hedges & Olkin, 1985; Cohen, 1988) is often deemed more suitable (Lakens, 2013) (Equation 2.5):

Equation 2.5:

$$g = d\left(1 - \frac{3}{4(n_c + n_{nc)} - 9}\right)$$

Cohen's d standardized effect sizes of 0.2/-0.2, 0.5/-0.5, and 0.8/-0.8 are typically used as thresholds for small, moderate, and large effects respectively, for interpretation of both Cohen's d and Hedges's g effect sizes (Cohen, 1988). Several researchers, including Glass et al., (1981), Thompson (2007) and Cohen (1988) himself are critical of this approach, arguing that these values are arbitrary, that the meaningfulness of an effect size is investigation specific, and that these benchmarks should only be used when findings are novel and comparisons to related findings in the literature are unavailable. Typically, when the findings are novel and the Cohen's d standardized effect sizes are suitable only large effect sizes ≥ 0.8 are reported as meaningful degrees of difference. Thus, effect sizes ≤ -0.8 or ≥ 0.8 indicate a meaningful difference between the groups. It is assumed the greater the magnitude of difference in size the greater the importance of the anthropometric in distinguishing between the groups.

To determine the degree of variability in each anthropometric between groups the coefficient of variation ratio (CV) was used. The coefficient of variation ratio is calculated using the coefficient of variation (CV%) as demonstrated in Equation 2.6. The coefficient of variation ratio can then be calculated by dividing the coefficient of variation for each group, with one another (Equation 2.7)

Equation 2.6:

$$CV\% = \frac{\sigma}{\mu}100$$

Equation 2.7:

$$CV\ ratio = \frac{CV\%^y}{CV\%^x}$$

Based upon the work of Drinkwater et al., (2007) ratios ≤ 0.9 and ≥ 1.1 indicate meaningful magnitude of difference in variability. It is assumed differences in variability greater than 1.1 and less than 0.9 the greater the importance of the anthropometric in distinguishing between the groups.

The characteristics that contribute to sporting success are multifaceted, and include physiological, psychological, morphological, biomechanical and social traits genetically inherited and acquired through training, exercise and nutritional regimes (Olds, 2009). If an anthropometric profile for a sporting population group exists it is most easily identified by assessing the most elite athletes from developed sports (Norton et al., 2002).

Developed sports

Little published literature has explored the definition of a developed sport. Olds (2009) and Lombardo (2012) define developed sports as sporting environments that present an artificial Darwinian system. In which individuals with 'inferior' optimisation are culled, and only the 'fittest' survive as competition is high yet rewards are sparse. Consequently, in order to succeed athletes must demonstrate optimised characteristics for their sport.

Sporting expertise

Several studies have proposed common criteria to categorise expertise and elite sports experience. Regardless, the definition of elite within published literature appears to be inconsistent (Pauw et al., 2013; Swann et al., 2014). The majority of previous investigations, such as Jeukendrup et al., (2000) and Pauw et al., 2013, identify 4-6 categories (from untrained to world class/professional) that are based upon within sport variables such as $\dot{V}O_2$max, power, annual/weekly training distance. However, these categorisation methods fail to account for individuals that meet a number of variables across categories or the practical feasibility of pre-experimental tests with expert samples. Moreover, few categorisation models include variables that facilitate between sports comparisons even though the expertise of an athlete is dependent upon the competitiveness of the sport, both nationally and globally (Swann et al., 2014).

Swann et al., (2014), presented a categorisation model for classifying expert samples in sport. This model takes into consideration five variables that address both 'within-sport comparisons' (A-C) and 'between-sports comparisons' (D-E) as illustrated in Table 2.1.

Table 2.1: Categorisation matrix for expert samples from Swann et al., (2014, p. 10).

Variable / Score	1	2	3	4	
A. Athlete's highest standard of performance	Regional Level; university level; semi-professional; 4th tier leagues or tours	Involved in talent development; 3rd tier professional leagues or tours	National level; selected to represent nation; 2nd tier professional leagues or tours	International level; top tier professional or tours	Within-sport comparisons
B. Success at the athlete's highest level	Success at regional, university, semi-professional, or 3rd/4th tier	National titles or success at 2nd / 3rd tier	Infrequent success at international level or top tier	Sustained success in major international, globally recognized competition	
C. Experience at the athlete's highest level	< 2 years	2-5 years	5-8 years	8+ years	
D. Competitiveness of sport in athlete's country	Sport ranks outside of top 10 in country; small sporting nation	Sport ranks 5-10 in country; small-medium sporting nation	Sport ranks top 5 in country; medium-large sporting nation	National sport; large sporting nation	Between-sports comparison
E. Global competitiveness of sport	Not Olympic sport; world championships limited to few countries; limited national TV audience	Occasional Olympic sport; World championships limited to a few countries; limited international TV audience	Recent Olympic sport with regular international competition; semi global TV audience	Regular Olympic sport with frequent major international competition; global TV audience	

The score for each variable (1-4) is entered into Equation 2.8 to quantify expertise in a single index.

Equation 2.8:

$$Swann\ score = [(A + B + C/2)/3][(D + E)/2]$$

Based on this model, semi-elite athletes (Swann score: 1 - 4) are involved in talent development programmes or compete competitively in lower tiered regional and national events. Competitive-elite athletes (Swann score: 4 - 8) regularly compete at national events, and occasionally at international events, but have not had any success at this level. Successful-elite athletes (Swann score: 8 - 12) regularly compete at national events, and occasionally at international events, and have some (infrequent) success at this level. World-class elite athletes (Swann score: 12 - 16) represent the top standard possible in their sport; regularly competing in national and international events, with repeated success over a prolonged period of time.

Irrespective of the analysis method used, within descriptive kinanthropometry, the anthropometrics that demonstrate the greatest magnitude of difference and variability are considered to be relatively more important (Norton & Olds, 2001; Schranz et al., 2010), as it is the anthropometrics that can be used to distinguish between groups. However, descriptive kinanthropometry presents only a cross sectional view of morphology and is unable to demonstrate the relative importance of anthropometric characteristics to performance. This can be achieved through applied kinanthropometry.

Applied kinanthropometry

Applied kinanthropometry examines the relationships between anthropometrics of population groups (descriptive kinanthropometry) and performance measures. Applied kinanthropometry is useful in determining the anthropometrics that should be monitored in performance, in understanding the biomechanical and physiological ramifications of certain anthropometrics, and in the creation of talent identification criteria.

Typically, the relationship between anthropometrics and performance measures is explored through regression analysis and the Variable Importance in Projection statistic (VIP) (Schranz et al., 2012) to identify the degree to which anthropometrics explains the variance in the performance measure. VIP is an estimated score of the importance of each variable. VIP is the weighted sum of squares of the PLSR-weights, with the weights calculated from the amount of Y- variance of each PLSR component (Wold et al., 1993, 2001). Anthropometrics demonstrating a VIP ≥ 0.8 are typically considered to meaningfully contribute to the variance of a performance measure (Wold, 1995). However, as outlined by Olds (2009) it is vital that all statistical associations made through applied kinanthropometry should be supported by plausible and quantifiable mechanisms, regarding both demand; how body size and shape may affect the external demands of a sporting performance, and supply; how body size and shape make it possible for an athlete to meet these external demands. Nevertheless, applied kinanthropometry only provides a cross sectional view of morphology and fails to identify stability of these relationships over time, for example during training phases or between seasons. This can be achieved through longitudinal kinanthropometry.

Longitudinal kinanthropometry

Longitudinal kinanthropometry explores descriptive or applied kinanthropometry over a period of time. It provides understanding of the stability of anthropometrics during training phases or between seasons. Similar to descriptive and applied, longitudinal kinanthropometry is useful in determining the anthropometrics that should be monitored in elite performance, in understanding the biomechanical and physiological ramifications of certain anthropometrics, and in the creation of talent identification criteria. Typically, longitudinal kinanthropometry is assessed using repeated measures statistical analysis methods and effect sizes.

In a broader context, Norton & Olds, (2001) suggested that longitudinal kinanthropometry is vital to understand the evolution of sport itself, as athletes' morphology adapts in response to modifications of the rules and structure of a sport. Norton & Olds, (2001) outlined that within longitudinal kinanthropometry morphology changes can be categorised into three forms of optimisation; Open ended optimisation: whereby change in population defining anthropometrics becomes extreme, and changes at a rate substantially beyond the change experience by the general population. For example, stature in basketball which increased by 3.1cm in a decade, over three times the rate of the general population (Ackland & Mazza, 1994). Relative optimisation; whereby change in population defining anthropometrics mirrors change in the general population. For example, stature in rugby players (from 1905 to 1999) which increased by 0.9 cm per year in line with the rate of the general population (Ackland & Mazza, 1994). As well as absolute optimisation: whereby there is no change in population defining anthropometrics, yet change does occur in the general population. For example, divers, jockeys and gymnasts whose stature has remained predominantly unchanged irrespective of an increase in the stature of the general population (Ackland & Mazza, 1994).

2.2.2 Simple and complex anthropometrics within sports kinanthropometry

Theoretically, an unlimited number of anthropometrics can be acquired in kinanthropometry (Olds, 2009). Typically, those used within kinanthropometry can be divided into two categories. However the method of categorisation is inconsistent within the literature. Several investigations have categorised anthropometrics by dimensionality, i.e. one-dimensional (1D), two-dimensional (2D) or three-dimensional (3D). Predominantly this is interpreted as the minimal dimensionality of data required to obtain the measurement. However, this definition is not consistently used, with several investigations classifying anthropometrics based on the dimensionality of the measure itself (Daniell et al., 2010) or the dimensionality of data used (Skals et al., 2016). For example, based on the minimum dimensionality of the data required, girth could be classed as a 2D anthropometric. Based upon the dimensionality of the measure, as girth is a measurement of length, girth could be classed as a 1D anthropometric. Yet, if dimensionality is based upon the data used, and 3D data were used, girth would be classed as a 3D anthropometric.

The absence of a clear and consistent definition of anthropometric dimensionality within kinanthropometry, and subsequently the confusion this causes, makes categorisation of anthropometrics based upon dimensionality an unsuitable method. An alternative categorisation method has been reported by Schranz et al., (2012) and alluded to by Olds (2009); classification of anthropometrics based upon the prevalence of measures in previous studies; traditional and new. However, the term ‘new’ appears potentially misleading, as although the use of these measures within kinanthropometry is new, the measures themselves are not. Consequently, classification of anthropometrics by prevalence appears unsuitable. A small number of investigations have categorised anthropometrics based on their complexity of measurement; simple and complex (McGee et al., 1985; Taiwo & Akinde, 2012; Bray et al., 2013). Whilst there still appears to be inconsistencies in the definition of these two groups, this terminology causes least confusion and theoretically appears most suitable. Consequently anthropometrics will be classified as ‘simple’ or ‘complex’, as outlined in Table 2.2.

Table 2.2: Categorisation of anthropometrics.

Measurement	Simple	Complex
Lengths	x	
Breaths	x	
Girths	x	
Body mass	x	
Comparisons of two or more of these measures, e.g. BMI and Somatotype	x	
Areas		x
Volumes		x
Shape analysis		x

Several investigations include the measurement of body composition as a surface anthropometric within kinanthropometry investigations. Body composition plays an important role within kinanthropometry, particularly in understanding the mechanisms behind associations with performance and in determining if change or differences are attributable to differences in muscle or fat mass, and as such will be included within this literature review. However, as this thesis will focus on exploring complex anthropometrics which measure the external geometry of the body, body composition will not be investigated within this programme of research.

Traditionally kinanthropometic investigations have used simple anthropometrics. The popularity of simple anthropometrics is attributable to their use of low cost, accessible and highly portable 'every day' equipment such as tape measures and callipers. The popularity of simple anthropometrics through manual measurement is fostered through standardised training and measurement protocols from several international scientific associations including ISAK, the American College of Sports Medicine (ACSM) and the World Health Organisation (WHO). Yet few kinanthropometric investigations have used complex anthropometrics. There appears to be several potential explanations for their unpopularity. First, complex anthropometrics can be difficult to measure (Olds & Honey, 2006; Sicotte et al., 2010). Whilst they can be estimated from simple anthropometrics using predictive equations, the equations are highly population specific and thereby often unsuitable for use on atypical population groups (Ackland, 2006). Additionally, they can be measured using 3D imaging devices, also known as body scanners, which, while regarded as very accurate and repeatable, are predominantly expensive and inaccessible. Second, irrespective of the measurement method, there are no standardised guidelines for the measurement of complex anthropometrics. As a result, their use within published investigations has been limited and thus reiterates their unpopularity through a lack of awareness and understanding about complex anthropometrics (Olds, 2004). It is unrealistic to believe that complex anthropometrics can be conducted in isolation from simple anthropometrics. However, it is possible that the use of complex anthropometrics alongside simple anthropometrics could be beneficial, as recent literature has suggested that complex anthropometrics can identify changes in body size and shape that might otherwise go unnoticed by simple anthropometrics (Rønnestad et al., 2010; Schranz et al., 2012) as well as providing a more realistic representation of the body (Daniell et al., 2013).

2.2.3 Complex anthropometrics within sports kinanthropometry

Using 3D imaging, Schranz et al., (2010) compared the importance of simple and complex anthropometrics in distinguishing between rowers and the general population, and in predicting junior rowing performance. Schranz et al., (Schranz et al., 2010) reported that elite senior rowers demonstrated a distinct morphology compared to the general population, which was more clearly demonstrated, particularly for heavyweight rowers, when complex anthropometrics such as segmental volumes and cross-sectional areas were included within kinanthropometric assessments. This promotion of complex anthropometrics is reiterated by Schranz et al., (2012) where it was demonstrated that complex rather than simple anthropometrics, were the best predictors of 2000m rowing ergometery performance of elite junior rowers. Whilst it is difficult to conclude that the results demonstrated by Schranz et al., (2012) are truly representative of all rowers, due to the small sizes and absence of similar investigations, the similarity with previous investigations that used simple anthropometrics, places confidence in this body of work. Schranz et al., (2012) suggested that future anthropometric investigations should consider incorporating complex anthropometrics. They suggested that future research within this field should explore longitudinal kinanthropometry, specifically the sensitivity of anthropometrics to performance seasons, how such changes relate to performance and how the anthropometrics of junior athletes relates to their anthropometry and performance as a senior.

Several authors reiterate the benefits of complex anthropometrics (Rønnestad et al., 2010; Coelho-E-Silva et al., 2013). For example Rønnestad, Hansen & Raastad (2010) detailed that only thigh cross sectional area (CSA) demonstrated a correlation with increases in thigh strength in well-trained national level cyclists following a 12 week strength training intervention. Thus, the complex anthropometric of CSA was able to detect change that was undetectable through simple anthropometrics alone. Furthermore, Bullas et al., (2016) suggested that, in the longitudinal kinanthropometric assessment of the lower body of an elite mountain bike cyclist, simple anthropometrics may misrepresent the magnitude of change in size and that complex anthropometrics such as volume and surface area may provide a more accurate representation of change throughout a body segment. However, Rønnestad, Hansen & Raastad (2010) and Bullas et al., (2016) are not alone in their use of complex anthropometrics in cycling, as many investigations have calculated frontal and surface areas of cyclists to estimate aerodynamic resistance during performance, due to its well established influence on aerodynamics (Kyle, 1989; Capelli et al., 1993, 1998); the frontal area of the cyclist (~18% of a cyclists body surface area) and the bicycle is responsible for the majority of drag force created while cycling (Faria et al., 2005a). It is unsurprising that kinanthropometry investigations have focused on the importance of complex anthropometrics in cycling, as whilst success in sport is multifaceted, optimal body dimensions are believed to be an important prerequisite of success in cycling (Mclean & Parker, 1989).

2.3 Kinanthropometry & cycling

Optimal body dimensions are regarded as important to cycling success for several reasons. As cycling is a sport that contains closed skill aspects in which the influence of the environment is reduced in comparison to other sports, body size and shape is believed to have a greater influence on performance determinants (Knapp, 1963). Furthermore, within cycling body dimensions can affect the external demands of the performance. For example the power a cyclist must generate to reach a certain speed will be proportional to the cyclist's body mass and frontal area (Olds, 2009). The importance of body dimensions is likely to vary between cycling disciplines, as performance determinants that body dimensions influence in cycling (power and aerodynamics) themselves vary in importance based upon the nature of the skills required for each sub discipline.

2.3.1 Road & track cycling

Track cycling is a generic term for bicycle racing sport that is held on specially built hard banked tracks or velodromes, typically made of wood or cement, with a circumference of 333 m or less (Coleman, 2012). With the exception of the Stockholm 1912 Olympics, track cycling has featured in every modern Olympic games (IOC, 2017a). Several cycling events fall under this umbrella term. However, typically track cycling events can be divided into 2 sub-disciplines: sprint (< 1000 m) and endurance (> 1000 m). Thus, sprint and endurance track cycling demonstrate differing physiological demands. Sprint cycling events, due to the short duration, are highly dependent upon power production (Craig & Norton, 2001), and are reported to produce peak powers easily exceeding 1000 watts. Endurance cycling events require highly developed aerobic capabilities, however, due to sprinting elements found in several endurance cycling events, the literature suggests high anaerobic capacities are also required (Craig & Norton, 2001). Consequently, due to the differing physiological demands of these two sub-disciplines, published kinanthropometry literature explores each sub-discipline separately.

The precedent to explore the kinanthropometry of cyclists based upon the sub-disciplines of a sport is also prevalent within road based cycling. Road cycling is a generic term for bicycle racing sport performed on paved roads. With the exception of the Paris 1900, St Louis 1904 and London 1908 Olympic Games, road cycling has featured in every modern Olympic games (IOC, 2017b) and receives wide international coverage during the annual Tour de France. Typically road cycling includes: Time trial (~30 - 100 km), single day (~250 km) and stage based tours (3 weeks) events. Single day and stage based events combine uphill cycling along hill / mountain passes (> 10 km) of mean gradient over 7.0%, and time trials of 40 – 60 km along flat routes (LucÍa et al., 2000). Consequently, kinanthropometry typically separate road cyclists into specialisms: time trial, sprint and endurance.

When analysing anthropometrics of track and road cyclists several investigations have combined these two disciplines, as they appear to demonstrate little difference from one another (White, Quinn, Al-Dawalibi, et al., 1982; White, Quinn, Mulhall, et al., 1982; Foley et al., 1989). Several investigations have explored the descriptive kinanthropometry of track and road cyclists. All track and road cyclists demonstrate exceedingly low percentages of body fat (Foley et al., 1989; Craig & Norton, 2001). This is because non-functional fat mass can substantially decrease performance by increasing the energy cost of acceleration, rolling resistance and the projected frontal area (Gregor & Conconi, 2000). The negative effect of non-functional mass is reported to be substantially more detrimental to road-based cyclists due to the uphill characteristics of race routes. Road cyclists are reported to be predominantly leaner than track-based cyclists. However, this varies between sub disciplines due to their differing physical and environmental demands. When analysing anthropometric dimensions of track and road cyclists several investigations have collated these two disciplines, as they appear to demonstrate little difference from one another (White, Quinn, Al-Dawalibi, et al., 1982; White, Quinn, Mulhall, et al., 1982; Foley et al., 1989). Instead published literature explores each specialism within these disciplines: sprint, pursuit, time trial, endurance and uphill cyclists, which, due to differing physical and environmental demands, demonstrate differing anthropometric profiles. Sprint cyclists are reported to demonstrate a mesomorphic somatotype (White, Quinn, Al-Dawalibi, et al., 1982; White, Quinn, Mulhall, et al., 1982; Foley et al., 1989; Mclean & Parker, 1989); heavy, short (Foley et al., 1989; Craig & Norton, 2001; Martin et al., 2007) with larger chest, arm, thigh and calf girths (Mclean & Parker, 1989). The greater mesomorphic somatotype is regarded as important during shorter duration events, such as sprint cycling (Craig & Norton, 2001) in which peak power production is a major determinant of performance (Hopker et al., 2012). The mesomorphic somatotype is believed to demonstrate the increased muscle volume and body size required to generate high degrees of power (White et al., 1979 cited by Foley, Bird & White, 1989; Mclean & Parker, 1989). This justification is supported by the research Katch & Katch (1974), whom demonstrated that body mass, lower limb surface area and lower limb volume accounted for 46% of the variability in power in sprint cycling. However, when the importance of peak power as a performance determinant reduces, alongside an increase in performance distance and gradient, cyclist's tendency pushes further towards ectomorphic somatotypes, a trend also seen in track and field athletics (Tanner, 1964). Consequently, pursuit, time trial, endurance and uphill cyclists are predominately taller, lighter, and smaller in girths with larger leg length to stature ratios (Mclean & Parker, 1989). This is regarded as beneficial as it reduces aerodynamic drag of the upper body (Foley et al., 1989). All the research outlined above has been conducted on male cyclists. However, recent literature suggested that the descriptive kinanthropometric profiles of female cyclists are similar to that of their male counterparts (Haakonssen et al., 2016).

Fewer investigations have explored applied kinanthropometry in track and road cycling. It is possible that published work is limited as such information may be believed to provide a competitive edge, and is not released or held in embargo by sports institutes and professional teams. Currently, published literature suggests that sprint performance is heavily dependent upon lower body size (Katch & Katch, 1974; Dorel et al., 2005). For example Dorel et al., (2005) measured the torque at which peak power is reached, regarded as a better measure of peak power by Driss et al., (2002) was significantly related to lean leg volume. However, Driss et al., (2002) based the lean leg volume calculations on the geometric modelling methods of Jones & Pearson, (1969), which is based upon non-cyclists and thereby potentially unsuitable for an atypical population group such as cyclists. Other investigations such as McLean & Ellis (1992) have reported similar findings in elite junior cyclists; significant relationships ($r = 0.85$, $p < 0.05$) between thigh volume, and both peak power output and total mechanical work done in a 15 second cycle ergometer test. Few other investigations have explored applied kinanthropometry in cycling for separate disciplines. A small number however have explored the relationship between anthropometry and performance in amateur road ultra-endurance events. For example Knechtle et al., (2009) concluded that anthropometry (age, stature, mass, BMI and percentage body fat) had a greater influence on race performance than training volume in recreational ultra-endurance cyclists. Although Knechtle et al., (2009) postulated that this finding is useful to recreational cyclists and not professional road cyclists, and the anthropometrics collected were minimal, this work demonstrates that in some context a relationship between anthropometry and performance exists.

There are also few investigations that explore longitudinal kinanthropometry in road and track cycling. White, Quinn, Al-Dawalibi, et al., (1982) and White, Quinn, Mulhall, et al., (1982) detailed the seasonal changes of the British male Olympic track and road cycling squads during the 1980 racing season. White, Quinn, Al-Dawalibi, et al., (1982) outlined that during the racing season track cyclists experience a reduction in body mass, due to a reduction in body fat mass, and thereby a reduction in endomorphic characteristics. White, Quinn, Mulhall, et al., (1982) further outlined that during the racing season track cyclists gain body mass whilst losing fat mass, potentially due to an increase in muscle mass and a need to ensure maximal functional mass. Although published several years ago, White, Quinn, Al-Dawalibi, et al., (1982) and White, Quinn, Mulhall, et al., (1982) findings are consistent with recent investigations on female cyclists (Haakonssen et al., 2016). Ema, Wakahara, Yanaka, Kanehisa, & Kawakami, (2016) investigated the influence of regular training in competitive cycling on individual muscle volume of the thigh and psoas major was examined using magnetic resonance imaging (MRI) over 6 months of competitive cycling. This investigation suggested that competitive cycling training induces muscle-specific hypertrophy of the synergistic muscles, reiterating the advantages of using internal imaging systems and volume anthropometrics.

2.3.2 Off road cycling

Off road cycling includes mountain bike cycling disciplines: cross-country, cyclo-cross, downhill, enduro, and bicycle motocross (BMX) cycling. Each of which demonstrates different physiological demands and skills sets. The most popular and researched off road cycling discipline is cross-country mountain bike cycling.

Cross-country mountain bike cycling

Having become an Olympic sport in 1996 and being the only mountain bike discipline currently within the Olympics, cross country mountain bike cycling is the most prevalent form of off road cycling in the UK (Gregory, 2002). Cross country mountain bike events are typically 1.5 to 2 hours in duration and consist of a mass start followed by five to seven laps, each of ~4 to 8 km in length, of an off-road circuit. The intention of the event is to complete the course as fast as possible. The mean power output during such events is ~330 - 350 watts, however cyclists have been reported to also produce multiple efforts over 1000 watts during the event when overtaking or accelerating up short sharp climbs (Passfield et al., 2012). Traditionally circuits have included short sprint phases, long alpine climbs and technically challenging downhill portions. However, since 2005 the Union Cycliste Internationale (UCI) has steadily moved world cup, world championships and Olympic events to more 'park style' circuits that are shorter in duration and distance, removing long periods of climbing that typically epitomised the sport (Passfield et al., 2012).

There are two additional forms of cross-country mountain bike cycling: Cross-Country Eliminator (XCE); whereby there are multiple rounds and the last one or two cyclists are eliminated in each round, and Cross-Country Marathon (XCM); which is typically longer in duration (~60 to 160 km, however unregulated in non-UCI events) than Olympic cross-country mountain bike events. However, as these two forms of cross-country mountain bike cycling are relatively new, established ~ 2010 and 2003 respectively, and underrepresented within the literature, this review will focus on Olympic cross-country mountain bike cycling.

Of the literature that has explored mountain bike kinanthropometry, it is predominantly descriptive. Cross country mountain bike cyclists have been reported to demonstrate similar anthropometric profiles to uphill road cyclists, due to similar physiological demands, as World Cup mountain bike courses place substantial emphasis on climbing (Lee et al., 2002). However, as mountain bike cycling performance is substantially more complex than track and road cycling; requiring sprint performance, endurance, bike handling skills alongside climbing (Passfield et al., 2012), mountain bike cyclists anthropometric profiles appear potentially more complicated. Although this is difficult to explore further, due to a lack of literature, a small number of studies have alluded to such anthropometric profiles. For example, as outlined by Impellizzeri & Marcora, (2007), two of the most successful competitive mountain bikers at the Athens 2004 Olympic Games, Bart Bretjens and Miguel Martinez, had body masses of 77 kg and 55 kg and statures of 188 m and 164 m, respectively. Although Impellizzeri & Marcora, (2007), fails to hypothesise the reason for this, it could be because being either large or small are advantageous due to the wide variety of performance determinants. I.e. being endomorphic; tall and lean, similar to uphill cyclists, would be beneficial in climbing aspects of a course, whilst being mesomorphic; small and powerful would be advantageous in the flat sprint aspect, similar to track sprint cycling. However, further research is necessary to confirm this.

One of the only studies to explore applied kinanthropometry in mountain bike cyclists is Knechtle et al., (2011), whom investigated whether, for recreational male cross-country marathon mountain bike cyclists, anthropometry, training, or pre-race experience were associated with race times of the Swiss Bike Masters 120 km mountain bike ultra-endurance marathon. Knechtle et al., (2011) concluded that success was more reliant upon the use of sophisticated equipment, experience coupled with high training volume, rather than anthropometry. This work demonstrated the complexity of the demands of mountain bike performance, and that due to the open skill nature there was a reduced effect of anthropometry on performance. There currently does not appear to be any longitudinal research on the anthropometric profiles of mountain bike cyclists. Very little research on cyclists from other off road cycling disciplines is published. It is possible that this is due to the underdeveloped nature of these sports within the UK, and subsequently the reduced importance of anthropometrics to performance. However further research would be necessary to confirm this.

2.3.3 Summary

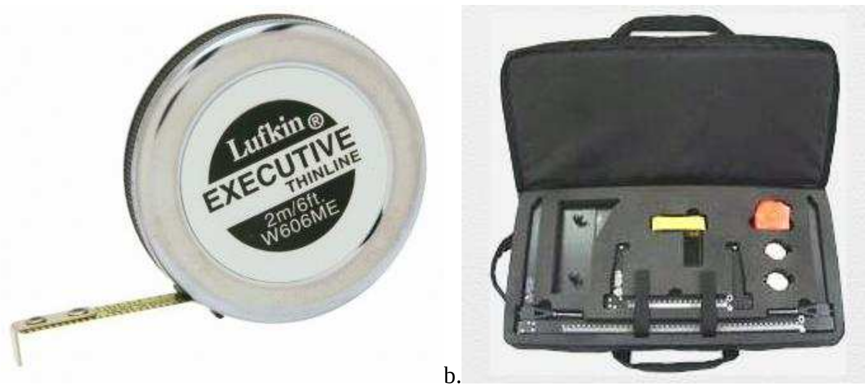
Though several published investigations are outlined above, the body of literature on the kinanthropometry assessment of cyclists is sparse, over 20 years old and has predominantly only focused on simple anthropometrics, in particular stature, mass and somatotype. Furthermore, there is an absence of literature on women in cycling, para-cycling, and off road cycling disciplines of BMX, cyclo-cross, downhill and endure. This lack of literature is perhaps because of the relatively under developed nature of these disciplines within the UK, thereby the absence of a Darwinian structure whereby optimisation must occur for individuals to be successful (Olds, 2009; Lombardo, 2012). Further research should focus on the importance of complex anthropometrics within kinanthropometrics assessment of cyclists, explore the longitudinal stability of anthropometrics in cycling and establish an up-to-date understanding of the importance of anthropometrics to cycling performance.

2.4 Review of measurement methods

There are two methods through which simple and complex anthropometrics can be acquired within kinanthropometric investigations: manual measurement and 3D imaging technologies.

2.4.1 Manual measurement

As outlined above in section 2.2.2, kinanthropometric studies have traditionally used manual measurement to acquire anthropometrics. Its popularity is due to its use of low cost, accessible and highly portable 'everyday' equipment (Figure 2.1) such as tape measures, callipers and scales, and standardised training and measurement protocols from several international scientific associations. Consequently, investigations often use manual methods as a gold standard, comparing other measurement system with it to determine accuracy (Bretschneider et al., 2009). A major advantage of manual measurement is the established industry standards, guidelines, training courses and accreditation.



a. b.

Figure 2.1: a) Anthropometric tape measure (Lufkin, 2016) and b) Rosscraft Centurion anthropometry kit (Rosscraft, 2016).

ISAK standards and guidelines

As outlined in Chapter One, ISAK is the successor to the IWGK and is the leading body for kinanthropometry industry standards, guidelines, and training courses and accreditation. ISAK is structured around two measurement profiles (Table 2.3) restricted and full (Stewart et al., 2011; Sutton & Stewart, 2012). ISAK guidelines typically suggest anthropometrics are only acquired from the right-hand side of the body irrespective of the preferred side of the participant, unless considered impractical (e.g. due to injury) (Stewart et al., 2011). This is because the bias associated with side preference / dominance is believed to be less than manual measurement error (Martorell et al., 1988; Moreno et al., 2002).

Table 2.3: Anthropometrics included in the restricted and full ISAK profiles (Stewart et al., 2011, pp.19)

Type	No.	Site	Restricted	Full
Basic	1	Mass	x	x
	2	Stature	x	x
	3	Sitting stature		x
	4	Arm span		x
Skinfolds	5	Triceps	x	x
	6	Subscapular	x	x
	7	Biceps	x	x
	8	Iliac crest	x	x
	9	Supraspinale	x	x
	10	Abdominal	x	x
	11	Front thigh	x	x
	12	Medial calf	x	x
Girths	13	Head		x
	14	Neck		x
	15	Arm (relaxed)	x	x
	16	Arm (flexed and tensed)	x	x
	17	Forearm (maximum)		x
	18	Wrist (distal styloids)		x
	19	Chest (mesosternale)		x
	20	Waist (minimum)	x	x
	21	Gluteal (hips)	x	x
	22	Thigh (1cm gluteal fold)		x
	23	Thigh (mid-troch-tib.lat.)		x
	24	Calf (maximum)	x	x
	25	Ankle (minimum)		x
Lengths	26	Acromiale-radiale		x
	27	Radiale-stylion		x
	28	Midstylion-dactylion		x
	29	Iliospinale height		x
	30	Trochanterion height		x
	31	Trochanterion-tibiale laterale		x
	32	Tibiale laterale height		x
	33	Tibiale mediale-sphyrion tibiale		x
Breadths	34	Biacromial		x
	35	A-P abdominal depth		x
	36	Biiliocristal		x
	37	Foot length		x
	38	Transverse chest		x
	39	A-P chest depth		x
	40	Humerus	x	x
	41	Bi-styloid		x
	42	Femur	x	x

ISAK requires practitioners to meet a minimum degree of accuracy and repeatability after the training courses and collection of a number of ISAK profiles for accreditation, dependent upon their level of accreditation. This is based upon TEM, as outlined in Table 2.4.

Table 2.4: Target intra and inter-tester ISAK TEM (%) following the training course and the submission of practice profiles. Gore et al., in Norton & Olds (2002).

ISAK level	Intra-observer		Inter-observer	
	Post course	Post profiling	Post course	Post profiling
1	2.0	1.5	2.5	2.0
2	1.5	1.0	2.0	1.5
3 - 4	1.5	1.0	2.0	1.5

Technical error of measurement

TEM is the square root of measurement error variance of repeat measurements on the same subject, either by the same observer, or multiple observers (Ulijaszek & Kerr, 1999). For absolute intra and inter-observer TEM are calculated using the difference between measurements (D) and the number of individuals measured (n) (Ulijaszek & Kerr, 1999) (Equation 2.9).

Equation 2.9:

$$TEM = \sqrt{\frac{(\sum D^2)}{2n}}$$

When two or more observers are assessed absolute inter-observer TEM are calculated using the measurement (m), the number of observers (k) and the number of individuals measured (n) (Ulijaszek & Kerr, 1999) (Equation 2.10). Although not typically included within ISAK standards, total TEM takes into account both intra- (TEM(intra)) and inter-observer (TEM(inter)) (Equation 2.11). Relative TEM can then be calculated using the absolute TEM and mean size (*μ)* (Equation2.12).

Equation 2.10:

$$TEM = \sqrt{\frac{\left(\sum_1^n\left((\sum_1^k m^2) - \left((\sum_1^k m)^2/k\right)\right)\right)}{n(k-1)}}$$

Equation 2.11:

$$total\,TEM = \sqrt{\left(\frac{\left((TEM(intra_1)^2) + (TEM(intra_2)^2) + (TEM(intra_3)^2)\right)}{3}\right) + TEM(inter)^2}$$

Equation 2.12:

$$TEM\ \% = \left(\frac{TEM}{\mu}\right)100$$

However, some researchers and practitioners are critical of manual measurement, suggesting it to be unsuitable due to several shortcomings (Maylia et al., 1999; Sicotte et al., 2010). Firstly, manual measurement is highly susceptible to human error due to its reliance on the experience, expectations, training and accuracy of the practitioner (Haas & Flegal, 1981; Cameron et al., 1986; Sonnenschein et al., 1993; Schreiner et al., 1995; Soderberg et al., 1996; Heuberger et al., 2007). Research has demonstrated high variability in manual measurements inter and intra-practitioner (Sicotte et al., 2010), which appears to be exacerbated when measuring atypical body types (Gibson, 1990; Atkinson et al., 2007). This is illustrated by Fairclough et al., (1994) who reported practitioners failed to notice an increase of 1.2 inches when measuring waist girth and Maylia et al., (1999) who identified intra-observer error, when using the same participant, of over 1.3 inches in thigh girth. To control for the effect of human error, standardised guidelines suggests multiple measurements should be acquired. This however makes this method time consuming, limiting its suitability for use, particularly in the assessment of large sample sizes. Thereby negating the value of manual measurement as an easy and quick method (Heuberger et al., 2007; Wells et al., 2007).

Secondly, although manual measurement directly acquires simple anthropometrics, it relies on population-specific predictive equations to estimate complex anthropometrics. The validity of these equations is heavily dependent upon the number of manual measures taken (Karges et al., 2003; Mayrovitz et al., 2007) which can range from the upper, mid and bottom girths of the segment (Jones & Pearson, 1969; Kaulesar Sukul et al., 1993; Perrin et al., 2000) to incremental girths measures every 3 - 12cm (Karges et al., 2003; Mayrovitz et al., 2007; Tan et al., 2013). Moreover, such equations are population specific: only correctly used when applied to the group upon which the formula was based, therefore are regularly unsuitable for use on atypical population groups, such as athletes (Karges et al., 2003; Mayrovitz et al., 2007; Mathur et al., 2008). This problem is exacerbated by the lack of standardised training or protocols for the measurement of complex anthropometrics. As the standardised training and protocols currently available are solely focused on the measurement of simple anthropometrics the suitability of this method for obtaining complex anthropometric is questionable (Rogers & Olds, 2004).

In summary, manual measurement is the most commonly used method that uses low cost, accessible and highly portable 'every day' equipment, and is accompanied by established industry standards, guidelines, training courses and accreditation. However, it is highly susceptibility to human error, reliant on predictive equations to estimate complex anthropometrics and lacks standardised procedures for such measurements, thereby making it unsuitable for use in this programme of research.

2.4.2 3D imaging

3D imaging technology creates digital 3D images of the internal and/or external geometry of the human body. Although only developed in the 1980s, there are now many types of 3D imaging systems, each using a variety of scientific principles, computer algorithms, equipment, calibration techniques and analysis software. Irrespective of the system used, using 3D imaging provides several advantages over manual measurement: 3D imaging systems offer the possibility of quick and direct contactless measurement of traditional and complex anthropometrics, making them highly suitable for studies with large sample sizes and atypical populations, such as SizeUSA, SizeUK (Treleaven, 2004), MySize (Bong et al., 2014) and SizeIndia (Kulkarni et al., 2011). The creation of a digital 3D image allows retrospective or immediate analysis of data and the ability to produce a digital representation of body changes over time, which is unfeasible through manual methods (Daanen & Van De Water, 1998; Robinette, 2013). These advantages make 3D imaging useful in an array of applications. Multiple kinathropometrists have recommended their use within kinanthropometry investigations (Olds & Honey, 2006; Olds, 2009; Stewart, 2010). 3D imaging has experienced rapid market growth, which is expected to continue; expected five-year compound annual growth rate (CAGR) of 17.7%, to a global market value 13.3 billion by 2020 (BCC Research, 2016). As such the industry has experienced an increase in the number of 3D imaging systems available. However, many 3D imaging systems use differing technology, hardware and software. As such the International Standards Office defined the acceptable degree of accuracy for 3D imaging systems as a method of body measurement within the ISO 20685-1 standard (ISO, 2010).

ISO 20685-1

ISO 20685-1 standard (ISO, 2010) details the minimum acceptable magnitude of error for 3D imaging systems as a method of body measurement (Table 2.5) in comparison to manual measurements. However, similar to ISAK, ISO 20685-1 only standardised simple anthropometrics.

Table 2.5: The maximum allowable error in 3D imaging systems (ISO, 2010, p. 8)

Measurement type	Max. error (mm)
Segment lengths (e.g. buttock-popliteal length)	5
Body heights (e.g. shoulder height)	4
Large girths (e.g. chest girth)	9
Small girths (e.g. neck girth)	4
Body breadths (e.g. biacromial breadth)	4
Body depths (e.g. chest depth)	5
Head dimensions without hair	1
Head dimensions with hair	2
Hand dimensions	1
Foot dimensions	2

Although the rapid market growth of 3D imaging has stimulated an increase in systems' performance and has generally decreased in cost, this technology predominantly remains inaccessible to many. Furthermore, as there are many different types of 3D imaging systems available and a lack of international standards and guidelines for the use of this method in kinanthropometry, comparisons between studies using different systems is very difficult. The following sections will critically review the most common 3D imaging systems currently available; laser, stereo radiography, millimetre wave, stereo photogrammetry and light based.

Minimum detectable change

Typically, alongside meeting established industry standards, a measurement method is deemed suitable if it is able to detect change or differences of importance. The minimum detectable change (MDC) is the smallest magnitude of change or differences detectable by a measurement method (Haley & Fragala-Pinkham, 2006). Whilst several method of estimating MDC exist, one of the most common indexes is the reliable change index (Stratford et al., 1998; Beaton et al., 2001; Haley & Fragala-Pinkham, 2006; Rábago et al., 2015). This is calculated using the intraclass correlation (ICC) and the standard deviation of the first session (σ) to calculate the standard error of the measurement method (SEM) (Equation 2.13), which is subsequently used to calculate MDC (Equation 2.14):

Equation 2.13:

$$SEM = \sigma\sqrt{(1 - ICC)}$$

Equation 2.14:

$$MCD = 1.96\, SEM\, \sqrt{2}$$

Laser imaging systems

Laser based imaging systems project laser lines, as one or more sharp thin stripes, onto the body. Simultaneously, the deformation of this line on the body surface is detected by light sensors and a 3D image of the external geometry of the body is created using the principles of triangulation; the creation of triangles using known points to calculate the location of unknown points (Lerch et al., 2007; Daanen et al., 2013). Several laser based imaging systems are available, such as the Vitronic Vitus 3D imaging systems (Figure 2.2).

Figure 2.2: Vitronic Vitus (Human Solutions, 2016)

The majority of laser based imaging systems use 100% eye safe lasers and have been reported to be capable of producing reliable and accurate data to within ± 1mm (Wang et al., 2006; Fourie et al., 2011; Daanen et al., 2013). Consequently, they have been used in several large-scale anthropometric surveys, such as CAESAR in the USA, Canada and Italy (Robinette et al., 1994). The principal disadvantage of laser imaging systems is their high cost: ranging from ~$37,000 to $65,000 (Daanen et al., 2013). Furthermore, as the laser line must sweep over the entire body, participants must remain completely motionless for the entire capture period, typically ~10 - 15 seconds which generates an increased risk of movement artefacts during the capture period. In summary, although laser based imaging systems are capable of capturing accurate anthropometric data repeatedly, their suitability appears to be limited by cost and a high risk of movement artefacts.

Stereo radiography imaging systems

Stereo radiography imaging systems create digital 3D images by collating multiple x-ray images. The main method of stereo radiography is computed tomography (CT). CT scanners consist of a narrow x-ray tube that rotates around one's body (Figure 2.3). The x-rays are passed through the body and received by detectors on the opposite side of the tube. The accuracy of the images is dependent upon the strength of the x-rays used.

Figure 2.3: Siemans SOMATOM Perspective CT Scanner (Siemans, 2016a).

CT scanners can accurately capture the external and internal geometry of the body. This allows for the identification of bone, muscle and fat, thereby enabling a more accurate calculation of density of segments: relevant for body segment inertial parameter (BSIP) calculations, and anthropometric characteristic of internal structures, such as the spine. Consequently, CT imaging is used in clinical studies investigating body composition (Borkan et al., 1983) and /or density (Pearsall et al., 1996)

However, CT scanners are not portable and are expensive; ~$55,000 - $275,000 (Block, 2014). This equipment must be operated by a trained radiographer (Westesson, 1993; NHS, 2015) and requires participants to remain still for approximately 30 seconds, thereby increasing the risk of movement artefacts (Yazdi & Beaulieu, 2007). Most crucially, CT systems use ionising radiation making whole body measurement or repeated measurement unsafe. As such, research studies using this method would need to investigate small body sections and one off measurements (Ackland et al., 2012; Al-Gindan et al., 2014).

In an attempt to negate the safety concerns of CT imaging, several studies have investigated the suitability of MRI systems (Figure 2.4). MRI creates highly accurate digital 3D images of the internal and external geometry of the body in a similar way to CT, but uses a magnetic field and radio waves instead of ionising radiation (Ng et al., 2003). 3D images are created through the detection of the energy produced by water molecules as they realign themselves after radiofrequency pulses.

Figure 2.4: Siemans MAGNETOM Aera MRI Scanner (Siemans, 2016b).

MRI systems have been reported to demonstrate accuracy comparable to CT systems (Brown et al., 1987; Pearsall & Reid, 1994) and are associated with fewer health risks. However, MRI scanners are not portable, are expensive ~$500,000 – $1.2 million (Block, 2014) and are at risk of movement artefacts due to a scan duration of ~30 minutes (Martin et al., 1989; Erasmus et al., 2004). Furthermore, although several studies have demonstrated MRI and CT scanners to be accurate in the measurement of body composition (Brown et al., 1987; Pearsall & Reid, 1994), their ability to extract accurate and reliable anthropometric measures has yet to be fully established. In conclusion, although accurate, stereo radiography imaging systems do not appear to be a suitable method of extracting anthropometric measures due to safety concerns and cost (Daly et al., 2006; Eston & Reilly, 2009).

Millimetre wave imaging systems

Millimetre wave imaging systems use electromagnetic radiation (millimetre waves) that are naturally emitted by human skin (passive) or projected onto the body (active) (Daanen et al., 2013). Once these signals are received by a linear array of antennae, using the time-of-flight principle (TOF), the distance to the surface is calculated and a 3D image of the external geometry of the body created. This method captures data through clothing and hair, eliminating the need for undressing (Treleaven & Wells, 2007; Apuzzo, 2009). As a consequence millimetre wave imaging systems are increasingly used as a as method of airport security to detect concealed metallic and non-metallic threats in the form of liquids, gels, plastics, etc. (Daanen et al., 2013; Accardo & Chaudhry, 2014) (Figure 2.5).

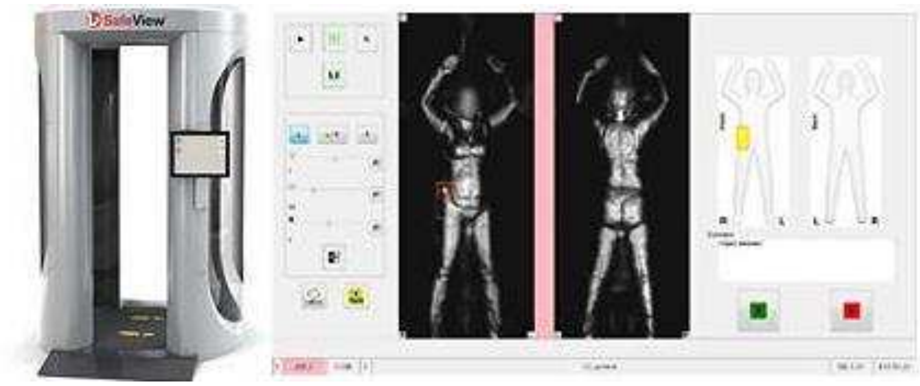


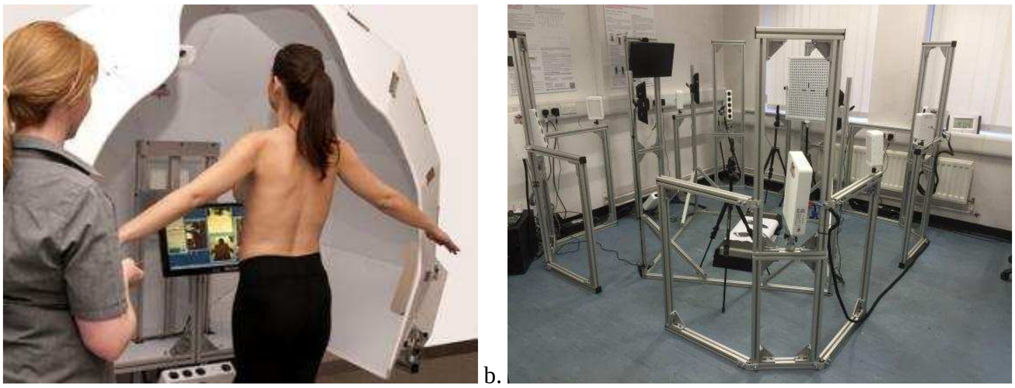
Figure 2.5: L3 SafeView ProVision (SDS, 2016).

Millimetre wave imaging systems are quick, ~2 - 5 seconds per scan (HERCA Group, 2010), and have been reported to be accurate within ±6 mm (Percoco & Galantucci, 2010). However, although this technology has translated into commercially available systems (the Intellifit System) this technology is in its infancy (Apuzzo, 2009; Daanen et al., 2013) and its ability to extract accurate and reliable anthropometrics has yet to be fully established. Moreover, the safety of this technology is still unknown. Although millimetre-wave imaging system use low levels of non-ionizing radiation that do not penetrate human tissue, producing only thermal effects (Accardo & Chaudhry, 2014), authorities including the HERCA (2010) still express concerns regarding the safety and suitability of this method due to the scarcity of published research. Furthermore, this technology is expensive, ~$100,000 - $200,000 (HERCA Group, 2010) and not portable. In summary, the suitability of this method is limited by ethical and health concerns, as although software to blur facial features or intimate body areas is available, the 3D image produced is of the individual nude. In summary, although this method is quick, its high cost and prevailing ethical and health concerns limit its suitability for use within this thesis.

Stereo photogrammetry imaging systems

Stereo photogrammetry, also known as multi-image or stereo-camera photogrammetry, uses synchronized digital cameras to obtain images from multiple angles and triangulation principles (Apuzzo, 2009; Daanen et al., 2013). Software is then used to match the corresponding points in the different images to create a digital 3D image of the external geometry of the body (Van der Mark et al., 2007; Lane & Harrell, 2008; Apuzzo, 2009; Lee et al., 2011). Consequently, it is not associated with any safety or health concerns.

Stereo photogrammetry imaging systems are generally classified into two categories: passive and hybrid (passive and active). Passive stereo photogrammetry uses natural patterns or landmarks on the surface of the target object, e.g. skin pores, freckles and scars, and triangulation techniques to create digital 3D images (Lane & Harrell, 2008; Tzou et al., 2014). Several passive stereo photogrammetry systems are commercially available, including the Cranfield Vectra M3, Canfield Vectra XT, Cranfield Vectra CR 3D and 3dMD (Figure 2.6). The majority of passive stereo photogrammetry imaging systems are reported to be accurate less than 0.2 mm (Tzou et al., 2014), due to the high camera quality and pixel integrity required to identify and match natural landmarks, and capture data quickly, ~2 - 8 ms. However, these systems are expensive, and typically have a small capture volume (Tzou et al., 2014).



a. b.

Figure 2.6: a) 3dMDTorso (3dMD, 2016) and b) 3dMDBody5.

Hybrid stereo photogrammetry uses natural patterns or landmarks on the surface of the target object (passive stereo photogrammetry) alongside a projected light pattern within triangulation techniques to create digital 3D images (active stereo photogrammetry) (Tzou et al., 2014). Due to the additional corresponding points between cameras, the process of finding these points is easier within hybrid stereo photogrammetry. Thus hybrid stereo photogrammetry is typically regarded as accurate, <0.2 mm, and quicker, ~1.5 ms, than passive stereo photogrammetry. Examples of stereo photogrammetry imaging systems include 3dMD 3D imaging range (Figure 2.6). Although the price and size of stereo photogrammetry imaging systems is decreasing (Pesce et al., 2014) those that are commercially available remain expensive and not portable, such as the 3dMD

Flex8 system which costs ~$190,000 (Daanen et al., 2013). In addition, several studies have reported difficulties in imaging bony, shiny, dark or shadowed surfaces (Littlefield et al., 2004; Aldridge et al., 2005; Weinberg & Kolar, 2005).

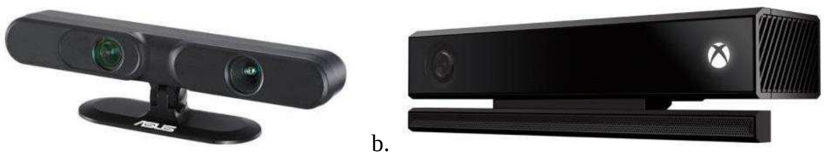
In summary, stereo photogrammetry imaging systems - particularly hybrid stereo photogrammetry imaging systems appear suitable for use within this programme of research. Their high cost and lack of portability is outweighed by their high degrees of accuracy, quick capture time and thereby the low risk of movement artefacts. Furthermore, the technology appears well developed, is commercially available and is not associated with any health, safety or ethical concerns.

Structured light based imaging systems

Structured light based imaging, also known as light coding or white light imaging, projects a pseudo structured light pattern onto the human body (Apuzzo, 2009; Daanen et al., 2013), similar to the active stereo photogrammetry. This pattern can consist of stripes, dots, bars, or any other light pattern (Apuzzo, 2009; Geng, 2011; Daanen et al., 2013), often using infrared light. Similar to laser imaging systems, digital 3D images of the external geometry of the body are created by comparing the distortion of the light pattern seen on the body with the original undistorted projection pattern, using triangulation principles (Geng, 2011; Daanen et al., 2013).

The majority of light based scanning systems require multiple cameras working in series, to avoid pattern interference and thus require a scanning duration of ~8 seconds ([TC]2, 2014), which increases the risk of movement artefacts. As a consequence several studies have criticised light projection based scanning systems due to their lower scan quality (Olds & Honey, 2006) and reduced accuracy when compared to stereo photogrammetry and laser scanning systems, ±3 mm in circumferential measures (Daanen et al., 2013; [TC]2, 2014). Regardless, several studies have reported light projection based scanning systems to be a suitable method of acquiring simple anthropometrics in non-clinical environments when compared to the manual methods (Sims et al., 2012), attributing the majority of differences to the compression of soft tissue by the tape (Mckinnon & Istook, 2002; Sims et al., 2012). Several companies have manufactured light projection based scanning systems, including Telmat (SYMCAD), 4ddynamics (Mephisto Ex-Pro / Mephisto CX-Pro/Gotcha) and [TC]2 Body Measurement System (TC2-18). However, light projection based scanning systems remain expensive, ~$10,000 - $190,000 (Daanen et al., 2013) and non-portable, requiring several hours to assemble and calibrate (Olds & Honey, 2006). Therefore the suitability of light based scanning systems appears to be limited by cost and portability. However, in an attempt to address this, several researchers and manufacturers have recently started to employ low cost, commercially available depth cameras that use light based imaging technology.

Depth cameras use the time of flight (TOF) principle or a pseudo structured light pattern, and computer vision techniques and algorithms such as iterative closest point (ICP) to create a digital 3D point cloud of the external geometry of the body. Depth cameras are used in several commercially available, natural user interface (NUI) sensor technologies, systems for human-computer interactions including the Asus Xtion Pro (ASUS, 2015), SoftKinetic depth sense cameras and modules (SoftKinect, 2015) and Microsoft Kinect for Xbox and Kinect for Xbox One (Figure 2.7).



a. b.

Figure 2.7: a) Asus Xtion Pro (ASUS, 2016) and b) Microsoft Kinect for Xbox One (Microsoft, 2016).

However, in line with increased popularity, depth cameras are becoming increasingly popular as add-ons for (Occiptal, 2015; Trimensional, 2015) and within smaller devices such as tablets and phones (HTC One M8, Google’s Project Tango). The main advantages of NUI technologies, in which depth cameras are used, are their low cost (~$200) allowing the creation of 3D body imaging systems for ~$1000, commercial availability, and portability: lightweight (0.2 - 1.4 kg), small and resilient (iPiSoft Wiki, 2013). Consequently, NUI technologies containing depth cameras have been used in a variety of research based (Clarkson et al., 2013; Bragança et al., 2014) and commercially available 3D body imaging systems (Fit3D and Styku). The prospect of many future consumer technologies containing some form of depth camera is encouraged by the Apple’s acquisition of Primesense in November 2013: a 3D sensing company best known for licensing and design of the hardware and chip used in the original Microsoft Kinect (Takahashi et al., 2013).

Several studies have subsequently investigated the accuracy and feasibility of these depth camera based 3D body imaging systems. These have predominantly demonstrated favourable but systematically overestimated results in the measurement of girths of solid objects (e.g. cylinders (Clarkson et al., 2013)) and human body segments (Zwane et al., 2010; Bullas et al., 2014). For example the [TC]^2 Kinect based imaging system reports accuracy of ± 3 mm ([TC]^2, 2014). Additionally, using a mannequin Clarkson et al., (2012) reported a Kinect based imaging system to demonstrate smaller errors in volume estimation than manual methods Yeadon’s geometric model (Yeadon, 1990) when compared to a high accuracy laser imaging system. This is accompanied by high levels of intra-calibration repeatability (technical error of measurement (TEM < 1 %) (Bullas et al., 2014; Clarkson et al., 2014).

At present the only reported limitations of depth camera based light imaging systems is noise due to participant distance from camera (Khoshelham & Elberink, 2012; Clarkson et al., 2013) and uncertainty surrounding the underlying calculation algorithms (Clarkson et al., 2012; Wang et al., 2012). Therefore, depth camera based 3D body imaging systems, although still in their infancy, appear to be capable of producing accurate and repeatable scans at low cost using portable and accessible equipment that may be a suitable method for collecting complex anthropometrics within kinanthropometry studies.

In summary, stereo radiography systems' use of radiation and necessity for a trained radiographer makes it unsuitable. Although millimetre wave based imaging systems show a great deal of potential, its high cost and prevailing ethical and health concerns limits its suitability for use within this thesis. Stereo photogrammetry and depth camera based light based imaging systems demonstrate the most suitable methods of acquiring anthropometrics.

2.4.3 Summary

This review has critically compared anthropometric measurement methods. Several methods appear unsuitable for use within this context, however, stereo photogrammetry and depth camera based light based imaging systems demonstrate the most suitable methods of acquiring anthropometrics. To the researcher’s knowledge, no study has investigated the natural daily variation of human body segments or identified the MDC important in body measurement. Consequently, in order to ensure any difference in anthropometrics, either between groups or over time, is not masked by the system’s variability, it is essential that the measurement method error is minimal. Based on this justification, this review of measurement methods suggests that a stereo photogrammetry imaging system would be the most suitable method for use within kinanthropometric assessments of cyclists. Whilst it is possible that the high cost, and thereby inaccessibility of this technology to other researchers, anthropometrists and practitioners, may limit the uptake of any findings using this system, accuracy in findings must remain of paramount importance.

2.5 Chapter summary

This literature review suggests that complex anthropometrics, such as area and volume, can identify changes in body size and shape that are not detectable with traditional anthropometrics of lengths, breadths, skinfolds and girths. Furthermore, whilst optimal body dimensions are believed to be an important prerequisite of success in cycling, the body of literature on the kinanthropometry assessment of cyclists is sparse, over 20 years old and has predominantly focused on simple anthropometrics. As such it appears research into the importance of complex anthropometrics within kinathropometric assessment of cyclists is warranted. With regards to measurement methods, this literature review suggests that a stereo photogrammetry imaging system would be the most suitable method for use within kinanthropometric assessments of cyclists. Although expensive, their high degrees of accuracy and repeatability should ensure any difference in anthropometrics, either between groups or over time, are not masked by the system’s variability.

Chapter 3 - Validation of the 3dMDbody5 imaging system using verification artefacts

3.1 Introduction

Chapter Two reviewed the methods of body measurement in kinanthropometric applications. This suggested stereo photogrammetry surface imaging systems to be the most suitable method for use in subsequent investigations. 3dMDbody5 (3Q Technologies Inc., Atlanta, GA) is a commercially available 360° hybrid stereo photogrammetry surface imaging system. It captures 3D images through both active stereo photogrammetry; the deformation of a projected pattern and triangulation calculations, and passive stereo photogrammetry, the matching of 2D images without the projection of a pattern (Tzou et al., 2014). It consists of 5 synchronised modular units, each containing three machine vision cameras and two infrared projectors, placed around a square 258 × 258 cm aluminium Bosch (Bosch Rexroth AG) strut frame (Figure 3.1). The system uses a single computer (Dell 64 Bit Windows 7 Professional 4 Core CPU 4.6GHz 8GB RAM) and is accompanied by four light boxes. All modular units collect data simultaneously. Thus, capture time is very short, ~1.5 ms, thereby minimising risk of movement artifacts.

Figure 3.1: 3dMDbody5 system

The manufacturer suggests 3dMDbody5 to have 'geometry accuracy' of < 0.5 mm (3dMD, 2017). Whilst it is unclear what is meant by 'geometry accuracy', previous investigations that used other 3dMD systems with similar reported degrees of accuracy have corroborated the manufacturer's accuracy estimations (Weinberg et al., 2006; Dindaroğlu et al., 2015). However, as suggested by Robinson et al., (2012), to ensure valid and reliable data are captured, every imaging system must be performance verified using high precision dimensional verification artefacts. Yet, to the author's knowledge, no study has independently investigated the accuracy and repeatability of the 3dMDbody5 system.

This chapter details an investigation into the validity of the 3dMDbody5 imaging system using verification artefacts. The aim of this investigation was to determine the suitability of the 3dMDBody5 system for use as a method of body measurement in kinanthropometric applications. The objectives were to:

- Identify verification artefacts of known dimensions, representative of body segments, to limit external influencing factors and act as a 'gold standard' for comparison against.
- Determine the intra-calibration accuracy and repeatability of each measurement method by collecting multiple 3D images of the verification artefacts at different positions within the calibrated capture volume.
- Determine the inter-calibration accuracy and repeatability of each measurement method by performing multiple system calibrations.
- Critically evaluate the intra and inter-calibration accuracy and repeatability of each measurement method through comparisons with established industry standards.

3.2 Method

3.2.1 Verification artefacts

Four precision-engineered cylinders of known dimensions were selected as the test objects for measurement. Based upon the National Physics Laboratory's 'Phantom Man', as detailed in Robinson et al., (2012), the cylinders were selected to limit external influencing factors typically associated with human measurement (e.g. hair, human movement, skin) and act as a 'gold standard' for comparison against. In an attempt to ensure the protocol was as closely representative of a human participant, all cylinders were representative of body segments in girth and length (Table 3.1).

Table 3.1: Cylinder size, representative body segment and ISO 20685-1 categorisation.

Cylinder No.	Representative body segment	Length (mm)	Girth (mm)	ISO 20685-1 girth category.
1	Lower arm / upper arm / lower leg	272.0	276.0	Small
2	Upper arm / lower leg / upper leg	373.0	355.0	Small
3	Upper leg / torso	373.0	509.0	Large
4	Torso	350.0	713.0	Large

The cylinders were manufactured from a solid aluminium section using a V290 centre lathe (Harrison Colchester, Heckmondwike, UK), the same as those used by Clarkson et al., (2015). Each cylinder was coated in a white powder, to create a non-reflective surface, and had a matt black band at each end (Figure 3.2). The dimensions of each cylinder were measured by a single experienced engineer using digital engineer's callipers (Kennedy, Leicester, UK), accurate to ± 0.01 mm.

Figure 3.2: Cylinders representative of typical body segments.

3.2.2 Research protocol

Each cylinder was captured using the 3dMDbody5 system three times in five positions within the capture volume (Figure 3.3). During data collection, each cylinder was placed on a raised platform to ensure it was positioned within the vertical centre of the calibrated volume. Each cylinder had the upper and lower lateral points marked using coloured markers, 0.8 cm in diameter, to ensure correct identification of the cylinder boundaries in the 3D images.

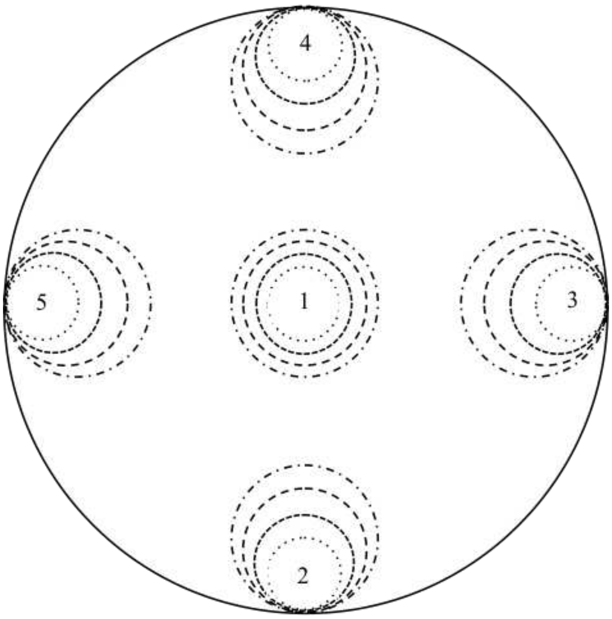


Figure 3.3: The capture positions of the cylinders; small, medium, large and extra-large, within the calibrated volume

Data were collected on three occasions, under three separate calibrations. The calibration procedure of the 3dMDbody5 system followed the manufacturer's guidelines: each camera unit was manually aligned to the centre point of a calibration plate placed within the centre of the system (Figure 3.4). Once aligned, a series of images were captured of the board in 5 positions using the 3dMDbody5 acquisition software. The 3dMDbody5 acquisition software then automatically calibrated the system. This process took ~3 - 5 minutes and created a calibrated cylindrical capture volume of 0.089 m^3; 0.56 m in height, with a radius of 0.23 m. However, the exact methods of alignment, filtering and refinement used in the proprietary software are unknown.

Figure 3.4: 3dMDbody5 calibration board.

3.2.2 Post processing of 3D images.

KinAnthroScan, custom software created in-house, facilitated the post processing of all 3D images. Each 3D image was manually digitised; manual identification of the marked landmarks by a single researcher by clicking directly on each manually marked point. One researcher conducted all digitising. This research had a mean intra-observer TEM of 0.009 ± 0.001% (0.04 ± 0.01 mm), a relative inter-calibration TEM 0.009% (0.05 mm) and a Total TEM of 0.044% (0.09 mm) when digitising. Once completed for all marked points, KinAnthroScan returned a set of 3D coordinates for these landmarks. These digitised points defined the boundaries of the cylinder, and were used to apply segmentation planes to isolate the region of interest (Figure 3.5).

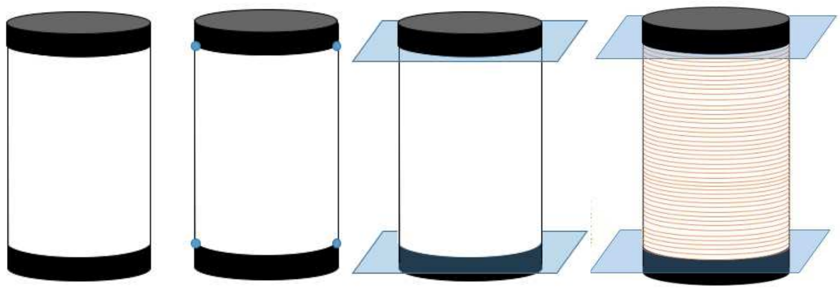


Figure 3.5: Post processing method of 3D the 3D images within KinAnthroScan.

The segmented region was divided into multiple 2 mm thick ‘slices’. This size was selected for use with data from a bespoke Microsoft Kinect (Microsoft Corporation, USA) based imaging system, to be small enough to ensure features of the data were not lost whilst also being large enough to ensure each slice contained sufficient points to enable calculation of anthropometrics (Clarkson, 2015). All data points contained within each slice were converted to a 2D coordinate system; the vertical Y component was disregarded, to assume all data points lay on a single plane. A penalised regression spline (ALGLIB, 2014) was then fitted. Virtual points were then applied along the spline at 1° intervals. The inter-point distance of all the created spline points was then calculated. These distances were summed to create the measurement of girth. This process was repeated for each slice within the segmented area to create a series of girth measures every 2 mm.

If a slice contained too many missing data points that created holes in the point cloud, then linear interpolation was used between the last and next available girth to estimate the missing girth. Furthermore, when the uppermost slice height was less than 2 mm and thereby contained insufficient data points to reliably fit the spline KinAnthroScan assumed the girth of the uppermost slice was the same as the penultimate slice, and that any differences were negligible due to the minimal distance between them. Similar to previous studies (Schranz et al., 2010) mean girths that fell ± 2 standard deviations away from the true cylinder size were re-measured.

3.2.3 Data analysis

Based upon the calculations outlined above in Section 3.2.2, for each 3D image girth every 2 mm was exported into Microsoft Excel (Microsoft Office 2011, Microsoft Corporation, USA) alongside all manually acquired measures. Only girths were explored for analysis as they form the basis from which complex anthropometrics are calculated and, as outlined in Section 2.4.1, are covered by established industry standards. To ensure the selection of suitable statistical analysis procedures the parametric nature of the data were first explored. A Shapiro-Wilks and Levene's test for equality of variance were conducted to determine the normality and homogeneity of variance, respectively, within SPSS (IBM SPSS Statistics 24.0). A series of paired t-tests and Pearson's correlation tests were then conducted within SPSS (IBM SPSS Statistics 24.0) to determine the significance of any differences intra or inter-calibration and positions. To explore the accuracy of the 3dMDbody5 system mean girths and absolute mean error were calculated within Microsoft Excel, using the manual digital calliper measures as 'gold standard'. To explore the nature of any differences Bland-Altman and ordinary least squares regression (OLS) analyses were conducted using Microsoft Excel, MATLAB (version 13.0b, MathWorks, USA) and SPSS (version 21.0, IBM, USA), following the guidelines of Bland & Altman (1999) and Ludbrook (1997, 2010). To explore the repeatability of the 3dMDbody5 system the relative and absolute intra-calibration TEM, relative inter-calibration TEM and total TEM were calculated using all girth measures, following the guidelines of Ulijaszek & Kerr (1999), as detailed in Section 2.4.1. To explore the MDC detectable by the 3dMDbody5 system the reliable change index was calculated using Equation 13 and Equation 14 as detailed in Section 2.4.2.

3.3 Results

3.3.1 Accuracy

Across all positions the 3dMDbody5 system demonstrated a mean error of -1.10 ± 0.49% (-3.0 mm ± 1.4 mm) (Table 3.2). The Bland–Altman ratio plots (Figure 3.6) demonstrated 3dMDbody5 to elicit small but statistically significant proportional bias and small but not statistically significant systematic bias (R^2 = 1.00, p ≤ 0.001. Slope b’ = 1.01, p ≤ 0.001. Intercept a’ = -0.01, p = 0.64) across all positions, suggesting the 3dMDbody5 system to be systematically underestimating cylinder girth by 0.6%. The presence of slight proportional and systematic bias is reiterated by the OLS analysis (Figure 3.7)

Table 3.2: Measurements of 3dMDbody5 accuracy.

Measure	Cylinder				
	Small	Medium	Large	Extra large	All
‘Gold standard’ girth (mm)	276.0	355.0	509.0	713.0	463.0 ± 193.0
Mean 3dMDbody5 derived girth (mm)	274.4 ± 1.0	352.7 ± 1.0	505.6 ± 0.9	708.1 ± 2.0	460.0 ± 191.1
Mean girth error (mm)	-1.6 ± 1.0	-2.3 ± 1.0	-3.5 ± 0.9	-4.7 ± 2.0	-3.0 ± 1.7
95% confidence interval (mm)	0.2	0.2	0.2	0.4	0.3 ± 0.1
Mean girth error (%)	-0.6 ± 0.3	-0.8 ± 0.4	-1.3 ± 0.3	-1.7 ± 0.7	-1.1 ± 0.5

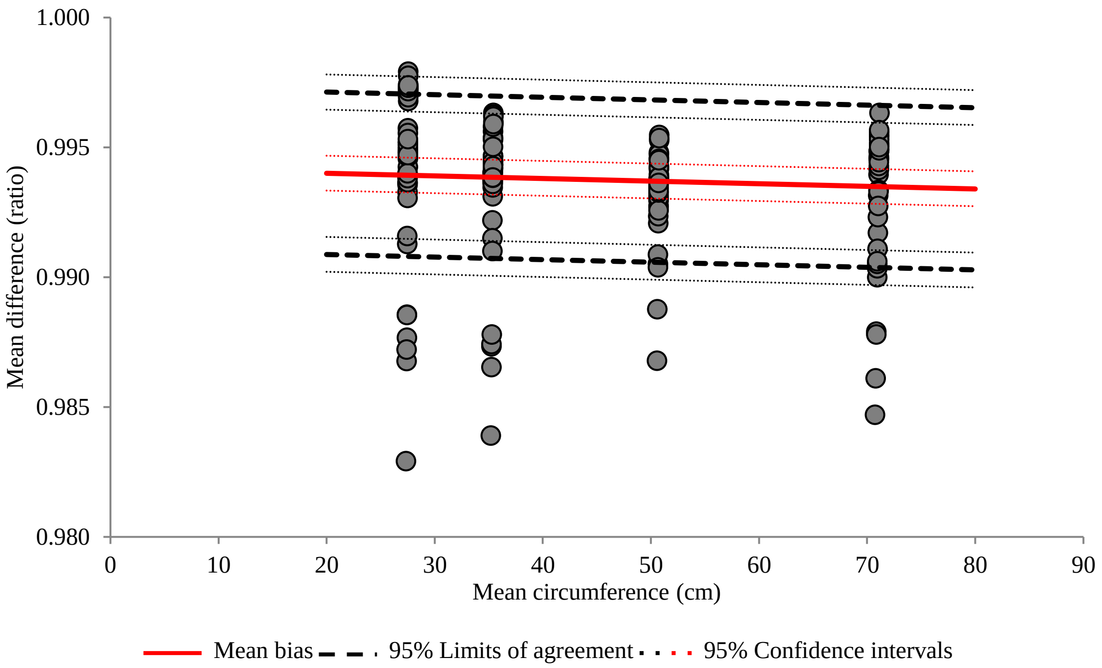


Figure 3.6: Bland–Altman plots of the ratio of mean cylinder girth (Correlation R^2 = 1.0, p ≤ 0.001. Slope *b’* = 1.00, p ≤ 0.001. Intercept *a’* = 0.001, p = 0.154.

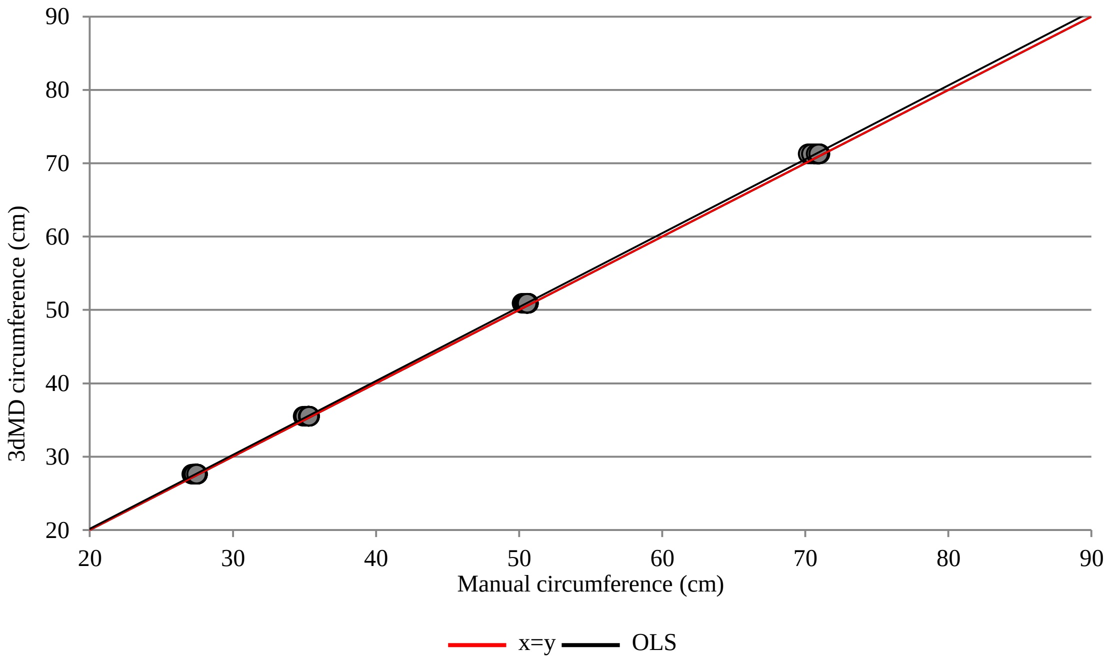


Figure 3.7: OLS plot of mean cylinder girth (Intercept a' = 0.02, Slope b' = 0.99, Correlation $R^2 = 1.0$)

3.3.2 Repeatability

Across all girths and positions, the 3dMDbody5 system demonstrated a mean intra-calibration TEM of 0.35 ± 0.03% (0.9 ± 0.1 mm) (Table 3.3). No significant differences between intra or inter-calibration sets ($p > 0.05$) were demonstrated. Across all girths and positions, the 3dMDbody5 system demonstrated a relative inter-calibration TEM 1.05% and a Total TEM of 1.05% (Table 3.3).

Table 3.3: Measurements of 3dMDbody5 repeatability: mean and standard deviation intra-calibration TEM, inter-calibration TEM and total TEM.

TEM		Cylinder				
		Small	Medium	Large	Extra Large	All
Mean intra calibration TEM	mm	1.0 ± 0.6	1.4 ± 0.4	1.1 ± 0.7	3.0 ± 0.5	0.9 ± 0.1
	%	0.36 ± 0.23	0.39 ± 0.11	0.21 ± 0.14	0.42 ± 0.07	0.35 ± 0.03
Inter calibration TEM	mm	0.4	0.5	0.5	0.8	0.3
	%	0.16	0.14	0.10	0.11	0.06
Total TEM	mm	1.5	2.3	2.0	4.4	1.4
	%	0.54	0.65	0.39	0.62	0.29

3.4 Discussion

The aim of this investigation was to determine the suitability of the 3dMDBody5 surface imaging system for use as a method of body measurement within kinanthropometric applications. 3D images of four precision-engineered solid aluminium cylinders of known dimensions, representative of body segments, were collected in 5 positions within the calibrated volume under three separate calibrations.

3.4.1 Accuracy

The results of this investigation demonstrate the 3dMDbody5 system to underestimate by 3.0 ± 1.4 mm (~0.6%). This exceeds the manufacturer's suggested 'geometry accuracy' of < 0.5 mm (3dMD, 2017). Previous unpublished work that analysed 3dMD data in both KinAnthroScan and the commercially available Geomagic Studio 8 (Raindrop Geomagic, USA) demonstrated no statistically significant differences between measures calculated. Consequently, it is unlikely that the underestimation demonstrated within this investigation is attributable to the analysis algorithms. It is most likely that the underestimation demonstrated within this investigation is attributable to hardware or the calibration technique. As previous investigations, that used other 3dMD systems with similar reported degrees of accuracy, have corroborated the manufacturer's accuracy estimations when measuring distance within clinical contexts when comparing against other imaging systems (Weinberg et al., 2006) and manually acquired measures (McKinnon et al., 2007), further research would be necessary to confirm this.

As outlined in Section 2.4.2, the ISO 20685-1 standard (ISO, 2010) defines the acceptable magnitude of error for body measurements from 3D imaging systems when measuring humans in comparison to manual measurement methods: 95% confidence interval of ± 0.8 cm and ± 4 cm for large and small girths respectively. The error demonstrated within this investigation falls within the requirements of the ISO 20685-1 standards (ISO, 2010). Consequently, based upon these standards 3dMDbody5 is adequately accurate for use as a method of body measurement within kinanthropometric applications.

3.4.2 Repeatability

The 3dMDbody5 system demonstrated high intra-calibration and inter-calibration repeatability (mean total TEM of 0.55 ± 0.12%). As outlined in Section 2.4.1, ISAK standards require the most experienced (level 4) ISAK anthropometrist's to demonstrate intra-observer and inter-observer TEM for girths of < 1.0% (Sutton & Stewart, 2012). The repeatability demonstrated within this investigation falls within the requirements of an ISAK level 4 anthropometrist. Therefore, based upon these standards 3dMDbody5 is adequately repeatable for use as a method of body measurement within kinanthropometric applications.

As discussed in Chapter Two, alongside meeting established industry standards, a measurement method is deemed suitable if it is able to detect change or differences of importance. The MDC, as detailed Section 2.4.2, is the smallest magnitude of change or differences detectable by a measurement method (Haley & Fragala-Pinkham, 2006). The results of this study suggest that, when measuring verification artefacts, the 3dMDbody5 system would be able to detect change greater than 0.8 mm. I.e. change or differences identified that exceeded 0.8 mm could be regarded as true change - not attributable to the variation within the system. However, to the researcher's knowledge, no study has investigated the MDC necessary for anthropometric methods. As a result, although the results of this study fall within the recommended limits of established industry standards, it is difficult to determine with confidence if the MDC reported by this investigation is sufficient to allow the measurement and detection of true change, or if this would be masked by the system's variability when used within kinanthropometric investigations.

3.4.3 Limitations

This study has several limitations that require consideration. Firstly, although the cylinders selected were representative of body segments, the use of cylinders reduces the applicability of the results to human participants. It is possible that the magnitude of error demonstrated by this investigation will increase when measuring human participants due to additional factors such as hair, human movement, and skin. However, it is hoped that the high quality cameras used within this system and the short capture period will minimise the effect of these influencing factors. Due to the inherent error within manual measurement of human participants, as detailed in Section 2.4.1, and thereby an absence of a 'gold standard' for the measurement of human participants further research may be problematic and would be required to focus on repeatability and agreement as opposed to accuracy. Secondly, this investigation has focused solely on girth, which is only one of many anthropometrics. Only girths were explored for analysis as they form the basis from which complex anthropometrics are calculated and, as outlined in Section 2.4.1, are covered by industry standards. However, this means that the results of this investigation can only suggest that the 3dMDbody5 system might be accurate and repeatable enough for extracting other anthropometrics in kinanthropometric applications.

3.5 Conclusions

The results of this investigation suggest that the 3dMDbody5 system is accurate and repeatable within that required by established industry standards, and consequently it can be suggested that 3dMDbody5 is a suitable method of body measurement within kinanthropometric applications. However, it is possible that the magnitude of error demonstrated by this investigation will increase when measuring human participants due to the external influencing factors such as hair, human movement and skin. Future kinanthropometric investigations should consider exploring the suitability of the 3dMDBody5 system for use as a method of body measurement in kinanthropometric applications when using human participants.

Chapter 4 - Validation of the 3dMDbody5 imaging system using human participants

4.1 Introduction

Chapter Three demonstrated that the 3dMDbody5 system systematically underestimates girth by 0.6% when measuring precision engineered verification artefacts, and that the 3dMDbody5 system would be able to detect change greater than 0.8 mm in girth. Although this magnitude of difference is small, it is possible that it will increase when measuring human participants due to the external influencing factors such as hair, human movement and skin. Furthermore, Chapter Three focused solely on girth. Thus, the results of this investigation can only suggest that the 3dMDbody5 system might be a suitable measurement method for other anthropometrics, such as CSA, volumes and surface areas. Consequently further investigation into the validity of the 3dMDbody5 system using human participants was warranted. However, as discussed in Section 2.4, when measuring human participants no gold standard currently exists. Manual measurement is the most commonly used and predominantly the only available measurement method. Thus, although manual measurement is accompanied by error it was deemed the most suitable method for comparison.

This chapter details an investigation into the validity of the 3dMDbody5 system when using human participants. The aim of this investigation was to determine the suitability of the 3dMDBody5 system as a method of body measurement in kinanthropometric applications. The objectives were to:

- Collect girth anthropometrics of human participants, using the 3dMDbody5 system and manual measurement, in order to establish the intra-calibration / observer repeatability and agreement between methods for simple anthropometrics.
- Collect girth, CSA, volume and surface area anthropometrics of human participants, using 3D surface imaging over multiple calibrations, in order to establish the inter-calibration repeatability of the 3dMDbody5 system for simple and complex anthropometrics.
- Critically evaluate the agreement between measurement methods and, the intra and inter-calibration repeatability of each measurement method through comparisons with established industry standards.

4.2 Method

4.2.1 Participants

Through convenience sampling, 30 healthy recreationally active volunteers participated in this study (Table 4.1). At the time of testing all volunteers were required to be over the age of 18 years and able to stand unaided for an extended period of time, as all data were collected standing. All volunteers were screened to determine their suitability for participation and required to provide written informed consent (Appendix A.1.2, Appendix A.1.3 and Appendix A.1.4). During data collection participants were required to wear non-compressive form fitting shorts (that extended no further than the mid-thigh) or loose shorts affixed (with duct tape) above the gluteal fold, a shirt of their own choice and no socks. This maximised the number of markers placed directly on the skin rather than clothing, thereby minimising the movement of the markers away from the bony locations they were identifying. The participant's standing stature and body mass were acquired using a stadiometer (Leicester, Seca Vogel, Germany) and digital scales (Weight Watchers Limited, UK), respectively. All procedures were approved by Sheffield Hallam University Research Ethics Committee (Appendix One).

Table 4.1: Participant descriptives.

Participant descriptives	Groups	
Sex	Female	Male
No. of Participants	15	15
Age (years)	23 ± 9	21 ± 4
Stature (cm)	164.9 ± 5.6	181.0 ± 7.2
Mass (kg)	66.72 ± 21.92	82.45 ± 13.29

4.2.2 Research protocol

Each participant attended one 60 minute data collection session, during which anthropometrics of the right upper leg were acquired both manually and using the 3dMDbody5 system. The right upper leg was selected for examination within this investigation as it predominantly demonstrates a progressive change in shape across the length of the segment, and because it was deemed to potentially be of interest for subsequent investigations. As discussed in Section 2.1.1, ISAK guidelines suggest that anthropometrics are typically only acquired from the right-hand side of the body irrespective of the preferred side of the participant, unless considered impractical (e.g. due to injury) (Stewart et al., 2011), because the bias associated with side preference / dominance is believed to be less than manual measurement error (Martorell et al., 1988;

Moreno et al., 2002). As a comparison between sides was not necessary, anthropometrics of only the right leg were collected.

Landmarking

The right upper leg was defined using standardised ISAK anthropometric locations. The upper leg was defined as the area encompassed between the upper thigh (the 1 cm distal to the medial aspect of the gluteal (Stewart et al., 2011, p. 85) and the midpoint of the superior border of the patella (Stewart et al., 2011, p. 46) (Figure 4.1). This method differs slightly from that used within biomechanical modelling or mechanical analysis, in which the upper leg segment is segmented at the epicondyles of the knee and the upper aspect of the 'thigh flap' (area encompassed by the anterior superior iliac spine, hip joint or greater trochanter, and the gluteal furrow) (Wu et al., 2002; Mok et al., 2013; Zuk & Pezowicz, 2015). However, a definition of the upper leg segment based upon ISAKs standardised anthropometric locations is more popular within kinanthropometry literature (Jones & Pearson 1969; Tothill & Stewart 2002; Coelho-E-Silva et al., 2013).

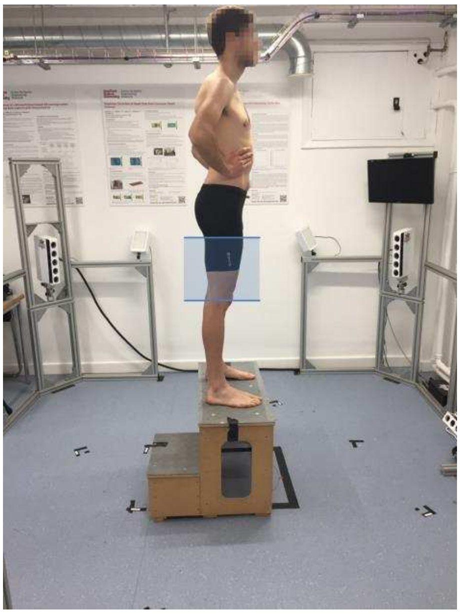


Figure 4.1: The segmented region of interest.

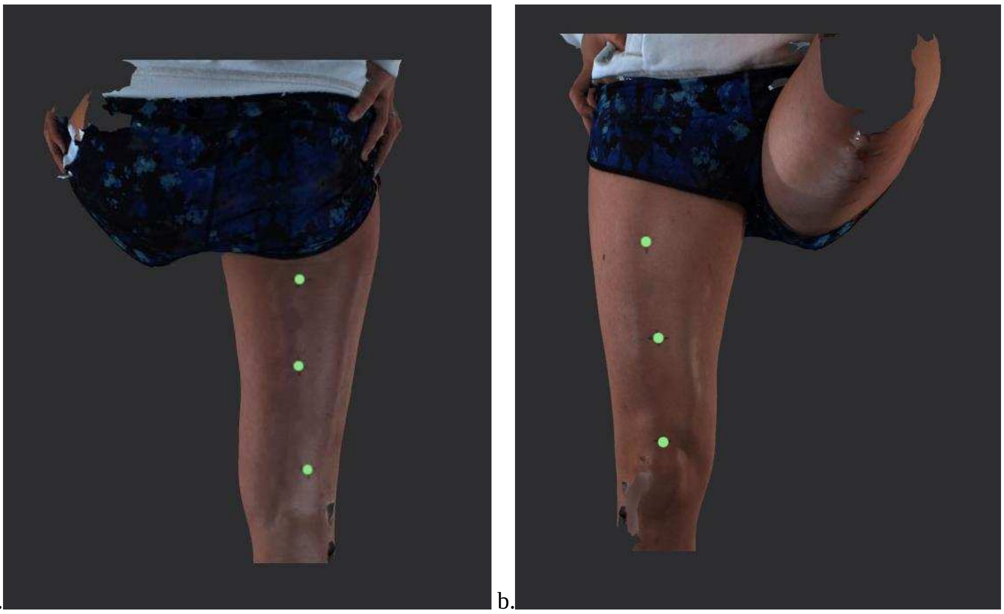
To define the upper leg as outlined above and to facilitate the extraction of anthropometrics from the correct location, six anatomical landmarks (Figure 4.2) of the right leg were used:

- The midpoint of the superior border of the patella (Stewart et al., 2011, p. 46).
- The level of the midpoint of the superior border of the patella (Stewart et al.,

2011, p. 46) on the posterior of the upper leg.

- The point equidistant from Trochanterion and Tibiale Laterale (Stewart et al., 2011, p. 84) on the anterior of the upper leg.
- The point equidistant from Trochanterion and Tibiale Laterale (Stewart et al., 2011, p. 84) on the posterior of the upper leg.
- 1 cm distal to the gluteal fold site - perpendicular to the long axis (Stewart et al., 2011, p. 85).
- 1 cm distal to the gluteal fold site - perpendicular to the long axis (Stewart et al., 2011, p. 85) on the anterior of the upper leg.

These locations were manually palpated and identified by a level one ISAK kinanthropometrist (the author) and marked using coloured markers 0.8 cm in diameter (Figure 4.2) to ensure correct identification of the anatomical landmarks in the 3D images. The same level one ISAK kinanthropometrist performed this procedure across all participants.



a. b.

Figure 4.2: The anatomical landmarks marked on the a) anterior and b) posterior of the right upper leg.

Experimental protocol

To allow the collection of 3D images of the right upper leg participants stood on their right leg, with their arms raised above their hips (Figure 4.3). The left leg was raised and placed on a higher platform to avoid occlusion by the contralateral limb. The position was adopted on a raised platform to ensure that participants' right upper leg was placed within the centre of the calibrated volume. Participants were asked to remain relaxed in accordance with ISAK guidelines (Stewart et al., 2011).

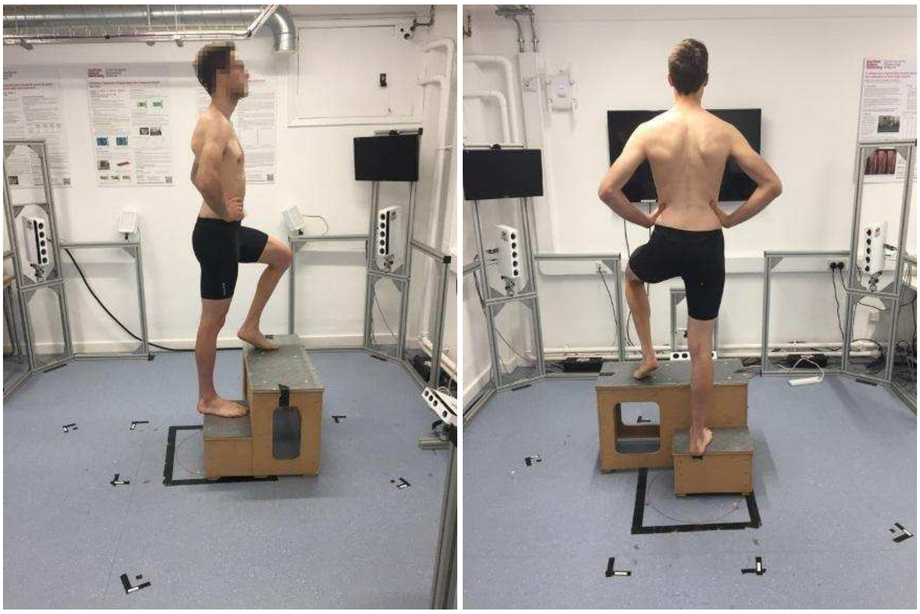


Figure 4.3: Participant position.

To minimise postural sway; the deviation in the position of the centre of pressure on the supporting surface (Ku et al., 2014), all participants were asked to visually focus on small circular coloured wall mounted markers. As focusing gaze on a stationary target during standing reduces postural sway (Ustinova & Perkins, 2011; Thaler et al., 2013). Several investigations have suggested the use of physical support or light touch stabilisation methods to minimise postural sway (Lackner et al., 2001; Kouzaki & Masani, 2008). However, physical support was not provided within the investigations of this thesis conducted due to its obstruction of multiple cameras views and the impracticality of ceiling mounted supports. Due to the quick capture duration (1.5 ms) the absence of physical support was deemed acceptable.

Manual measurement

Manual measurements were included as the comparative measurement method within this investigation. All manual measurements were acquired by a level one accredited ISAK kinanthropometrist (the author) using a metal anthropometric tape measure (Lufkin Executive Thinline 2 m, W606PM), and adhered to ISAK guidelines (Stewart et al., 2011). Three girths of the right upper leg were acquired: upper thigh girth, mid-thigh girth and knee girth, based upon the definitions detailed in Table 4.2. Each girth was collected three times to prevent outliers, and in adherence to ISAK guidelines (Stewart et al., 2011). Upon collection all values were inputted into Microsoft Excel (Microsoft Office 2011, Microsoft Corporation, USA).

Table 4.2: The definition and measurement method of each anthropometric.

Measurement method	Anthropometric		Description
Manual; 3dMDbody5	Girth	Upper-thigh girth	Girth of the Upper-thigh at 1 cm distal to the gluteal fold site - perpendicular to the long axis (Stewart et al., 2011, p. 85)
Manual; 3dMDbody5	Girth	Mid-thigh girth	Girth of the upper-thigh about the point equidistant from Trochanterion and Tibiale Laterale.
Manual; 3dMDbody5	Girth	Knee girth	Girth of the knee at the midpoint of the posterior superior border of the patella (Stewart et al., 2011, p. 46)..
3dMDbody5	CSA	Upper-thigh CSA	CSA of the Upper-thigh at 1 cm distal to the gluteal fold site - perpendicular to the long axis.
3dMDbody5	CSA	Mid-thigh CSA	CSA of the upper-thigh about the point equidistant from Trochanterion and Tibiale Laterale.
3dMDbody5	CSA	Knee CSA	CSA of the knee at the midpoint of the posterior superior border of the patella.
3dMDbody5	Volume	Upper leg volume	Volume encompassed between the upper thigh (the 1 cm distal to the medial aspect of the gluteal (Stewart et al., 2011, p. 85) and the midpoint of the superior border of the patella (Stewart et al., 2011, p. 46)
3dMDbody5	Surface area	Upper leg surface area	Surface area surrounding the volume encompassed between the upper thigh (the 1 cm distal to the medial aspect of the gluteal (Stewart et al., 2011, p. 85) and the midpoint of the superior border of the patella (Stewart et al., 2011, p. 46).

Only girth anthropometrics were collected manually for comparison with the 3dMDbody5 system. This was because, as outlined in Section 2.4, manual measurement relies on population-specific predictive equations to estimate complex anthropometrics, of which are only correctly used when applied to the group of which the formula was based upon (Karges et al., 2003; Mayrovitz et al., 2007; Mathur et al., 2008). Furthermore, although the agreement between the 3dMDbody5 system and manual measurement in extracting complex anthropometrics is of interest, as the subsequent investigations of this thesis will not interchange between measurement methods, it is the repeatability of the system in the measurement of complex anthropometrics that is of paramount importance.

3dMDbody5

3dMDbody5, a commercially available 360° hybrid stereo photogrammetry surface imaging system, as described in Section 3.0, was used to collect the 3D images. The configuration and calibration procedure of the 3dMDbody5 system followed the manufacturer's guidelines, as detailed in Section 3.2. Data were collected in three sets; each set consisted of three scans of the right upper leg, separated by a recalibration of the system. Thus, a total of nine scans were acquired for each participant. All 3D images were post processed within KinAnthroScan, following the same process as that detailed in Section 3.2.2. Based upon the calculations outlined in Section 3.2.2 girth was collected every 2 mm along the long axis of the segment. In addition, cross sectional area, volume and surface area anthropometrics were exported, as listed in Table 4.2. These were calculated as followed:

Cross sectional area

Continuing on from the processes conducted to export girth, as detailed in Section 3.2.2, cross sectional area was calculated by fitting a series of triangles to the 2D coordinate system of each slice; their vertices were located in the centre of the splined data points and bounded by the spline itself - two successive points on the fitted spline, Figure 4.4. The area of the triangles were then calculated and summed to estimate cross sectional area.

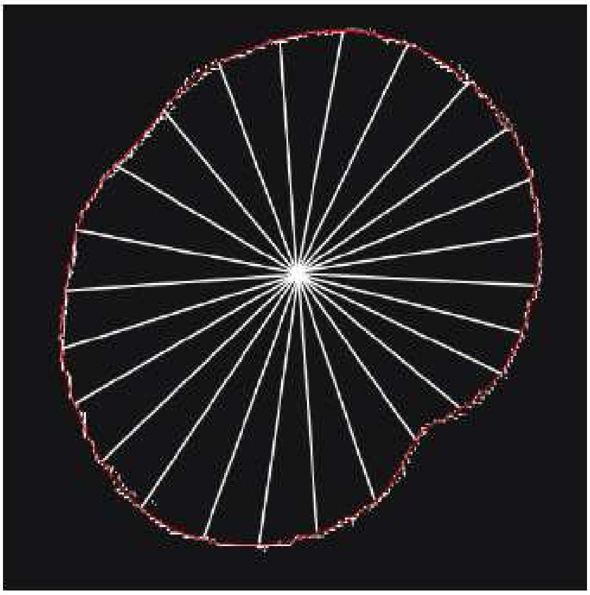


Figure 4.4: CSA calculation within KinAnthroScan (Clarkson, 2015).

Volume

To calculate volume, each CSA was multiplied by the height of each slice - the Y component disregarded in the calculation of the girth hereinabove. This was then summed to create the estimated volume of the segment following Crisco & Mcgovern

(1998) method based upon Green's theorem (Wrede, 2010).

Surface area

To calculate surface area, the estimated girth for each slice was multiplied by the height of each slice - the Y component disregarded in the calculation of the girth hereinabove. This was then summed to create the estimated surface area of the segment.

All anthropometrics exported from the 3dMDbody5 system were collated in Microsoft Excel (Microsoft Office 2011, Microsoft Corporation, USA) alongside all manually acquired girths.

4.2.3 Analysis

For both methods and all anthropometrics, the mean and standard deviation were calculated. To ensure the selection of suitable statistical analysis procedures the parametric nature of the data were first explored. A Shapiro-Wilks and Levene's test for equality of variance were conducted to determine the normality and homogeneity of variance, respectively, within SPSS (IBM SPSS Statistics 24.0). A series of paired t-tests and Pearson's correlation tests were then conducted within SPSS (IBM SPSS Statistics 24.0) to determine the significance of any differences or correlations, between methods, calibrations and sexes.

Agreement

The absolute and relative mean differences and standard deviations between girths acquired manually and using the 3dMDbody5 system were calculated within Microsoft Excel (Microsoft Office 2011, Microsoft Corporation, USA). To explore the nature of any differences Bland-Altman and ordinary least products regression (OLP) analyses were conducted using the manual measurement method data (x) and the first calibration set of the 3dMDbody5 data (y). Following the guidelines of Bland & Altman (1999) and Ludbrook, (2010), Bland-Altman plots were created within Microsoft Excel. Linear regression was then conducted, using the Data Analysis tool within Microsoft Excel, to determine the significance of any bias. Following the guidelines of Ludbrook (1997, 2012) OLP plots were created in Microsoft Excel. The OLP slope, intercept and 95% confidence intervals were calculated in MATLAB (version 13.0b, MathWorks, USA) using gmregress (Trujillo-Ortiz & Hernandez-Walls, 2010). Linear regression was then conducted for both the Bland-Altman and OLP analysis, using the Data Analysis tool within Microsoft Excel, to determine the significance of any bias.

Repeatability

To explore the repeatability of the measurement methods relative and absolute intra-calibration TEM were calculated for each anthropometric, calibration set and method, using all measures, following the guidelines of Ulijaszek & Kerr (1999) (Section 2.4.1). Relative and absolute inter-calibration TEM and total TEM, was calculated using the method outlined in Section 2.4.1. To explore the MDC detectable by the 3dMDbody5 system the reliable change index was calculated for each anthropometric using Equation 13 and Equation 14, as reported in Section 2.4.2.

4.3 Results

The female and male data did not demonstrate statistically significant differences ($p > 0.05$) in either absolute size or the degree of agreement between the systems. Consequently, the results from each sex are presented together.

4.3.1 Agreement

Across all girths, manual measurement and 3dMDbody5 system (first calibration set) demonstrated a statistically significant ($p > 0.05$) difference of -0.45 ± 1.43 % (-0.27 ± 0.8 cm) (Table 4.3), yet a strong positive correlation ($r = 0.997$, $p < 0.01$). Exploration of these differences revealed the 3dMDbody5 system to produce slightly larger girths than manual measurement.

Table 4.3: the mean and standard deviation for each girth measurement for each measurement method, alongside the mean and standard deviation of the differences between the two methods.

Measurement method		Girth		
		Upper thigh	Mid-thigh	Knee
Manual (mm)		582.6 ± 59.6	544.3 ± 56.2	395.9 ± 34.9
3dMDbody5 (mm)		589.7 ± 62.8	545.0 ± 59.0	396.5 ± 37.0
Mean difference	Raw (mm)	-7.1 ± 9.0	-0.7 ± 6.8	-0.6 ± 5.2
	Absolute (%)	-11.8 ± 15.1	-0.8 ± 11.9	-1.2 ± 13.0

Analysis of the Bland-Altman plot (Figure 4.6) suggests that the hypothesis a’ = 0 (no fixed bias between the methods) is rejected because the intercept (a’) $p < 0.05$, and that the hypothesis b’ = 0 (no proportional bias between the methods) is rejected because the slope (b’) $p < 0.05$. Furthermore, analysis of the OLP plot (Figure 4.6) suggests that the hypothesis a' = 0 (no fixed bias between the methods) is rejected because a' < 0 and the 95% confidence interval for a' does not include zero, and that the hypothesis b' = 1 (no proportional bias between the methods) is rejected because b' > 1 and the 95% confidence interval for b' does not include one. Consequently, both the Bland-Altman and OLP analysis (Figure 4.5 and Figure 4.6 respectively) demonstrate statistically significant, yet small, negative fixed bias alongside statistically significant, yet small, positive proportional bias. Further examination of the OLP plot suggests that the manual measurement method overestimates in comparison to the 3dMDbody5 system at smaller girths. However, this difference progressively decreases at larger girths, at which the manual measurement method underestimates in comparison to the 3dMDbody5 system.

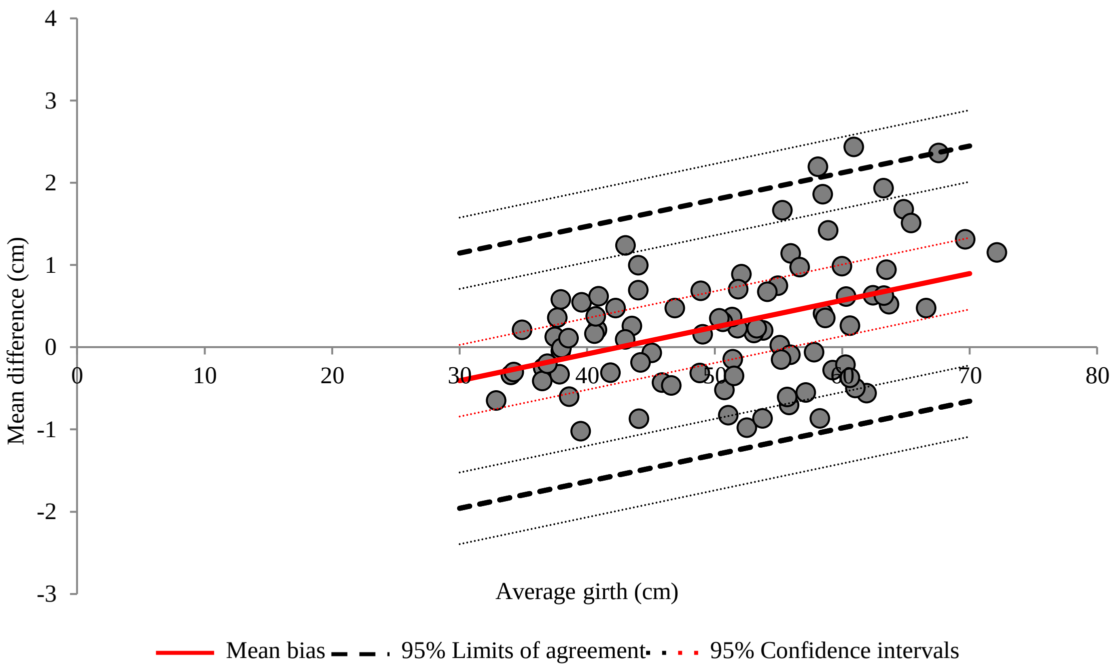


Figure 4.5: Bland–Altman plot of average girth (cm) against mean difference between the two methods (cm) (Correlation $R^2 = 0.42$, $p \leq 0.00$. Slope b' = 0.03, $p \leq 0.001$. Intercept a' = -1.40, $p \leq 0.001$. 95% Limits of Agreement = -1.27, 1.83)

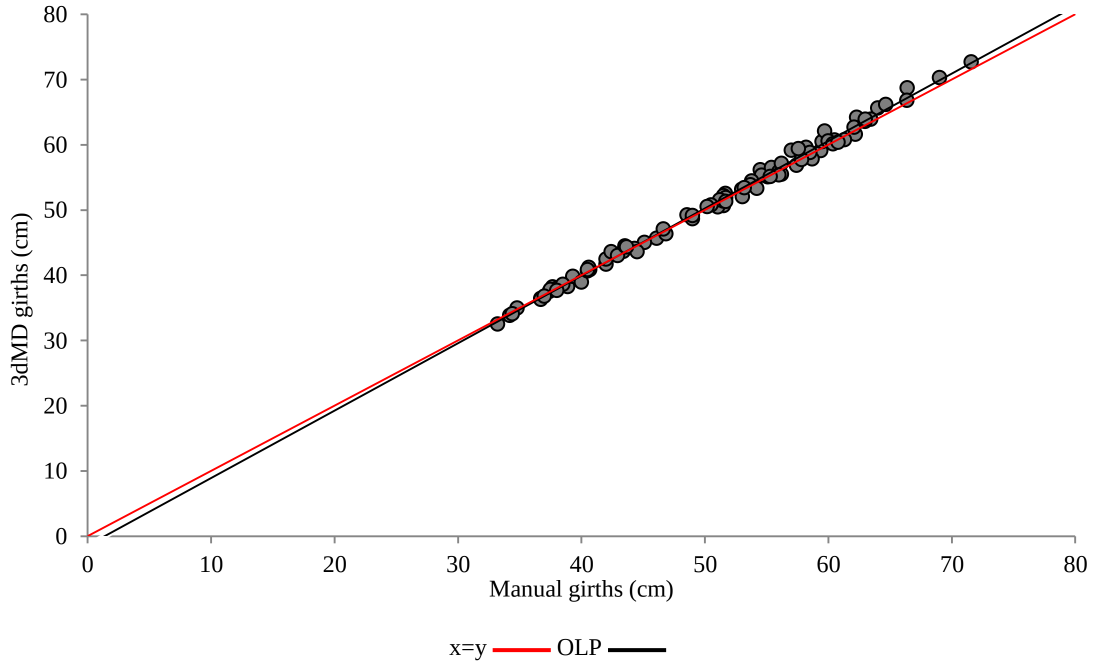


Figure 4.6: OLP plot of mean girth (Intercept a' = -1.40, Confidence Intervals = -0.61 - -2.20. Slope b' = 1.03, Confidence Intervals = 1.02 - 1.05)

4.3.2 Repeatability

Manually acquired girths demonstrated intra-observer TEM of 0.05%; 0.05%, 0.08% and 0.05% for knee girth, mid-thigh girth and upper thigh girth respectively.

Across all anthropometrics and calibration sets, the 3dMDbody5 system demonstrated TEM $\leq$ 0.22% (Table 4.4). Neither method demonstrated significant differences between intra or inter-calibration sets (p>0.05). The 3dMDbody5 system demonstrated a MDC of 0.67 cm for girths, 0.48 cm^2 for cross sectional areas, 67.85 ml for volumes and 0.99 cm^2 for surface areas.

Table 4.4: Intra calibration, Inter calibration and total TEM, absolute (Abs.) and relative (%) for each anthropometric.

TEM		Girths (cm)				CSA (cm^2)				Volumes (ml)	Surface Area (cm^2)
		Upper thigh	Mid-thigh	Knee	All	Upper thigh	Mid-thigh	Knee	All		
Intra calibration	Abs.	0.03 ± 0.02	0.03 ± 0.00	0.02 ± 0.01	0.02 ± 0.01	0.06 ± 0.04	0.02 ± 0.01	0.03± 0.02	0.02 ± 0.01	4.22 ± 1.99	0.05 ± 0.01
	%	0.05 ± 0.02	0.05 ± 0.00	0.05 ± 0.02	0.04 ± 0.01	0.22 ± 0.13	0.08 ± 0.03	0.24 ± 0.19	0.08 ± 0.05	0.09 ± 0.04	0.05 ± 0.01
Inter calibration	Abs.	0.48	0.28	0.20	0.34	0.37	0.19	0.13	0.25	34.84	0.51
	%	0.82	0.51	0.51	0.67	1.32	0.79	1.02	1.16	0.77	0.45
Total	Abs.	0.49	0.28	0.20	0.34	0.37	0.19	0.13	0.25	35.67	0.51
	%	0.82	0.52	0.52	0.72	1.33	0.80	1.05	1.19	0.94	0.55

4.4 Discussion

The aim of this investigation was to determine the suitability of the 3dMDBody5 system as a method of body measurement in kinanthropometric applications, using human participants. Thirty recreationally active volunteers had girths of their upper right leg measured manually and by the 3dMDbody5 system. Overall, the 3dMDbody5 system demonstrated high, intra and inter-calibration, repeatability alongside strong agreement with manual measurement methods.

4.4.1 Agreement

The results of this investigation demonstrate that overall the 3dMDbody5 system produced slightly larger girths, by 0.45 ± 1.43% (0.27 ± 0.8 cm), in comparison to manual measured girths. Examination of the OLP analysis suggests that the manual measurement method overestimates in comparison to the 3dMD system at smaller girths. However, this difference progressively decreases at larger girths, at which the manual measurement method underestimates in comparison to the 3dMD system. As discussed in Section 3.4.1, previous unpublished work has demonstrated little difference in the anthropometrics exported from KinAnthroScan and Geomagic Studio 8 (Raindrop Geomagic, USA), thus it is unlikely that the differences are attributable to the analysis software. Furthermore, as measurement locations were marked directly onto participants' skin it is unlikely that differences are attributable to differing measurement locations. Therefore, it is most likely that the differences demonstrated within this investigation are attributable to hardware, the calibration technique and / or the manual measurement method. However, as both methods are subject to error it is unclear to what extent each method contributes to this difference.

There are several potential explanations for the differences demonstrated. As Chapter Three demonstrated the 3dMDbody5 system to underestimate by 0.6% when measuring cylinders of known dimensions, it is unlikely that all error is attributable to the manual method measurement alone. Furthermore, as it is anticipated the magnitude of error to be greater than that reported in Chapter Three due to the measurement of human participants as opposed to cylinders, it is unlikely that the manual measurement method is underestimating and 3dMBbody5 system is correct or that 3dMDbody5 system is overestimating and that the manual measurement method is correct. It appears most probable that both methods are underestimating. Based on the critique of manual measurement in Section 2.4.1, it is possible that manual measurement is underestimating due to human error - potentially over tightening of the tape measure. However, irrespective of the source of the differences, it is worthwhile to note that the difference demonstrated between these methods is small in magnitude.

As outlined in Section 2.4.2, the ISO 20685-1 standard (ISO, 2010) defines the acceptable magnitude of error for body measurements from 3D imaging systems when measuring humans in comparison to manual measurement methods; 95% confidence interval of ± 0.8 cm and ± 0.4 cm for large and small girths respectively. The error demonstrated within this investigation falls within the requirements of the ISO 20685-1 standards (ISO, 2010). Consequently, based upon these standards 3dMDbody5 is adequate for use as a method of body measurement within kinanthropometric applications. However, as the subsequent investigations of this thesis will not interchange between measurement methods, it is the repeatability of the system that is of paramount importance.

4.4.2 Repeatability

The 3dMDbody5 system demonstrated excellent intra-calibration repeatability in girth anthropometrics, comparable to manual measurement; intra-calibration TEM of 0.05 ± 0.01% and 0.05% respectively. Furthermore, the 3dMDbody5 system demonstrated excellent intra-calibration repeatability across all anthropometrics, alongside high relative inter-calibration TEM. As outlined in Section 2.4.1, ISAK standards require the most experienced (level 4) ISAK anthropometrists to demonstrate intra-calibration and inter-calibration TEM for girths of < 1.0% (Sutton & Stewart, 2012). The repeatability demonstrated within this investigation falls within the requirements of an ISAK level 4 anthropometrist for both measurement methods. Therefore, based upon the ISAK standards 3dMDbody5 is adequately comparable to manual measurement for the acquisition of girth anthropometrics. Furthermore, although at present no ISAK TEM threshold is available for complex anthropometrics - as discussed in Section 2.4.1, all TEM reported within this investigation for cross sectional, volume and surface area anthropometrics also fall within the requirements of an ISAK level 4 anthropometrist.

As discussed previously in Section 2.4.2, alongside meeting established industry standards, a measurement method is deemed suitable if it is able to detect change or differences of importance. The MDC, as detailed in Section 2.4.2, is the smallest magnitude of change or differences detectable by a measurement method (Haley &

Fragala-Pinkham, 2006) . The results of this study suggest that the 3dMDbody5 system demonstrates a MDC of 0.67 cm for girths, 0.48 cm^2 for cross sectional areas, 67.85 ml for volumes and 0.99 cm^2 for surface areas. This suggests that the 3dMDbody5 system would be able to detect change greater than these values, i.e. change or differences identified that exceeded these values could be regarded as true change - not attributable to the variation within the system. However, to the researcher's knowledge, no study has investigated the MDC necessary for anthropometric methods. As a result, as discussed in Section 3.4.2, although the results of this study fall within the recommended limits of established industry standards, it is difficult to determine with confidence if the accuracy and repeatability reported by this investigation is sufficient to allow the measurement and detection of true change, or if this would be masked by the system's variability when used within kinanthropometric investigations.

4.4.3 Limitations

This study has limitations that require consideration. As this investigation focused on comparing the 3dMDbody5 system with manual measurement, examination of agreement focused solely on girths, the results of this investigation can only suggest that the 3dMDbody5 system might be suitable for extracting other simple and complex anthropometrics in kinanthropometric applications. Furthermore, as this investigation only captured the upper leg of human participants it is unclear if the degree of agreement and repeatability demonstrated within this investigation would be consistent when measuring other body segments. Consequently, further research would be necessary to confirm this.

4.5 Conclusions

The results of this investigation suggest that the 3dMDbody5 demonstrates sufficient agreement and repeatability to adhere to established industry standards. Consequently, it can be suggested that 3dMDbody5 is a suitable method of body measurement within kinanthropometric applications. Future investigations should consider the use of the 3dMDBody5 system for use as a method of body measurement in kinanthropometric applications, considering change or differences greater than 0.67 cm in girths, 0.48 cm^2 in cross sectional areas, 67.85 ml in volumes and 0.99 cm^2 in surface areas to be true change - not attributable to the systems variability.

Chapter 5 - Methods

5.1 Introduction

Chapter Two highlighted the need for research into the importance of complex anthropometrics in the kinanthropometric assessment of cyclists, and the suitability of stereo photogrammetry based surface imaging system as a method of anthropometrics acquisition. Chapter Three and Four demonstrated that the 3dMDbody5 imaging system was accurate and repeatable, and therefore a suitable method of body measurement within kinanthropometric applications. This chapter presents the methods using the 3dMDbody5 imaging system that remained consistent throughout the subsequent investigations of this programme of research. This chapter is divided into three sections. The first section outlines the participant information that was consistent throughout the studies of this thesis; age, health, sex, expertise and clothing. The second section details the body measurement protocol, primarily the landmarking and measurement methods. The third section provides a description of the experimental method used to collect 3D images, and outlines the post-processing of the 3D images and handling of the data exported through this process.

5.2 Participant information

Within the subsequent investigations of this programme of research all volunteers that participated in the investigations of this thesis were recruited through convenience sampling. This was achieved through email communications, advertisement at cycling events within the Yorkshire region, social media sites (e.g. Twitter and Facebook), cycling companies, and online articles. For each cycling discipline, data collection occurred during peak season to minimise variability in anthropometrics due to seasonal variations. At the time of testing all volunteers were required to meet the criteria outlined below. To acquire this information all participants completed a consent form, screening form and a cycling and physical activity background questionnaire prior to participation. These are presented alongside the ethical approval for each investigation within the appendices.

5.2.1 Sex

As outlined in Section 2.1.1, if an anthropometric profile for a sporting population group exists, it is most easily identified by assessing the most elite athletes from developed sports (Norton et al., 2002). Although in recent years gender equality in cycling has substantially improved there still are considerable disparities and women's cycling remains less developed than men's cycling (Pfister, 2010; McLachlan, 2016; Oosterhuis, 2016). Consequently, it was deemed most suitable to investigate the anthropometric profiles of male cyclists. Therefore only male cyclists were recruited.

5.3.2 Age

Ageing significantly influences cycling performance (Grassi et al., 1991; Balmer et al., 2005), and thereby potentially the anthropometrics of cyclists. To control for the effects of aging, all participants (cyclists and non-cyclists) were required to be aged 18 - 45 years. The lower age boundary of 18 years was used to ensure all participants were post pubescent and thereby had ceased long bone growth, to reduce the risk of errors within the data set due to growth variations. After the age of 30 years, cycling performance is believed to decline due a reduction in peak power (Balmer et al., 2005). Although the exact mechanisms for this reduction in peak power remains unclear, before the age of 45 years the deterioration is predominantly attributable to reversible factors, such as a reduction in physical activity, and that after the age of 45 years, deterioration is predominantly attributable to irreversible factors, such as a reduction in lean muscle mass (Grassi et al., 1991). Thus, all participants recruited were no older than 45 years.

5.3.3 Health

All participants were required to disclose any health issues before participation. Furthermore, all participants were required to be free from and have never experienced any disease or illness that may have influenced physical growth / development, be able to stand unaided and have never experienced any major lower limb trauma. These criteria assisted in ensuring participants' safety during data collection and preventing anomalies within the anthropometric data-set due to current or previous health conditions or previous medical treatments.

5.2.4 Experience & expertise

Cyclists

As outlined in Section 2.1.1 and Section 5.2.1, if an anthropometric profile for a sporting population group exists, it is most easily identified by assessing the most elite athletes from developed sports (Norton et al., 2002). Consequently, all participants were required to be competing at, at least, regional events, and have been doing so for a minimum of 2 years. All cyclists recruited were required to score 1+ on the Swann et al., (2014) categorisation model reported in Section 2.1.1. Ideally recruitment would solely be of world-class athletes. However, as data collection for this thesis occurred during peak season, access to successful-elite and world-class elite cyclists was limited, a common limitation of elite sport based research. Consequently, the majority of the cyclists recruited for this these were semi / competitive elite. The categorisation model by Swann et al., (2014) was deemed the most suitable for use within this thesis as it requires within sports comparisons, between sports comparisons and the categorisation of expertise without the need for physical screening.

Non-cyclists

All non-cyclists were required to be recreational active; scoring 'moderate' to 'high' on the international physical activity questionnaire (IPAQ) (IPAQ, 2002), to prevent anomalies in the anthropometric data set due to physical inactivity. The degree to which ex-athletes retain elite traits following the cessation of elite performance remains unclear (Smith & McManus, 2009). As such all non-cyclists were required to also have never competed or trained in cycling at an elite level and have not competed or trained in any sport at an elite level in the last ten years.

5.3 Body measurement

As reported in Section 2.3.1, both the upper and lower body contribute to cycling performance. However, it is predominantly the lower body that is responsible for force production (Canivel, Wyatt & Baker, 2012) and thus it is believed to hold the strongest relationship with anthropometrics. Consequently, as the lower body was deemed more important within this context, the subsequent investigations explore only lower body anthropometrics.

5.3.1 Clothing

During body measurement clothing and footwear were standardised for all participants. Identical to Section 4.2.1, all participants were required to wear non-compressive form fitting shorts (that extended no further than the mid-thigh), a shirt of their own choice and no socks.

5.3.2 Landmarking

The lower leg was defined at the region defined by the epicondyles of the knee and that of the ankle (Figure 5.1). The upper leg was defined as the area encompassed between the medial aspect of the gluteal fold and epicondyles of the knee (Figure 5.1).

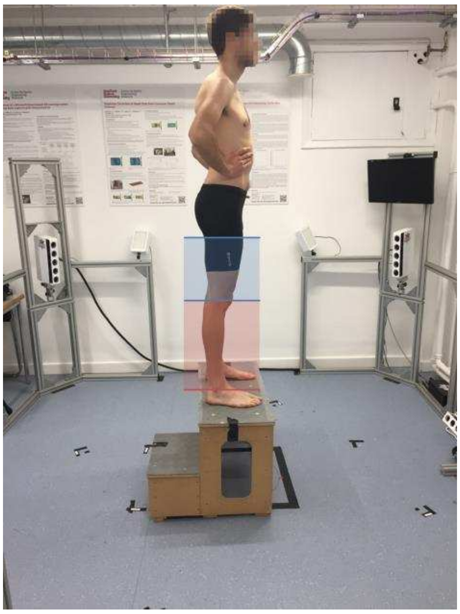


Figure 5.1: The segmented regions of interest: upper leg, lower leg.

To define the lower body as outlined above and to facilitate the extraction of anthropometrics from the correct location, ten anatomical landmarks (Figure 22), five per leg were used:

- The inferior aspect of the distal tip of the lateral malleolus.
- The inferior aspect of the distal tip of the medial malleolus (Stewart et al., 2011, p. 49).
- The most superior point on the medial border of the head of the tibia (Stewart et al., 2011, p. 48).
- The most superior point on the lateral border of the head of the tibia (Stewart et al., 2011, p. 43).
- The gluteal fold; the horizontal crease formed by the inferior aspect of the buttocks and the posterior aspect of the thigh.

Figure 5.2: Images of marked landmarks.

These locations were manually palpated and identified by a level one ISAK kinanthropometrist (the author) and marked using coloured markers 0.8 cm in diameter, as illustrated in Figure 5.2, to ensure correct identification of the anatomical landmarks in the 3D images. The same level one ISAK kinanthropometrist performed this procedure across all participants and studies in this program of research.

As discussed in Section 2.1.1, anthropometrics are typically only acquired from the right-hand side of the body irrespective of the preferred side of the participant, unless considered impractical (e.g. due to injury) (Stewart et al., 2011), because the bias associated with side preference / dominance is believed to be less than manual measurement error (Martorell et al., 1988; Moreno et al., 2002). However, as cycling is predominantly a bilateral sport, it was hypothesised that the degree of symmetry demonstrated by cyclists may be one of the anthropometric traits that distinguish cyclists from non-cyclists. Therefore, 3D images of both the dominant and non-dominant legs were collected.

5.3.2 Measurement systems

Participant's standing stature and body mass were acquired using a stadiometer (Leicester, Seca Vogel, Germany) and digital scales (Weight Watchers Limited, UK), respectively, in adherence to ISAK guidelines (Stewart et al., 2011). 3dMDbody5 was the stereo photogrammetry surface imaging system used within the subsequent investigations of this programme of research, identical to that validated within Chapter Three and Four. The configuration and calibration procedure of the 3dMDbody5 system followed the manufacturer's guidelines, as detailed in Section 3.2.

5.3.3 Experimental protocol

Each anthropometric data collection lasted approximately 20 minutes. To ensure the collection of 360° images of the lower and upper legs of both the right and left sides, and avoid occlusion by the contralateral limb participants were asked to adopt three positions. To allow the collection of 3D images of the lower leg, participants stood with feet shoulder distance apart with their arms placed on their hips (Figure 5.3), whilst ensuring the body segment of interest remained vertical to 3dMDbody5's coordinate system. To allow the collection of 3D images of the upper legs participants stood on one leg, with their arms raised above their hips (Figure 4.3), identical to Chapter Four. The second leg was raised and placed on a higher platform to avoid occlusion by the contralateral limb. This position was adopted on each side. All positions were adopted on a raised platform to ensure that participants' body segments were placed within the centre of the calibrated volume. Participants were asked to remain relaxed in accordance with Stewart et al., (2011) guidelines. All participants were asked to visually focus on small circular coloured wall mounted markers, as previously conducted within Chapter Four, to minimise postural sway; the deviation in the position of the centre of pressure on the supporting surface, identical to chapter Four. Physical support was not provided within these investigations for the reason detailed in Section 4.2.2.

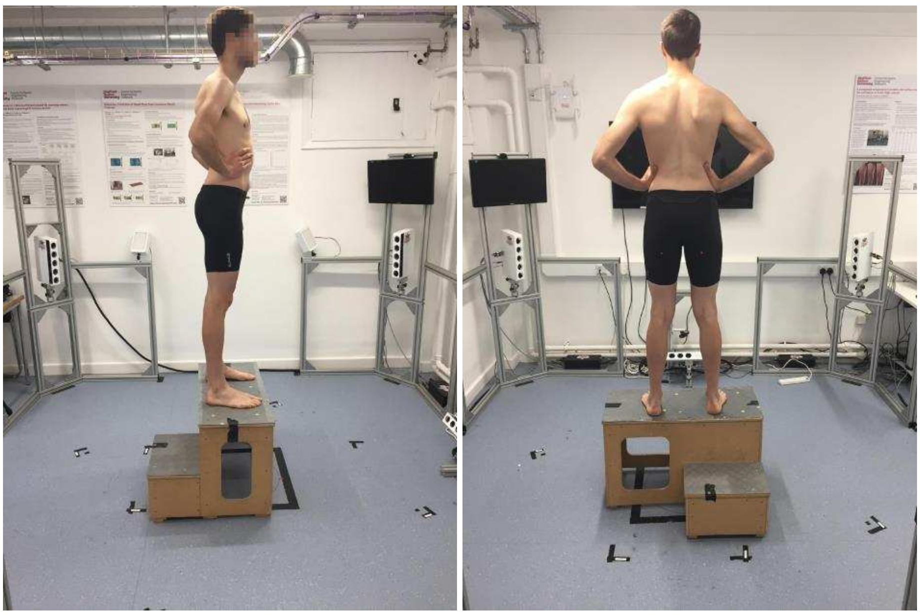


Figure 5.3: Participant position for capture of 3D images of the lower legs.

One 3D image of each position was collected, resulting in a total of three 3D images per participant, due to the high level of repeatability of the 3dMDbody5 system reported in

Chapter Three and Four.

5.3.4 Post processing of 3D images.

KinAnthroScan, as detailed in Section 3.2.2 facilitated the post processing of all 3D images. Each 3D image was manually digitised: manual identification of the marked anatomical landmarks by a single researcher by clicking directly on each manually marked point. Once completed, KinAnthroScan returned a set of 3D coordinates for these marked anatomical landmarks. These digitised points defined the boundaries of the body segment and were used to apply segmentation planes to isolate the regions of interest (Figure 5.4).

To process lower leg 3D images two proximal and two distal points were used to create the upper and lower boundaries; medial and lateral epicondyles of the knee and the medial and lateral epicondyles of the ankle respectively, as detailed in Section 5.3.2. The anterior posterior angles of the planes were presumed to be horizontal to the capture system's global coordinate system. However, due to practical difficulties in locating two proximal anatomical locations in line with the gluteal fold a separate segmentation techniques was necessary for the upper leg. To process upper leg 3D images three distal points and one proximal point were used to create the upper and lower boundaries; the medial and lateral epicondyles of the knee, and the gluteal fold respectively, as detailed in Section 5.3.2. The midpoint marker between the medial and lateral epicondyles of the knee determined pitch of the plane. Each 3D image was visually inspected to ensure the applied planes laid horizontally to the segment.

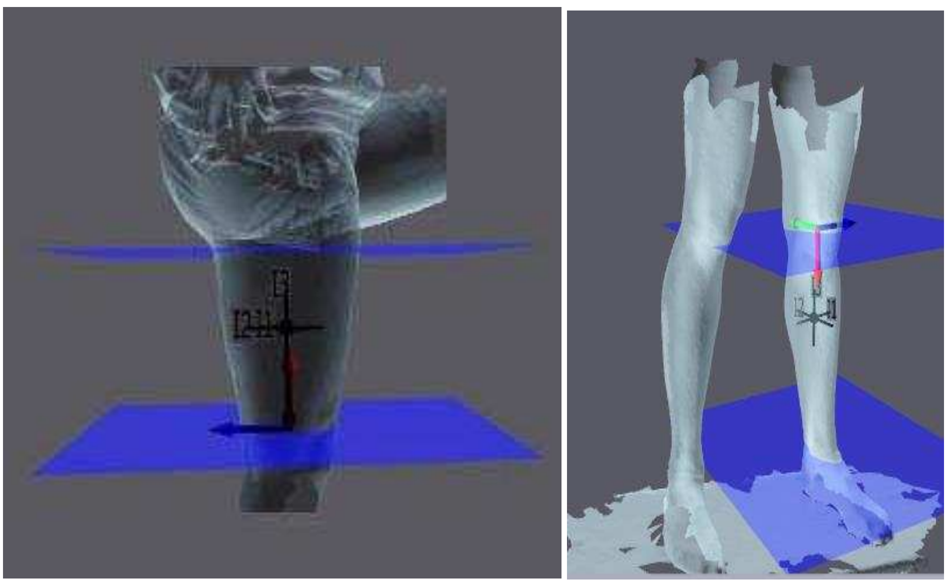


Figure 5.4: Segmentation of the 3D images within KinAnthroScan.

The anthropometrics exported from KinAnthroScan were calculated using the methods outlined in Section 3.2.2 for girth anthropometrics and in Section 4.2.2 for cross sectional area, volume and surface anthropometrics. The length of a segment was calculated as the distance between the centre points of the digitised points. For the lower leg it was calculated as the distance between the centre points of the medial and lateral epicondyles of the knee and the centre points of the medial and lateral epicondyles of the ankle. For the upper leg it was calculated as the distance from the centre points of the medial and lateral epicondyles of the knee up to in line with the gluteal fold.

Based upon these calculations, 10 anthropometrics for each leg were exported from KinAnthroScan:

- Lower leg length
- Upper leg length
- Lower leg girth every 2 mm
- Upper leg girth every 2 mm
- Lower leg CSA every 2 mm
- Upper leg CSA every 2 mm
- Lower leg volume
- Upper leg volume
- Lower leg surface area
- Upper leg surface area

From these 10 anthropometrics, 48 anthropometrics were extracted for analysis (21 simple, 27 complex); 32 size anthropometrics (16 per side) and 16 symmetry anthropometrics (normalised differences between sides) (Table 5.1). A normalised measure of absolute (ABS) symmetry was used, using measurements of both the dominant (m_D) and non-dominant sides (m_{ND}) (Equation 5.1). This allowed easier comparison between groups and eliminated the effect of body size.

Equation 5.1

$$S = \frac{(ABS(m_D - m_{ND}))}{(m_D/100)}$$

There is limited literature exploring measurement methods of, or using, anthropometric symmetry in the kinanthropometric assessment of athletes. However, there are many investigations that explore anthropometric symmetry in different research contexts, such as beauty and attractiveness (Singh, 1995; Rikowski & Grammer, 1999; Havlíček et al., 2017) and, growth and development (Hodges-Simeon et al., 2016). It is possible that the sparseness of literature on anthropometric symmetry in sport is attributed to standardised guidelines such as ISAK, in which anthropometrics are typically only acquired from the right-hand side of the body irrespective of the preferred side of the subject, unless considered impractical (e.g. due to injury) (Stewart et al., 2011), as previously discussed in Section 2.4.1.

A list of all 48 anthropometrics, alongside their definitions, is located in Appendix Two. Although the majority of anthropometrics adhered to traditional guidelines and previous investigations when possible, a few differences are worth noting. Mainly, as the greater trochanter of many participants fell outside of the capture volume calculation of the mid-thigh based upon ISAK guidelines was not suitable. As such the mid-thigh was taken as the middle of the thigh segment, bounded by the epicondyles of the knee and gluteal fold.

Once exported, these 48 anthropometrics were collated into Microsoft Excel (Microsoft Office Professional Plus 2010, Microsoft Corporation, Redmond, USA) alongside all manually acquired measures (stature and body mass) and data acquired from the participant pre exercise screening form and participant cycling and physical activity background questionnaire. All data were stratified based on self-reported cycling experience and by side dominance, collected through the participants' cycling background questionnaires. When participants were either unaware of, or did not believe they exhibited, a dominant side the largest size, based on the anthropometric measures was labelled as the dominant side, due to the expected greater muscle growth on the dominant side. If the anthropometric measures demonstrated did not highlight a dominant side, then the dominant side was considered as the same side as the dominant hand, due to the strong correlation between handedness and footedness (Coren et al., 1981; Augustyn & Peters, 1986; Nicholls et al., 2013). Similar to previous studies (Schranz et al., 2010) all anthropometrics ± 2 standard deviations away from the respective group mean were re-measured.

Table 5.1: Exported anthropometrics.
D=dominant, ND=non-dominant, SA=surface area.

No.	Simple / Complex	Size / Symmetry	Dimension type	Measurement	Unit
1	Simple	Size	Length	D lower leg length	cm
2	Simple	Size	Girth	D calf girth	cm
3	Complex	Size	Area	D calf CSA	m^2
4	Simple	Size	Girth	D ankle girth	cm
5	Complex	Size	Area	D ankle CSA	m^2
6	Complex	Size	Volume	D lower leg volume	ml
7	Complex	Size	Area	D lower leg SA	m^2
8	Simple	Size	Length	D upper leg length	cm
9	Simple	Size	Girth	D knee girth	cm
10	Complex	Size	Area	D knee CSA	m^2
11	Simple	Size	Girth	D mid-thigh girth	cm
12	Complex	Size	Area	D mid-thigh CSA	m^2
13	Simple	Size	Girth	D thigh girth	cm
14	Complex	Size	Area	D thigh CSA	m^2
15	Complex	Size	Volume	D upper leg volume	ml
16	Complex	Size	Area	D upper leg SA	m^2
17	Simple	Size	Length	ND lower leg length	cm
18	Simple	Size	Girth	ND calf girth	cm
19	Complex	Size	Area	ND calf CSA	m^2
20	Simple	Size	Girth	ND ankle girth	cm
21	Complex	Size	Area	ND ankle CSA	m^2
22	Complex	Size	Volume	ND lower leg volume	ml
23	Complex	Size	Area	ND lower leg SA	m^2
24	Simple	Size	Length	ND upper leg length	cm
25	Simple	Size	Girth	ND knee girth	cm
26	Complex	Size	Area	ND knee calf CSA	m^2
27	Simple	Size	Girth	ND mid-thigh girth	cm
28	Complex	Size	Area	ND mid-thigh calf CSA	m^2
29	Simple	Size	Girth	ND thigh girth	cm
30	Complex	Size	Area	ND thigh calf CSA	m^2
31	Complex	Size	Volume	ND upper leg volume	ml
32	Complex	Size	Area	ND upper leg SA	m^2
33	Simple	Symmetry	Length	Lower leg length symmetry	%
34	Simple	Symmetry	Girth	Calf girth symmetry	%
35	Complex	Symmetry	Area	Calf CSA symmetry	%
36	Simple	Symmetry	Girth	Ankle girth symmetry	%
37	Complex	Symmetry	Area	Ankle CSA symmetry	%
38	Complex	Symmetry	Volume	Lower leg volume symmetry	%
39	Complex	Symmetry	Area	Lower leg SA symmetry	%
40	Simple	Symmetry	Length	Upper leg length symmetry	%
41	Simple	Symmetry	Girth	Knee girth symmetry	%
42	Complex	Symmetry	Area	Knee CSA symmetry	%
43	Simple	Symmetry	Girth	Mid-thigh girth symmetry	%
44	Complex	Symmetry	Area	Mid-thigh CSA symmetry	%
45	Simple	Symmetry	Girth	Thigh girth symmetry	%
46	Complex	Symmetry	Area	Thigh calf CSA symmetry	%
47	Complex	Symmetry	Volume	Upper leg volume symmetry	%
48	Complex	Symmetry	Area	Upper leg SA symmetry	%

Chapter 6 - The importance of complex anthropometrics in the descriptive kinanthropometric assessment of cyclists

6.1 Introduction

As outlined in Chapter Two, descriptive kinanthropometry identifies the anthropometrics of population groups, based upon their sport, expertise, position or specialism. This is typically achieved by comparing the anthropometrics of a selected athletic population against that of a reference population, usually the general population, other athletic groups or levels of expertise (Olds, 2009). Descriptive kinanthropometry is used as the participant descriptives in biomechanical and physiological investigations (Reilly, 2008), to monitor responses to training and to determine talent identification criteria. Previous literature has suggested that the greatest differences between elite athletes and the general population were seen in complex anthropometrics, such as segmental volumes and cross-sectional areas, as opposed to simple anthropometrics (Schranz et al., 2010). This chapter reports an investigation into complex anthropometrics and descriptive kinanthropometry. The aim of this investigation was to determine the importance of complex anthropometrics in distinguishing between cycling groups. The objectives were to:

- Obtain 3D images of the lower body of elite cyclists and non-cyclists, using 3D surface imaging.
- Extract simple and complex anthropometrics from the 3D images.
- Compare the anthropometrics of non-cyclists and each cycling discipline.
- Explore the degree to which simple and complex anthropometrics can distinguish between non-cyclists and each cycling discipline.

6.2 Methods

6.2.1 Participants

In line with the methods described within Chapter Three Section 3.2, 80 male volunteers were recruited for participation within this investigation. All procedures and documents were approved by Sheffield Hallam University Research Ethics Committee (Appendix Three).

6.2.2 Research protocol

Experimental protocol

As detailed in Chapter Three Section 3.4 and 3.5, all participants attended one 20 minute anthropometric data collection on a single occasion. Each participant had 12 anatomical locations on each leg manually palpated and marked. 3D images of the lower legs were then acquired, from which 48 anthropometrics (32 size anthropometrics and 16 symmetry anthropometrics) were exported.

Data analysis

All participants were stratified into groups based on their cycling experience and current sub-discipline of preference. To ensure the selection of suitable analysis procedures the parametric nature of all variables (anthropometrics, age, stature, body mass and, physical activity and cycling experience) were first explored. A Shapiro-Wilks and Levene's test for equality of variance were conducted to determine the normality and homogeneity of variance, respectively, within SPSS (IBM SPSS Statistics 24.0). When separated by cycling discipline, several variables were normally distributed and demonstrated homogeneity of variance. However, because many variables demonstrated skewness and kurtosis, and the data set demonstrates high degrees of multicollinearity, the parametric nature was therefore accepted with caution. A one-way ANOVA with Games-Howell post hoc correction was then executed to explore the differences in group descriptives (age, stature, body mass and, physical activity and cycling experience). Games-Howell was selected due to its suitability for use within unequal and small sample sizes (Field, 2009).

To determine the magnitude of difference between each group, effect sizes (ES) for each anthropometric were calculated using the Hedges's g procedure (Hedges & Olkin, 1985), as detailed in Chapter Two, due to its correction for unequal and small sample sizes (Lakens, 2013). Although, as discussed in Chapter Two, Cohen's d (1988) standardized effect sizes thresholds are criticised for their inappropriate use, as previous investigations using complex anthropometrics in cycling are sparse and the meaningful degree of difference one would hope to detect is unknown, they were deemed the most suitable for use within this investigation. However, to reduce the risk of type one errors, caution was still adopted and only large effect sizes ≥ 0.8 are reported as meaningful degrees of difference. For size anthropometrics, positive effect sizes ≥ 0.8 indicated that the cyclists group were meaningfully larger than the non-cyclists group, and negative effect sizes ≤ -0.8 indicated the cyclists group were meaningfully smaller than the non-cyclists group. For symmetry anthropometrics, positive effect sizes ≥ 0.8 indicated that the cyclists group were meaningfully more asymmetrical than the non-cyclists group, and negative effect sizes ≤ -0.8 indicated the cyclists group were meaningfully more symmetrical than the non-cyclists group. Furthermore, these thresholds ensure any differences detected were attributable to true change - not attributable to the systems variability (MDC) identified in Chapter Four (0.67cm in girths, 0.48cm^3 in cross sectional areas, 67.85ml in volumes and 0.99cm^3 in surface areas).

To determine the degree of variability for each anthropometric in comparison to the non-cyclists group the coefficient of variation ratio (CV) was calculated as outlined in Chapter Two. Based upon the work of Drinkwater et al., (2007) ratios ≥ 1.1 indicated that the anthropometric of the cyclists group were substantially more variable than the non-cyclists group, whereas ratios ≤ 0.9 indicated that the anthropometric of the cyclists group were substantially less variable than the non-cyclists group.

Typically to determine differences between groups, a series of statistical difference tests would be conducted followed by post hoc testing to determine the location of any differences. However, as outlined in Chapter Two, due to the small degree of differences between groups conservative post hoc techniques such as the Bonferroni and Tukey's corrections quashed any differences between groups. Thus it would be necessary to use unconservative post hoc corrections, such as LSD, which whilst potentially highlighting differences, fail to correct for type one error and thereby potentially skew the degree to which the results are representative of the wider population. Consequently, such further statistical analysis was not conducted. Previous investigations, such as Schranz et al., (2010) investigating rowers, have also explored the differences between simple and complex anthropometrics in distinguishing between groups through measures of central tendency of effect and coefficient of variation ratio per dimension type: lengths, girths, cross-sectional areas, surface areas and volumes. However, due to the wide range of effect sizes and coefficient of variation ratio demonstrated within this investigation, measures of central tendency were highly generalised and uninformative. Furthermore, due to high degrees of multicollinearity between anthropometrics and the small magnitude of differences demonstrated between groups, alternative statistical methods of analysis such as multinomial logistic regression and statistical parametric mapping were deemed unsuitable. Furthermore, as outlined in Chapter Two, several published kinanthropometric investigations have suggested using the 'overlap zone' (OZ) (Norton & Olds, 2001; Norton et al., 2002; Ackland, 2006; Olds, 2009), where '0' equates to no overlap and '100' equates to perfect overlap. However, as this method is only suitable for normally distributed data of equal sample sizes (Norton et al., 2002), it was unsuitable for use with this data set.

6.3 Results

Stratification of all participants created five groups: non-cyclists, sprint (track and road), endurance (road, > 50 miles), time trial (road, < 50 miles) and mountain bike (cross-country and enduro) as listed in Table 6.1. All groups demonstrated no significant differences in age and stature. Several statistically significant differences ($p \leq 0.05$) were demonstrated in body mass (Table 6.1).

Table 6.1: Group descriptive for each group.

Group descriptives	Non-cyclists group	Cyclists groups			
		Sprint	Endurance	Time Trial	Mountain
n	23	8	9	15	25
Age (years)	29 ± 6	32 ± 10	28 ± 11	28 ± 9	33 ± 7
Stature (cm)	179.5 ± 5.9	182.5 ± 6.0	180.4 ± 7.2	178.8 ± 8.4	181.1 ± 9.3
Body mass (kg)	77.8 ± 10.6^{*E}	79.2 ± 10.7	67.1 ± 7.2^{*N*M}	74.3 ± 8.7^{*M}	78.1 ± 8.1^{*E*T}
	-	4.1 ± 1.0	5.0 ± 1.3	3.9 ± 1.9	2.0 ± 1.1
Swann Classification	-	Semi / competitive elite ^{*M}	Semi / competitive elite ^{*M}	Semi / competitive elite ^{*M}	Semi elite ^{*S*E*M}
Hours per week – Training	-	11.0 ± 5.4	12.8 ± 3.8	9.7 ± 4.5	8.7 ±4.5
Hours per week – Competing	-	2.8 ± 1.8	3.0 ± 1.7	1.7 ± 0.8	1.9 ± 2.1
IPAQ	Moderate / high	High	High	High	Moderate / high

*N= significantly different ($p \leq 0.05$) to the non-cyclists group.
*S= significantly different ($p \leq 0.05$) to the sprint group.
*E= significantly different ($p \leq 0.05$) to the endurance group.
*T= significantly different ($p \leq 0.05$) to the time trial group.
*M= significantly different ($p \leq 0.05$) to the mountain bike group.
IPAQ score categorisation: low =~ < 600 MET-min/week, moderate = ~601 - 2999 MET-min/week, high = ~ > 3000 MET-min/week.

6.3.1 Comparisons to the non-cyclists group

Sprint group

In comparison to the non-cyclists group, when all anthropometrics were considered, the sprint group were predominantly larger in size and demonstrated an increased degree of asymmetry, mostly a bias towards the dominant leg. Approximately 26% (7/27; simple 2/12, complex: 5/15) of upper leg anthropometrics demonstrated meaningful effect sizes ($\leq$ -0.8 and $\geq$ 0.8) (Figure 6.1). 63% (17/27, simple: 5/12, complex: 12/15) of upper leg anthropometrics demonstrated meaningful degrees of variability in comparison with the non-cyclists group (Figure 6.2). Upper leg anthropometrics that exhibited a meaningful effect size ($\leq$ 0.8 and $\geq$ 0.8) and a meaningful coefficient of variation ($\leq$ 0.9 and $\geq$ 1.1) were: upper leg length symmetry, dominant upper leg volume, dominant and non-dominant upper leg surface area and knee CSA symmetry.

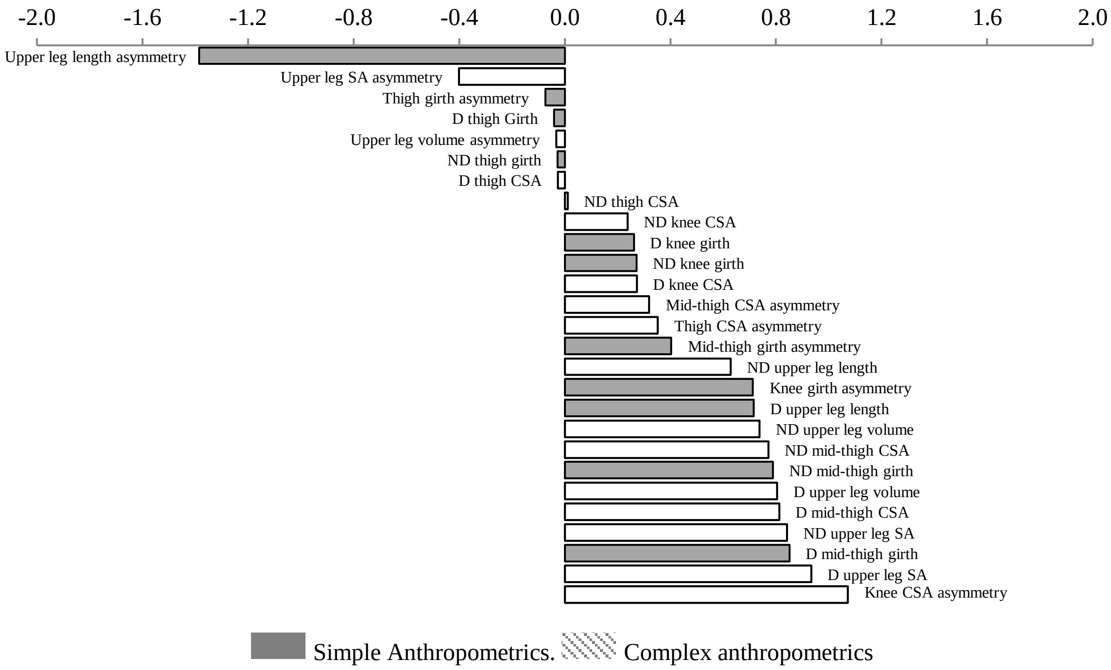


Figure 6.1: Effect sizes of the upper leg anthropometrics of sprint group in comparison to non-cyclists. For size anthropometrics, effect sizes ≥ 0.8 indicated that the sprint group were larger than the non-cyclists group, and effect sizes ≤ -0.8 indicated the sprint group were smaller than the non-cyclists group. For symmetry anthropometrics, effect sizes ≤ -0.8 indicated the sprint group were more symmetrical than the non-cyclists group, and effect sizes ≥ 0.8 indicated that sprint group were more asymmetrical than the non-cyclists group.

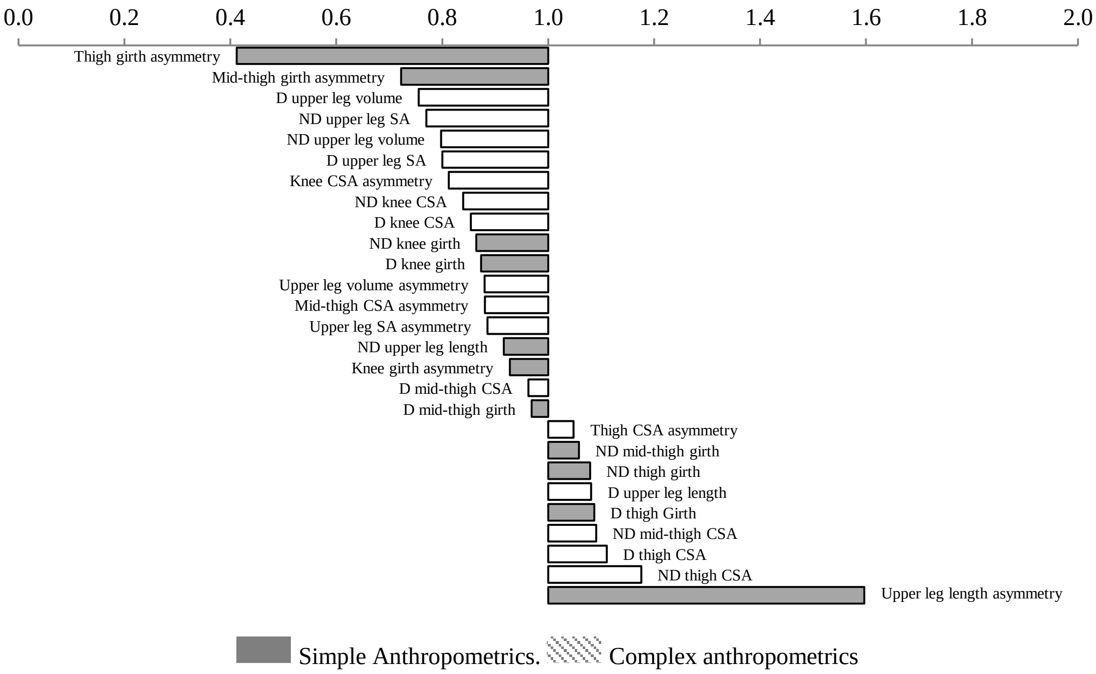


Figure 6.2: Coefficient of variation of the upper leg anthropometrics of the sprint group in comparison to the non-cyclists group. Coefficient of variation > 1.1 indicated that the sprint group were meaningfully more variable than the non-cyclists group, and coefficient of variation ≤0.9 indicated that the sprint group were substantially meaningfully less variable than the non-cyclists group.

Approximately 24% (5/21; simple: 2/9, complex: 3/12) of lower leg anthropometrics demonstrated meaningful effect sizes (≤ -0.8 and ≥ 0.8) (Figure 6.3). Of the lower leg anthropometrics (21/21; simple: 9/9, complex: 12/12) of the sprint group exhibited meaningful degrees of variation (≤ 0.9 and ≥ 1.1) in comparison to the non-cyclists group (Figure 6.4). Lower leg anthropometrics that demonstrated both a meaningful effect size (≤ 0.8 and ≥ 0.8) and a meaningful coefficient of variation (≤ 0.9 and ≥ 1.1) were: non-dominant ankle girth, dominant ankle girth, dominant ankle CSA, lower leg surface area symmetry and lower leg volume symmetry.

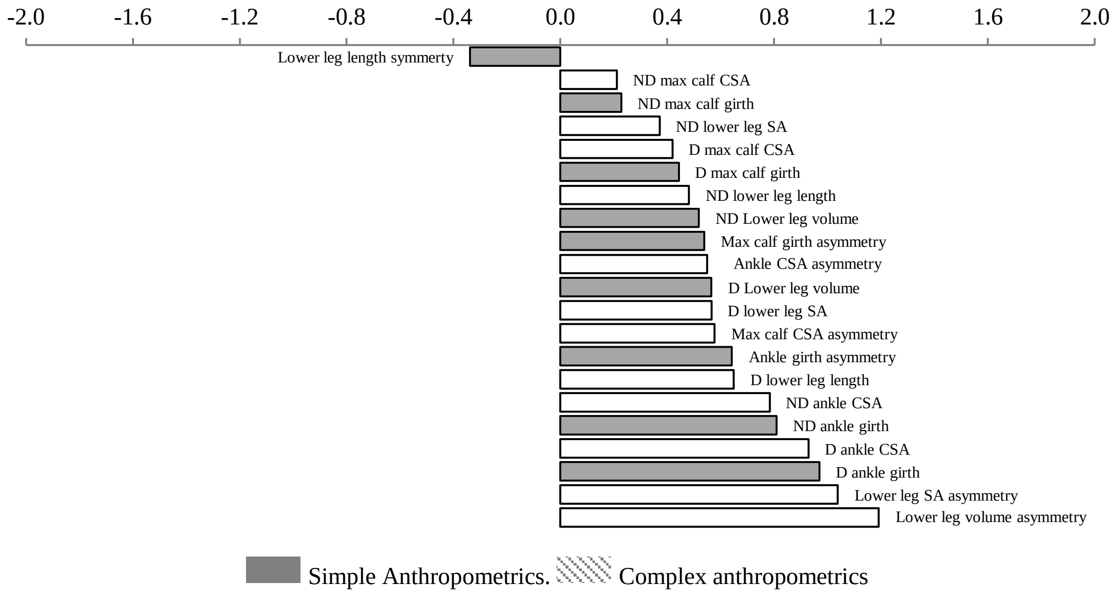


Figure 6.3: Effect size of the lower leg anthropometrics of the sprint group in comparison to the non-cyclists group. For size anthropometrics, effect sizes ≥ 0.8 indicated that the sprint group were larger than the non-cyclists group, and effect sizes ≤ -0.8 indicated the sprint group were smaller than the non-cyclists group. For symmetry anthropometrics, ≤ -0.8 indicated the sprint group were more symmetrical than the non-cyclists group, and effect sizes ≥ 0.8 indicated that sprint group were more asymmetrical than the non-cyclists group.

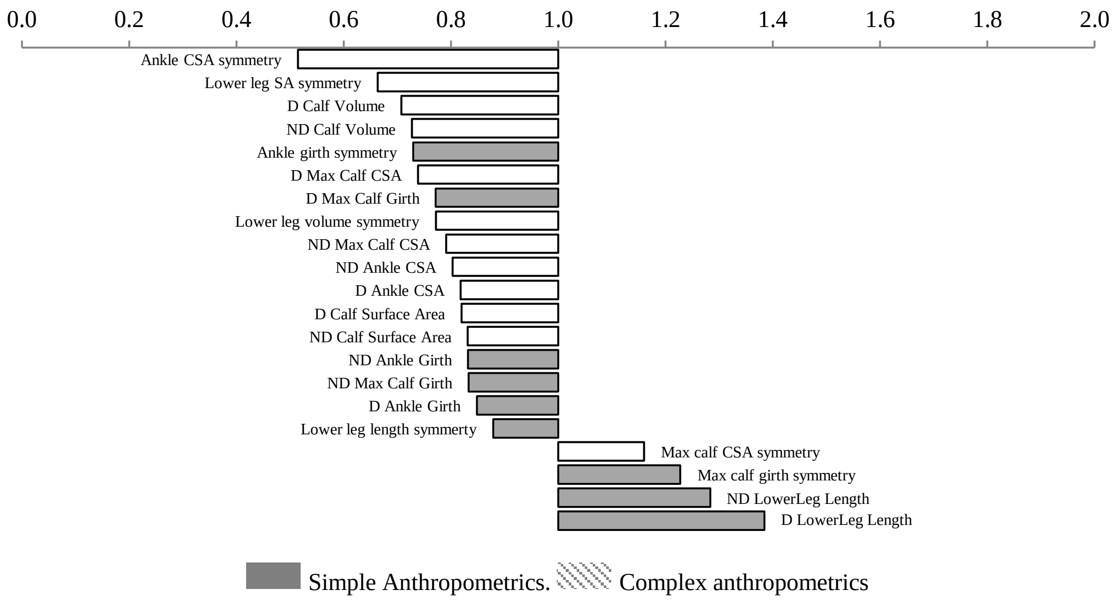


Figure 6.4: Coefficient of variation of the lower leg anthropometrics of the sprint group in comparison to the non-cyclists group. Coefficient of variation > 1.1 indicated that the sprint group were meaningfully more variable than the non-cyclists group, and coefficient of variation ≤0.9 indicated that the sprint group were substantially meaningfully less variable than the non-cyclists group.

Endurance group

In comparison to the non-cyclists group, when all anthropometrics were considered, the endurance group were predominantly smaller in size and demonstrated little difference in symmetry. Approximately 22% (6/27; simple: 3/12, complex: 3/15) of upper leg anthropometrics demonstrated meaningful effect sizes (≤ - 0.8 and ≥ 0.8) (Figure 6.5). Approximately 89% (24/27; simple: 9/12, complex: 15/15) of upper leg anthropometrics exhibited meaningful degrees of variability in comparison with the non-cyclists group (Figure 6.6). Upper leg anthropometrics that demonstrated both a meaningful effect size (≤ - 0.8 and ≥ 0.8) and a meaningful coefficient of variation (≤ 0.9 and ≥ 1.1) were: non-dominant thigh CSA, dominant thigh girth, knee CSA symmetry and knee girth symmetry.

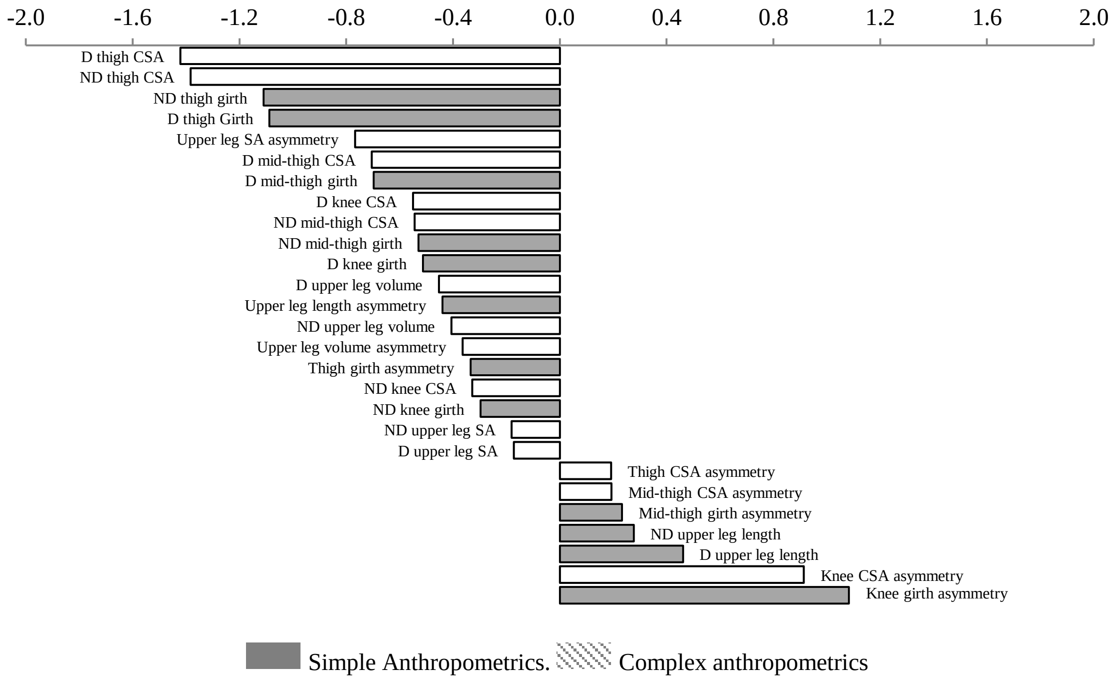


Figure 6.5: Effect size of the upper leg anthropometrics of the endurance group in comparison to the non-cyclists group. For size anthropometrics, effect sizes ≥ 0.8 indicated that the endurance group were larger than the non-cyclists group, and effect sizes ≤ -0.8 indicated the endurance group were smaller than the non-cyclists group. For symmetry anthropometrics, ≤ -0.8 indicated endurance group were more symmetrical than the non-cyclists group, and effect sizes ≥ 0.8 indicated that endurance group were more asymmetrical than the non-cyclists group.

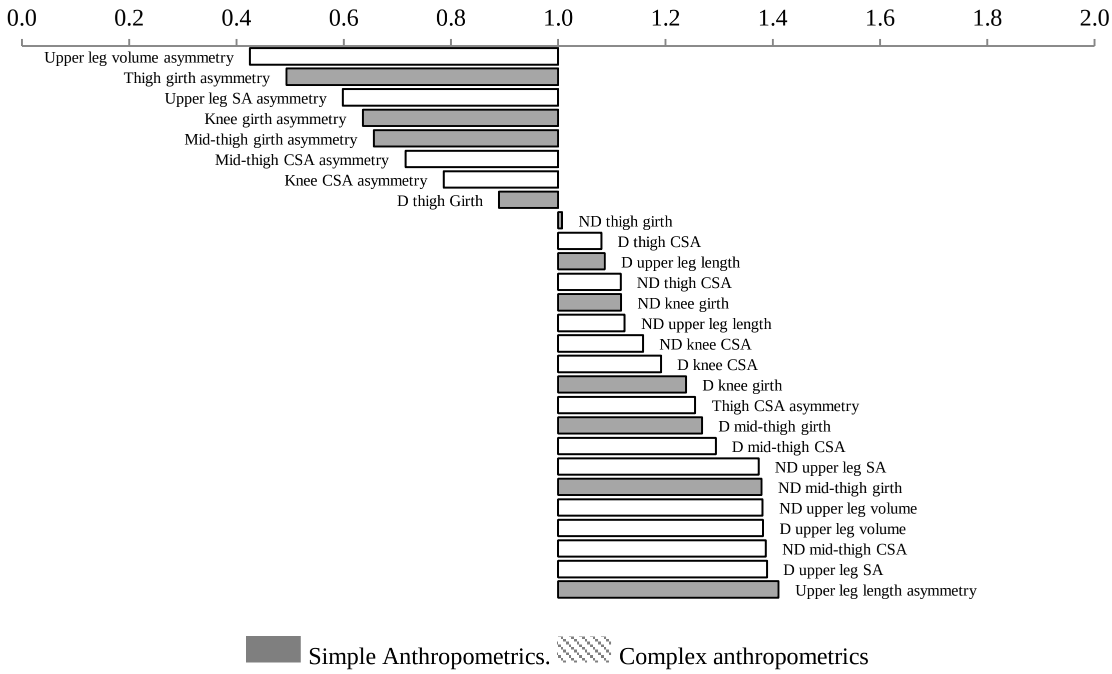


Figure 6.6: Coefficient of variation of the upper leg anthropometrics of the endurance group in comparison to the non-cyclists group. Coefficient of variation > 1.1 indicated that the endurance group were meaningfully more variable than the non-cyclists group, and coefficient of variation ≤0.9 indicated that the endurance group were substantially meaningfully less variable than the non-cyclists group.

Approximately 19% (4/21; simple: 2/9, complex: 2/12) of lower leg anthropometrics demonstrated meaningfully smaller effect sizes (≤ -0.8 and ≥ 0.8) (Figure 6.7). Approximately 33% (7/21, simple: 3/9, complex: 4/12) of lower leg anthropometrics exhibited meaningful degrees of variation (≤ 0.9 and ≥ 1.1) in comparison to the non-cyclists group (Figure 6.8). Lower leg anthropometrics that demonstrated both a meaningful effect size (≤ - 0.8 and ≥ 0.8) and a meaningful coefficient of variation (≤ 0.9 and ≥ 1.1) were: dominant and non-dominant calf girth.

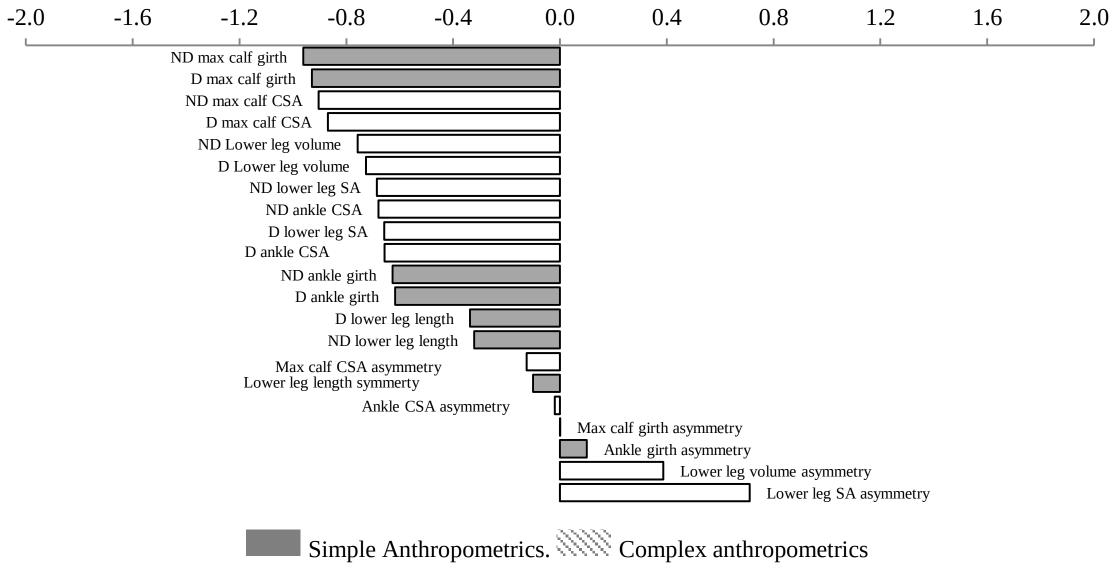


Figure 6.7: Effect size of the lower leg anthropometrics of the endurance group in comparison to the non-cyclists group. For size anthropometrics, effect sizes ≥ 0.8 indicated that the endurance group were larger than the non-cyclists group, and effect sizes≤ -0.8 indicated the endurance group were smaller than the non-cyclists group. For symmetry anthropometrics, ≤ -0.8 indicated endurance group were more symmetrical than the non-cyclists group, and effect sizes ≥ 0.8 indicated that endurance group were more asymmetrical than the non-cyclists group.

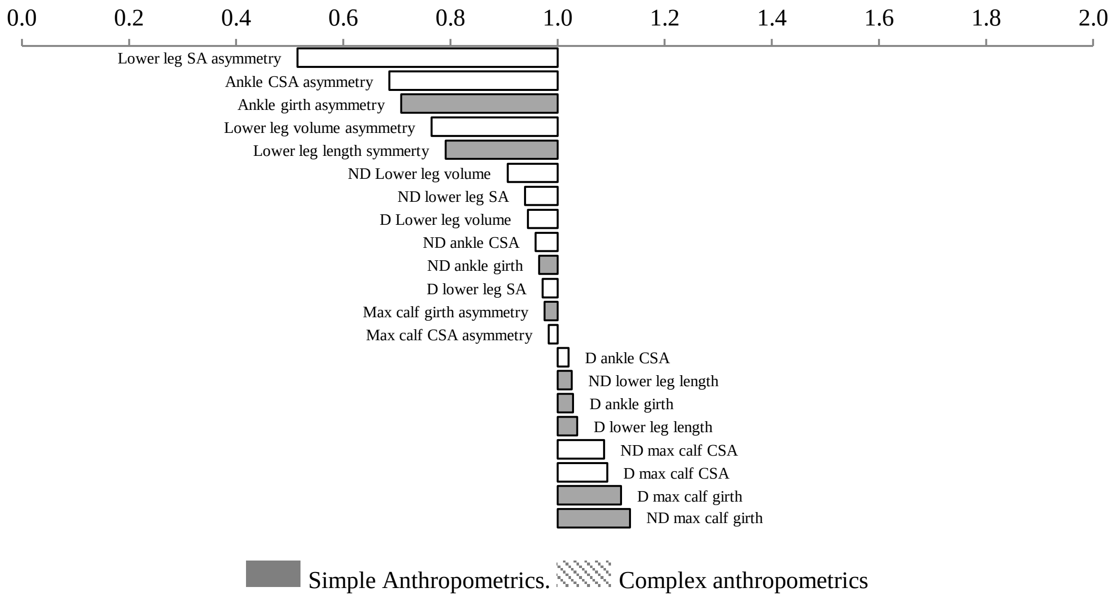


Figure 6.8: Coefficient of variation of the lower leg anthropometrics of the endurance group in comparison to the non-cyclists group. Coefficient of variation > 1.1 indicated that the endurance group were meaningfully more variable than the non-cyclists group, and coefficient of variation ≤ 0.9 indicated that the endurance group were substantially meaningfully less variable than the non-cyclists group.

Time trial group

In comparison to the non-cyclists group, when all size anthropometrics were considered, the time trial group demonstrated little difference in size and symmetry. Approximately 7% (2/27; simple: 0/12, complex: 2/15) of upper leg anthropometrics demonstrated meaningful effect sizes (≤ -0.8 and ≥ 0.8) (Figure 6.9). Approximately 82% (22/27, simple: 9/12, complex: 13/15) of upper leg anthropometrics exhibited meaningful degrees of variability in comparison with the non-cyclists group (Figure 6.10). Upper leg anthropometrics that exhibited a meaningful effect size (≤ -0.8 and ≥ 0.8) and a meaningful coefficient of variation (≤ 0.9 and ≥ 1.1) were: dominant and non-dominant thigh CSA.

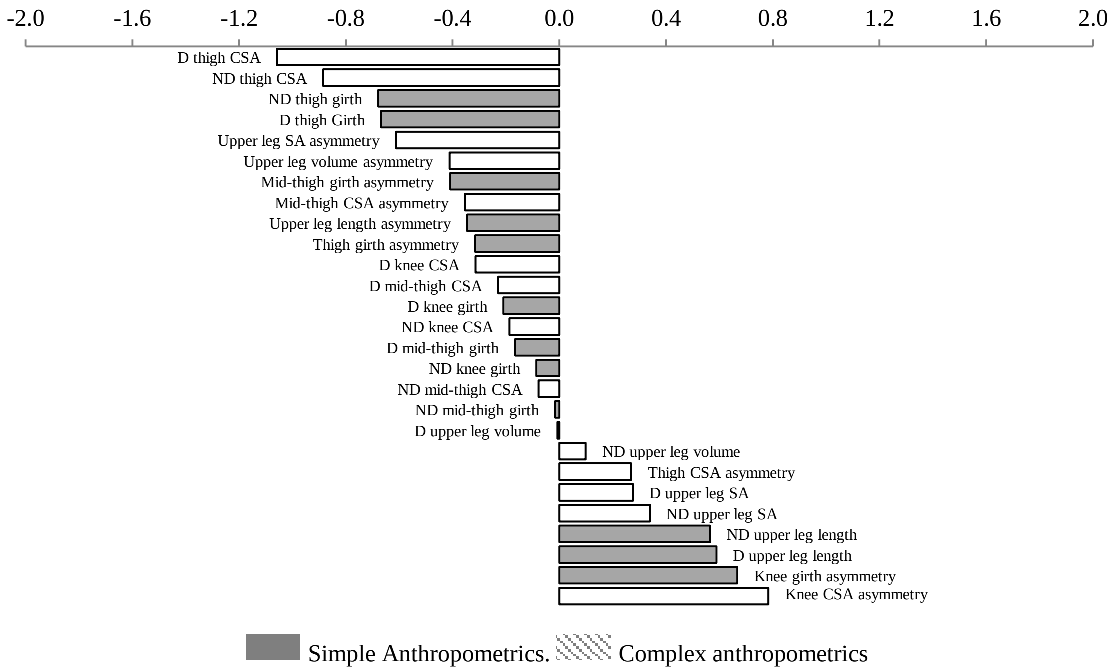


Figure 6.9: Effect size of the upper leg anthropometrics of the time trial group in comparison to the non-cyclists group. For size anthropometrics, effect sizes ≥ 0.8 indicated that the time trial group were larger than the non-cyclists group, and effect sizes ≤ -0.8 indicated the time trial group were smaller than the non-cyclists group. For symmetry anthropometrics, ≤ -0.8 indicated the time trial group were more symmetrical than the non-cyclists group, and effect sizes ≥ 0.8 indicated that the time trial group were more asymmetrical than the non-cyclists group.

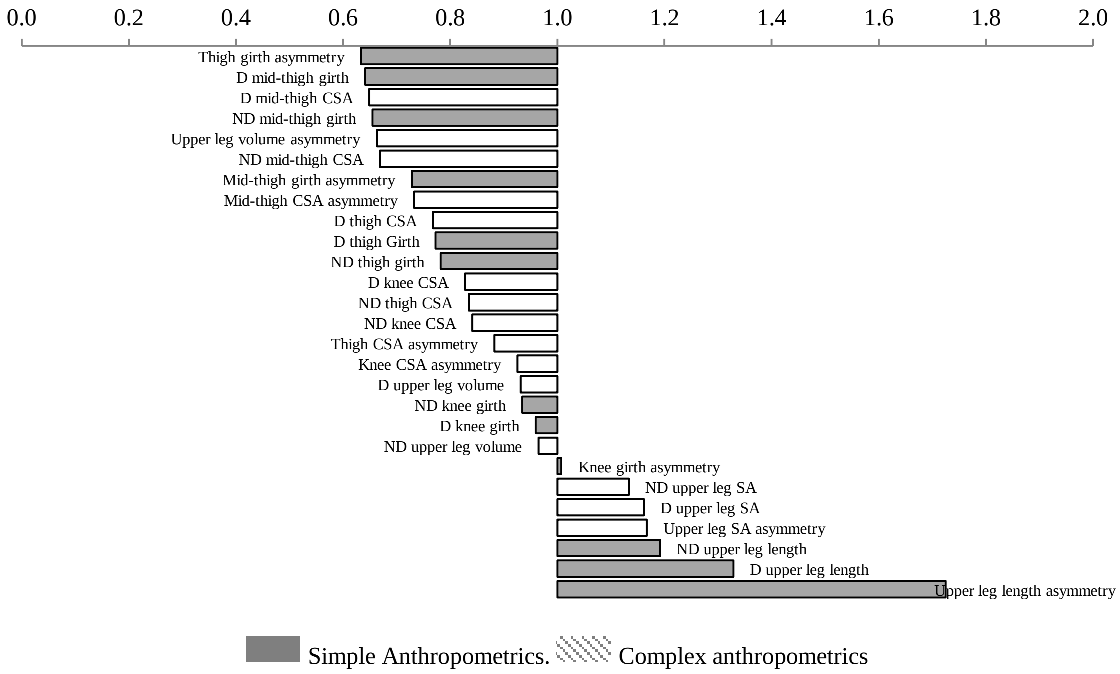


Figure 6.10: Coefficient of variation of the upper leg anthropometrics of the time trial group in comparison to the non-cyclists group. Coefficient of variation > 1.1 indicated that the time trial group were meaningfully more variable than the non-cyclists group, and coefficient of variation ≤0.9 indicated that the time trial group were substantially meaningfully less variable than the non-cyclists group.

The lower leg of the time trial group demonstrated little difference with the non-cyclists group. No anthropometric demonstrated a meaningful magnitude of difference (≤ -0.8 and ≥ 0.8) (Figure 6.11). Approximately 71% (15/21, simple: 7/9, complex: 8/12) of lower leg anthropometrics exhibited meaningful degrees of variation (≤ 0.9 and ≥ 1.1) in comparison to the non-cyclists group (Figure 6.12). No anthropometric demonstrated both a meaningful effect size (≤ -0.8 and ≥ 0.8) and a meaningful coefficient of variation (≤ 0.9 and ≥ 1.1).

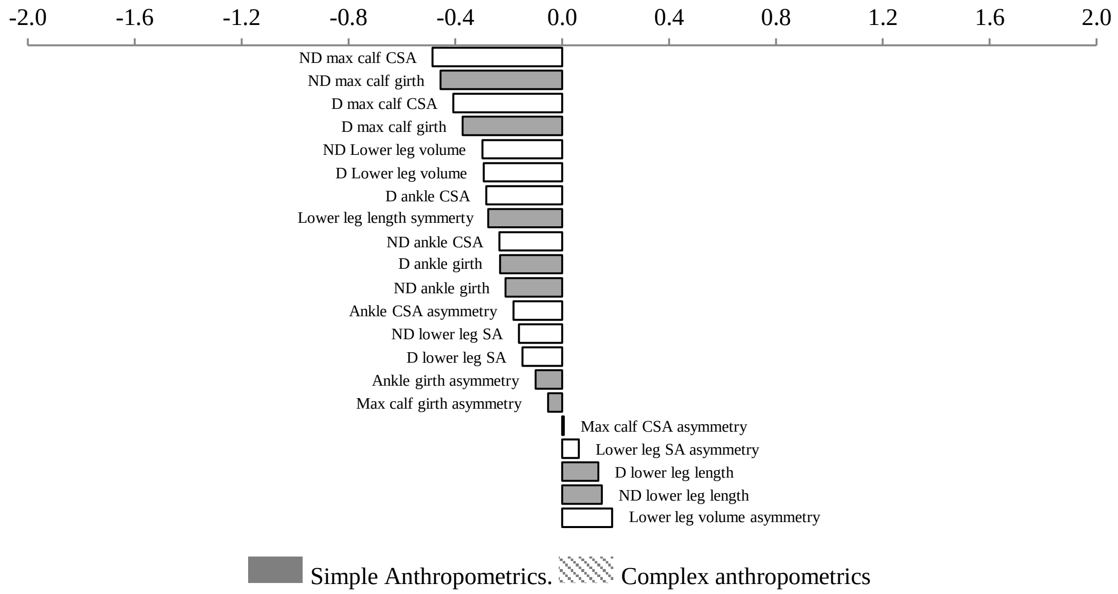


Figure 6.11: Effect size of the lower leg anthropometrics of the time trial group in comparison to the non-cyclists group. For size anthropometrics, effect sizes ≥ 0.8 indicated that the time trial group were larger than the non-cyclists group, and effect sizes ≤ -0.8 indicated the time trial group were smaller than the non-cyclists group. For symmetry anthropometrics, ≤ -0.8 indicated the time trial group were more symmetrical than the non-cyclists group, and effect sizes ≥ 0.8 indicated that the time trial group were more asymmetrical than the non-cyclists group.

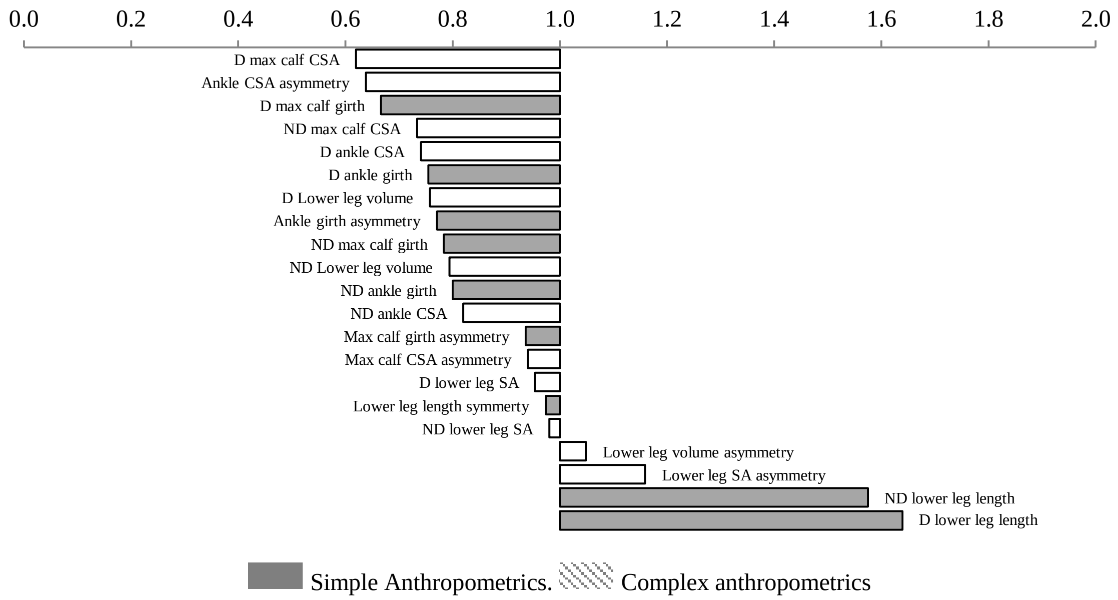


Figure 6.12: Coefficient of variation of the lower leg anthropometrics of the time trial group in comparison to the non-cyclists group. Coefficient of variation > 1.1 indicated that the time trial group were meaningfully more variable than the non-cyclists group, and coefficient of variation ≤0.9 indicated that the time trial group were substantially meaningfully less variable than the non-cyclists group.

Mountain bike

In comparison to the non-cyclists group, when all size anthropometrics were considered, the mountain bike group demonstrated little difference in size or symmetry to non-cyclists. No anthropometric demonstrated a meaningful magnitude of difference (≤ -0.8 and ≥ 0.8) (Figure 6.13). Approximately 74% (20/27, simple: 8/12, complex 12/15) of upper leg anthropometrics exhibited meaningful degrees of variability in comparison with the non-cyclists group (Figure 6.14). No upper leg anthropometrics demonstrated both a meaningful effect size (≤ -0.8 and ≥ 0.8) and a meaningful coefficient of variation (≤ 0.9 and ≥ 1.1).

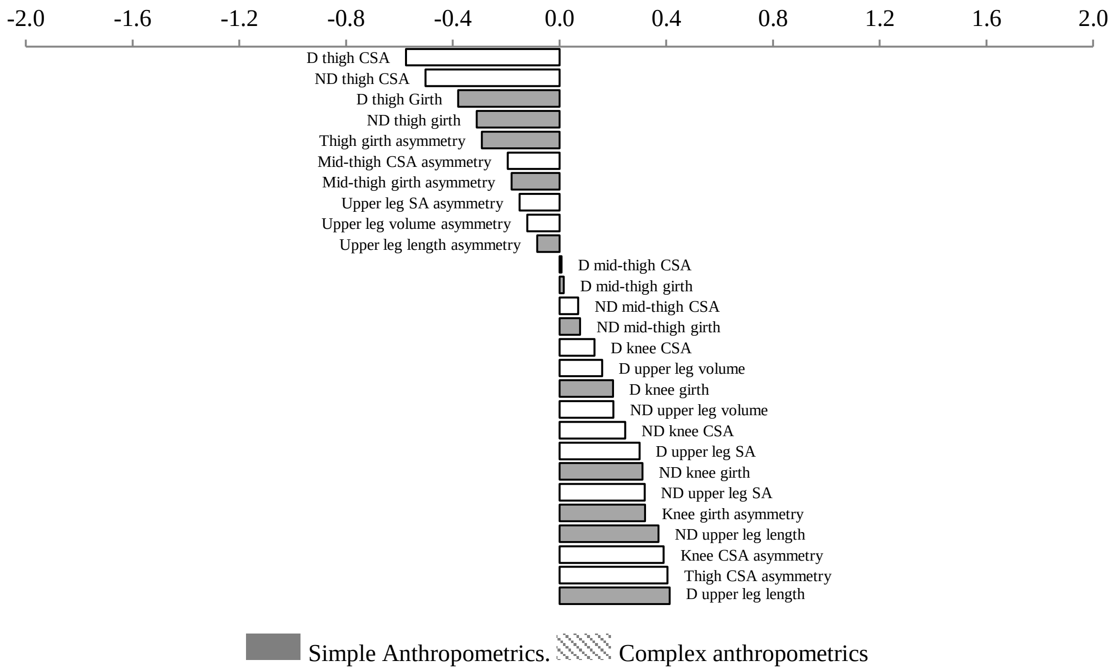


Figure 6.13: Effect size of the upper leg anthropometrics of the mountain bike group in comparison to the non-cyclists group. For size anthropometrics, effect sizes ≥ 0.8 indicated that the mountain bike group were larger than the non-cyclists group, and effect sizes ≤ -0.8 indicated the mountain bike group were smaller than the non-cyclists group. For symmetry anthropometrics, ≤ -0.8 indicated the mountain bike group were more symmetrical than the non-cyclists group, and effect sizes ≥ 0.8 indicated that the mountain bike group were more asymmetrical than the non-cyclists group.

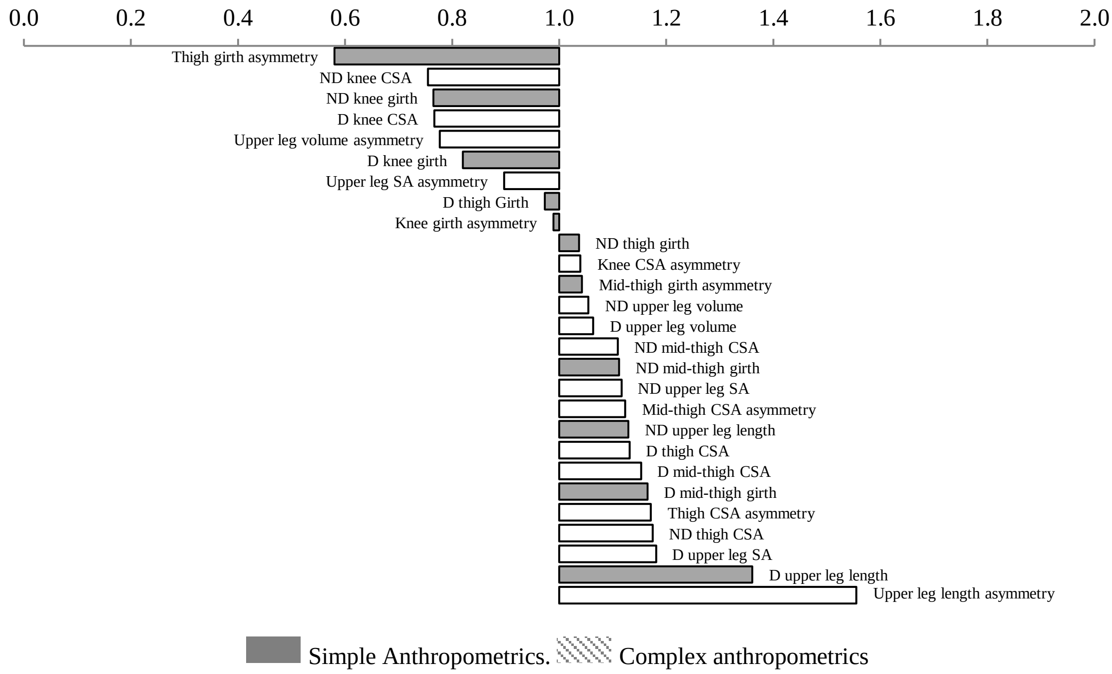


Figure 6.14: Coefficient of variation of the upper leg anthropometrics of the mountain bike group in comparison to the non-cyclists group. Coefficient of variation > 1.1 indicated that the mountain bike group were meaningfully more variable than the non-cyclists group, and coefficient of variation ≤0.9 indicated that the mountain bike group were substantially meaningfully less variable than the non-cyclists group.

The lower leg of the mountain bike group demonstrated little difference with the non-cyclists group. No anthropometric demonstrated a meaningful magnitude of difference (≤ -0.8 and ≥ 0.8) (Figure 6.15). Approximately 81% (17/21, simple: 7/9, complex: 10/12) of lower leg anthropometrics exhibited meaningful degrees of variation (≤ 0.9 and ≥ 1.1) in comparison to the non-cyclists group (Figure 6.16). No lower leg anthropometric demonstrated a difference through statistical testing ($p \leq 0.05$), a meaningful effect size (≤ -0.8 and ≥ 0.8) and a meaningful coefficient of variation (≤ 0.9 and ≥ 1.1).

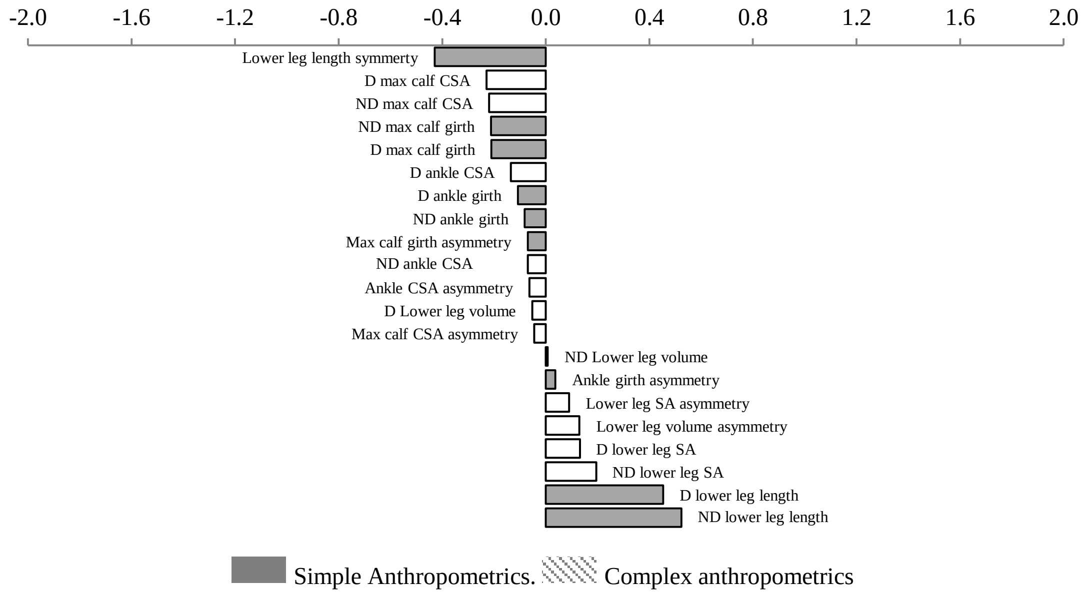


Figure 6.15: Effect size of the lower leg anthropometrics of the mountain bike group in comparison to the non-cyclists group. For size anthropometrics, effect sizes ≥ 0.8 indicated that the mountain bike group were larger than the non-cyclists group, and effect sizes ≤ -0.8 indicated the mountain bike group were smaller than the non-cyclists group. For symmetry anthropometrics, ≤ -0.8 indicated the mountain bike group were more symmetrical than the non-cyclists group, and effect sizes ≥ 0.8 indicated that the mountain bike group were more asymmetrical than the non-cyclists group.

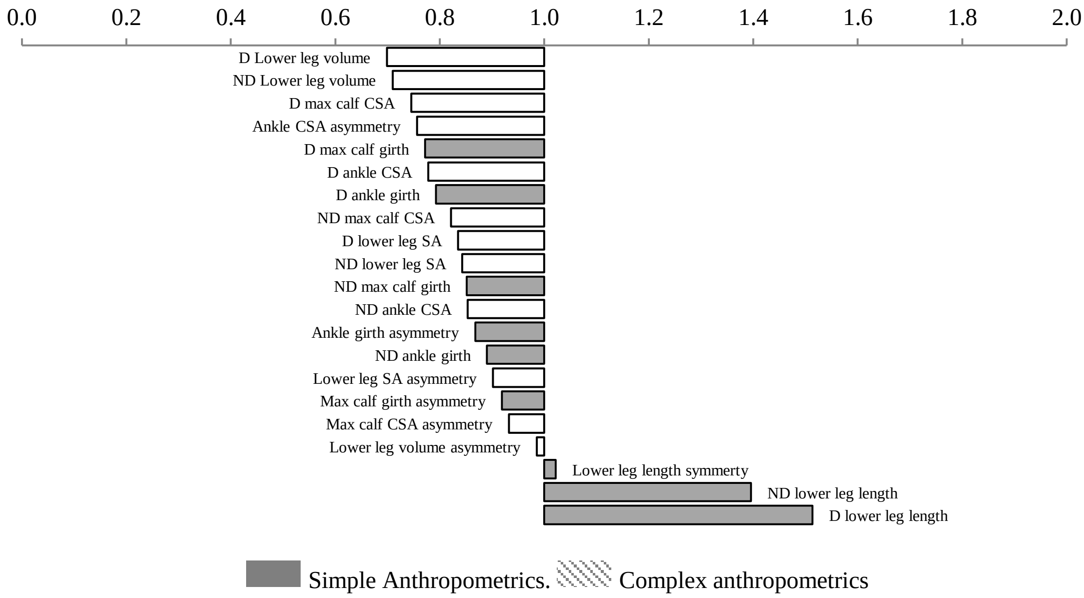


Figure 6.16: Coefficient of variation of the lower leg anthropometrics of the mountain bike group in comparison to the non-cyclists group. Coefficient of variation > 1.1 indicated that the mountain bike group were meaningfully more variable than the non-cyclists group, and coefficient of variation ≤0.9 indicated that the mountain bike group were substantially meaningfully less variable than the non-cyclists group.

6.3.2 Comparison between cycling disciplines

Several anthropometrics differed between cycling disciplines as outlined in Table 6.2. The sprint group demonstrated the largest magnitude of difference with other cycling disciplines. In all cases of significant and meaningful anthropometrics, the sprint group were suggested to be larger and demonstrate greater degrees of asymmetry. The only other cycling disciplines to demonstrate differences from one another were the endurance and mountain bike groups, in which, in all cases, the mountain bike group were suggested to be larger in size than the endurance group.

Table 6.2: Simple and complex anthropometrics that demonstrated large ES (≤ -0.8 and ≥ 0.8) and meaningful coefficient of variations (≤ 0.9 and ≥ 1.1). D=dominant, ND=non-dominant, SA=surface area.

	Non-cyclists group & sprint group	Non-cyclists group & endurance group	Non-cyclists & time trial group	Non-cyclists & mountain bike group	Sprint group & Endurance group	Sprint group & Time trial group	Sprint group & Mountain bike group	Endurance group & Time trial group	Endurance group & Mountain bike group	Time trial group & mountain bike group
Total:	10/48	6/48	2/48	0/48	23/48	16/48	3/48	0/48	8/48	0/48
Simple:	3/21	4/21	0/21	0/21	7/21	4/21	0/21	0/21	2/21	0/21
Complex:	7/27	2/27	2/27	0/27	16/27	12/27	3/27	0/27	6/27	0/27
	ND upper leg SA D upper leg volume D upper leg SA Upper leg length symmetry Knee CSA symmetry ND ankle girth D ankle CSA D ankle girth Calf SA symmetry Calf volume symmetry	Knee CSA Symmetry Knee Girth Symmetry ND Thigh CSA D Thigh Girth ND Max Calf Girth D Max Calf Girth	D thigh CSA ND thigh CSA	None	ND upper leg volume ND upper leg SA ND mid-thigh girth ND mid-thigh CSA D thigh girth D upper leg volume D upper leg SA D knee CSA D mid-thigh girth D mid-thigh CSA ND calf girth ND calf CSA ND calf volume ND calf SA ND ankle girth ND ankle CSA D calf girth D calf CSA D calf volume D calf SA D ankle girth D ankle CSA Upper leg length symmetry	ND thigh CSA ND mid-thigh girth ND mid-thigh CSA D thigh CSA D thigh volume D mid-thigh CSA D mid-thigh girth D calf girth D calf CSA D calf SA D ankle girth D ankle CSA Calf volume symmetry Calf SA Symmetry Ankle CSA symmetry	Calf volume symmetry Calf SA symmetry	None	D calf girth ND calf SA ND calf girth ND calf volume D calf SA D calf volume ND calf CSA D calf CSA	None

6.4 Discussion

The aim of this investigation was to determine the importance of complex anthropometrics in distinguishing between population groups. 80 male volunteers were recruited and stratified into five groups: non-cyclists, track and road sprint, road endurance (> 50 miles), road time trial (< 50 miles) and mountain bike (cross-country and enduro) cyclists. 3D images of the lower body of each participant were captured using 3dMDbody5 from which simple and complex anthropometrics were exported. All anthropometrics were compared between groups to establish anthropometric profiles for each group and then explored to determine the contribution of simple and complex anthropometrics to these profiles.

6.4.2 Size anthropometrics

Typically, cycling disciplines in which peak power production is a major determinant of performance are associated with mesomorphic somatotypes (Craig & Norton, 2001; Hopker et al., 2012), due to the increased muscle volume required to generate high degrees of power (White et al., 1979; Mclean & Parker, 1989). However, as the importance of peak power reduces, alongside an increase in performance distance and gradient, the somatotypes of cyclists typically alter towards an ectomorphic profile (Tanner, 1964). The results of this investigation support the current literature as the sprint group were demonstrated to be the largest in body size followed by the mountain bike, time trial and endurance groups. The smallest differences were demonstrated by the time trial and mountain bike groups in comparison to the non-cyclists group and one another. As the time trial and mountain bike groups were the least experienced cycling groups, it is possible that the absence of difference is attributable to a lack of expertise. However, previous investigations have suggested that in time trial and mountain bike cycling it is advantageous to be ectomorphic for climbing and endurance features of a course, and mesomorphic for flat sprint features (Impellizzeri & Marcora, 2007; Passfield et al., 2012). Thus, it is possible that time trial and the mountain bike groups demonstrate both sprint and endurance anthropometric characteristics which present a generalized anthropometric profile. However, further research, ideally using more experienced cyclists, would be necessary to confirm this.

The results of this investigation suggest that complex size anthropometrics were able to distinguish between groups as effectively as simple size anthropometrics, particularly when comparing girth and CSA anthropometrics. For example, distinguishing between the sprint and time trial groups, and endurance and mountain bike groups. However, in some cases, such as surface area and volume, complex anthropometrics were able to distinguish differences that were unidentifiable through simple size anthropometrics alone. An example of this would be distinguishing between the non-cyclists and time trial groups, and the non-cyclists and sprint groups. It is possible this is because complex anthropometrics consider the whole segment, presenting a better representation of change, as opposed to a single point. These finding are similar to those outlined by Schranz et al., (2010), in which the greatest differences between elite rowers and the general population were seen in complex anthropometrics, such as segmental volumes and cross-sectional areas, as opposed to simple anthropometrics. However, this is not to suggest that complex size anthropometrics should replace simple size anthropometrics as there is undoubtedly value in single point anthropometrics – instead, collection of both would be preferable.

All cyclist groups demonstrated, although trivial in effect size, longer leg length than the non-cyclists group. Previous literature has demonstrated that the time trial group had significantly longer leg lengths (Foley et al., 1989). Yet, sprint cyclists are believed to have shorter leg length, due to shorter bone lengths, as it is believed athletes with shorter limbs can tolerate high cadences (Astrand & Rodahl, 1977). However, within this investigation little difference was demonstrated between cycling disciplines. It is possible that this study has demonstrated differing results due to the differences in the cyclists' expertise or the differing landmarking of the upper leg: distance between the epicondyles of the knee and gluteal fold, opposed to the distance between the epicondyles of the knee and greater trochanter used in previous investigations.

6.4.2 Symmetry anthropometrics

Cycling is typically regarded as symmetrical in nature, whereby each leg makes an equal contribution. Whilst a degree of asymmetry is common within humans, it is conjectured that asymmetry would be reduced in cyclists. However, within this investigation all cyclist groups demonstrated little difference or a meaningful increase in asymmetry when compared to the non-cyclists group. Little research appears to have been conducted on the asymmetries in anthropometrics of cyclists. Previous investigations into the asymmetries in anthropometrics of athletes from other theoretically symmetrical sports suggest asymmetry is associated with sub elite populations (McGregor et al., 2002). However, as conflicting literature is also present

(Tomkinson & Olds, 2000; Parkin et al., 2001; Tomkinson et al., 2003) it is difficult to conclude if this is the cause.

In distinguishing between cycling disciplines, symmetry anthropometrics did identify differences between the sprint group and other cycling disciplines. The sprint group predominantly demonstrated an increased degree of asymmetry, specifically a bias towards the dominant leg. Several investigations have explored the asymmetries of pedalling kinetics, kinematics and muscle recruitment (Daly & Cavanagh, 1975; Smak et al., 1999; Carpes et al., 2010). Bini (2011) suggested that at higher power outputs (≥ 200 watts) pedalling asymmetries are exacerbated. He proposed that this causes the dominant leg to receive greater neural drive and provide a greater contribution to power output. As sprint cycling is predominantly performed at high power outputs, it is possible that the asymmetries in performance results in asymmetries in anthropometry.

Typically, it is accepted that differences in symmetry anthropometrics will be small (Moller, 1993). Although the symmetry anthropometrics that demonstrated a meaningful degree of difference between groups demonstrated differences greater than the 3dMDbody5 system variability (MDC reported in Chapter Four), the absolute differences demonstrated within this investigation do appear to be particularly small, thus the importance of the differences in asymmetry demonstrated within this investigation should not be overstated. For example, although the reduced asymmetry highlighted at the upper leg length of the sprint group in comparison to the non-cyclists group demonstrated a meaningfully large effect size, the mean absolute difference was a ~2 mm (0.6%) for the sprint group and ~5 mm (1.6%) the non-cyclists group. Furthermore, due to the small sample sizes used within this investigation, further research would be necessary to confirm if the differences in asymmetry demonstrated within this investigation are also present within the wider population groups.

The anthropometrics that demonstrated large effect size (≤ -0.8 and ≥ 0.8) and meaningful coefficient of variations (≤ 0.9 and ≥ 1.1) 12/68 were symmetry anthropometrics. Of these, 2/12 were lengths, 1/12 were girths, 3/12 were CSAs, 3/12 were volumes and 3/12 were surface areas. The results of this investigation suggest that complex symmetry anthropometrics were able to distinguish between groups as effectively as simple symmetry anthropometrics, and in some cases, were able to distinguish differences that were unidentifiable through simple symmetry anthropometrics alone.

6.4.3. Limitations

This study has limitations that require consideration. First, because of the small and unequal sample sizes within this investigation and the small magnitude of differences between groups, statistical difference testing, such as ANOVAs and multinomial regression, were unsuitable. Consequently, data analysis was solely reliant upon the calculation of effect size and coefficient of variation. Whilst these methods can determine the magnitude of difference and degree of variability between each group, the degree to which these results are representative of the wider population groups remains unknown. Therefore, further work using larger and equal sample sizes is necessary to confirm if these results are representative of the wider population groups. Second, whilst it is possible that the differences demonstrated between groups within this investigation are primarily due to differences in muscle mass, due to the high physical activity levels of all participants, the absence of body composition measurements means further work is required to confirm this. Third, whilst attempts were made to ensure ecological validity of the performance measure, i.e. participant's bike setup and footwear, the bike was stationary and therefore is unlikely to be truly representative of cycling performance (Jobson et al., 2007). Furthermore, as descriptive kinanthropometry only provides a cross sectional view of morphology it is unknown how these anthropometric profiles change over time. Future research should focus upon the importance of complex anthropometrics in applied and longitudinal kinanthropometric assessments of cyclists.

6.5 Conclusion

The results of this investigation demonstrate the non-cyclists, sprint, endurance, time trial and mountain bike groups demonstrated differing anthropometric profiles from one another. This investigation has provided a more detailed understanding about the lower body anthropometric profile of cyclists. Furthermore, it has demonstrated that when distinguishing between groups, complex anthropometrics could distinguish between groups as effectively as simple anthropometrics, and in some cases, can distinguish differences that are unidentifiable through simple anthropometrics alone. Future research should focus on the importance of complex anthropometrics in applied and longitudinal kinanthropometric assessments of cyclists.

Chapter 7 - The importance of complex anthropometrics in the applied kinanthropometric assessment of cyclists

7.1 Introduction

Chapter Six demonstrated that complex anthropometrics can distinguish between groups as effectively as simple anthropometrics, and in some cases, could distinguish differences that are unidentifiable through simple anthropometrics alone. However, the extent to which these anthropometrics are important to performance was not investigated. As outlined in Chapter Two, applied kinanthropometry explores the relationship between anthropometrics of a population group and a measurement of performance. Applied kinanthropometry is useful in determining the anthropometrics that should be monitored in elite performance, in understanding the biomechanical and physiological ramifications of anthropometrics, and the creation of talent identification criteria. Previous literature has suggested that complex rather than simple anthropometrics explained the greatest degree of variance in rowing performance (Schranz et al., 2012). Although several researchers have speculated on the importance of complex anthropometrics to cycling performance as detailed in Section 1.1, few investigations have explored the importance of complex anthropometrics in the applied kinanthropometric assessment of cyclists.

This chapter details an investigation into complex anthropometrics and applied kinanthropometry. The aim of this investigation was to determine the importance of complex anthropometrics in explaining variance in cycling performance. The objectives were to:

- Determine a suitable performance measure for all cycling disciplines
- Collect the performance measure from all cyclists
- Obtain 3D images of the lower body of cyclists, using 3D surface imaging.
- Extract simple and complex anthropometrics from the 3D images.
- Create and compare regression models using simple and, simple and complex anthropometrics to determine the degree to which simple and complex anthropometrics explains variance in peak power output.

7.2 Method

7.2.1 Participants

Alongside the methods outlined within Section 3.2, all participants were required to:

- 48 hours before data collection: refrain from heavy exercise; undertake only light exercise, and consume a high carbohydrate diet.

- 24 hours before data collection: refrain from all exercise and consume a high carbohydrate diet.
- the day of data collection: refrain from all exercise, consume a light carbohydrate meal 2 to 4 hours prior and nothing thereafter and refrain from caffeine or high (>12%) carbohydrate drinks 4 hours prior.

These criteria were included to ensure all participants were well hydrated, rested and had full glycogen stores, thereby reducing the confounding effects of acute physiological changes (Jones et al., 2009). Based on the criteria outlined above and those described within Section 3.2, 55 male cyclists were recruited for participation within this investigation. In addition to the consent form, screening form and a cycling and physical activity background questionnaire, as outlined in Section 4.2.1, all participants were required to complete a pre-exercise screening questionnaire. All procedures and documents were approved by Sheffield Hallam University Research Ethics Committee (Appendix Five).

7.2.2 Performance measure

Typically, performance measures used within applied kinanthropometric investigations are direct measures of performance (e.g. personal best times or distances) or major performance determinants (e.g. power output, anaerobic fitness or aerobic fitness). For example, Schranz et al., (2012) used self-reported best times in exploring the relationship between rowing performance and anthropometrics in junior rowers. Whilst this performance measure is potentially subjective, it is a direct measurement of performance itself. Few investigations have explored the importance of anthropometrics to performance measures across disciplines of cycling due to the differing durations and environment of each discipline, and thereby differing performances and performance determinants. Sprinting ability is a performance determinant of many cycling disciplines (Martin et al., 2007), in particular within track sprint, mountain bike and road time trial cycling performance and training, and endurance training.

Peak power output is regarded as a fundamental determinant of sprinting ability in cycling (Jeukendrup et al., 2000; Gardner et al., 2007). It is believed this ability is highly correlated to the muscle size (Dellanini et al., 2004; Martin et al., 2007; Hopker et al., 2010) and thereby potentially body size (Olds, 2009). This has been demonstrated in several previous investigations such as McLean & Ellis (1992), who reported significant relationships ($r = 0.85$, $p \leq 0.05$) between thigh volume, and both peak power output and total mechanical work done in a 15 second sprint ergometer test of elite junior cyclists. Consequently, peak power was used as the cycling performance measure in this investigation.

7.2.3 Research protocol

Experimental protocol – anthropometrics

As detailed in Section 3.4 and 3.5, all participants attended one 20 minute anthropometric data collection on a single occasion. Each participant had 12 anatomical locations on each leg manually palpated and marked following the methods outlined in Section 5.3.2. Due to the small degree of differences demonstrated in asymmetry in Chapter Six only the right sides were exported. 3D images of the legs were then acquired using 3dMDbody5, as detailed in Chapter Four, from which 24 anthropometrics (16 size anthropometrics and 8 symmetry anthropometrics) were exported following the methods detailed in Section 5.3.2.

Experimental protocol – peak power output test

Immediately following the anthropometric data collection, all participants completed a 45 minute performance measure data collection. During performance measure data collection all participants were required to wear exercise clothing of their choice. The type of footwear worn whilst cycling is believed to influences performance (Tate & Shierman, 1977; Lavoie et al., 1978; Lafortune & Cavanagh, 1983; Mornieux et al., 2008). As such, whilst it was not practical to standardise the brand and type footwear and cleat, all participants were required to wear cycling shoes and cleats.

Electromagnetically braked cycle ergometers (Lode Excalibur Sport with Pedal Force Measurement, Groningen, Netherlands) were used within this investigation. The setup of the ergometer was personalised to replicate each participants’ personal bike set up dimensions. The Lode ergometer was selected due to its automatic correction for inertia and its reported high accuracy of 2-5% (Lode, 2017). Verification of each ergometer was conducted to confirm the manufacturer's reported degree of accuracy, was conducted on multiple occasions (prior to, and twice during the investigation), following the manufacturer's standardised test procedure of executing a range of power outputs at a range of speeds, as detailed in Appendix A.5.1. This validation procedure suggested the Lode ergometer demonstrated a mean error of -2.4 ± 2.7 % (-10.2 ± 10.8

watts) (Appendix A.5.2).

For all participants the peak power test started with a 5 minute warm up of submaximal cycling (less at 50 - 70 $rev.min^{-1}$) against a resistance of ~2.5% BM(kg) for the first minute and then at a self-selected resistance for the remaining four minutes. Several investigations have highlighted the importance of untrained participants completing multiple familiarisation sessions prior to cycling based exercise testing to habituate participants to the protocol, in an attempt to reduce the risk of practice based improvements (McGawley & Bishop, 2006; Mendez-Villanueva et al., 2007). However familiarisation sessions for cycle-trained participants have been reported to be unwarranted (Martin et al., 2000; Pekünlü, 2015; Wehbe et al., 2015).

As all participants within this investigation were cycle trained, multiple familiarisation sessions were deemed unnecessary. However, to ensure each participant was still familiar with the protocol a full verbal explanation of the exercise testing protocol was provided prior to initiation of the protocol and participants were required to perform three 3 second sub maximal sprints interspersed throughout their warm up. Following the completion of the 5 minute warm up, participants were then given 1 minute to perform self-determined static stretches. The peak power test began 1 minute thereafter.

The peak power test consisted of four 6 second all out seated sprints against four loads of BM(kg) (7.5%, 9%, 10.5%, 12%) in a randomly assigned order, selected to produce peak pedalling rates of 100-200 $revs.min^{-1}$ (Coleman, 1994). Peak power output was recorded as the maximal peak power exerted over all sprints. In a few cases these resistances were insufficient and participants were asked to performance an additional sprint at 13.5% of BM(kg).

A short duration test was selected, opposed to more traditional 30 seconds tests such as the Wingate anaerobic test, because of the primary focus upon peak power –which has been reported to occur in the first 3-5 seconds (Driss & Vandewalle, 2013). Several researchers have recommended shorter tests when exploring peak power output (Moussa et al., 2003; Eston & Reilly, 2009; Wehbe et al., 2015) to avoid unnecessary exertion by the participant as power output decreases rapidly with time (Wilkie, 1960; Driss & Vandewalle, 2013).

Multiple sprints against different loads were selected in an attempt to ensure each participant performed against an appropriate resistance to permit the participant's highest possible power output. Traditionally peak power tests have used 7.5% of BM(kg) as the optimal resistive load, originally proposed by Ayalon et al., (1974) for the 30 second Wingate anaerobic test. However, several studies have criticised this level of resistance, particularly for trained or powerful athletes and suggested higher magnitudes of resistance is necessary (Vandewalle et al., 1985; Üçok et al., 2005; Jaafar et al., 2015). As there is no consensus on the optimal resistance for peak power production several researchers have suggested the use of an array of break forces (Eston & Reilly, 2009; Driss & Vandewalle, 2013).

Each sprint was conducted from a seated stationary start. This differs from the traditional 30 second Wingate anaerobic test proposed by Ayalon et al., (1974), which begins from a rolling start. However, as rolling starts are suggested to be an unnecessary use of energy (Vargas et al., 2015), several investigations have favoured stationary starts due to their ease of standardisation and apparent facilitation of higher peak power outputs (Macintosh et al., 2003; Novak & Dascombe, 2004; Driss & Vandewalle, 2013). All participants were required to start with a pedal angle of 30° above the horizontal on the dominant leg, as recommended by Tanner & Gore (2013), and remain seated throughout.

On the command of 'go', participants began to pedal. As verbal encouragement can influence performance (McNair et al., 1996), all verbal encouragement was scripted and attempts were made to keep tone, tempo and timbre consistent. Each sprint was separated by 5 minutes (4 minute active recovery + 1 minute stationary rest) similar to previous investigations (Pirnay & Crielaard, 1979; Vandewalle et al., 1987a; Bogdanis, 1996; Santos et al., 2002), in an attempt to minimise fatigue and maximise recovery.

To ensure participants' safety, all participants were visually and verbally monitored throughout the peak power test, with particular attention given to identifying symptoms detailed within the (ACSM, 2013) safety guidelines: a desire to stop, extreme fatigue, leg cramping, poor perfusion. Each participants' heart rate and the rate of perceived exertion (RPE), using a polar heart rate monitor (Polar Electro, Kempele, Finland) and the RPE Borg scale (Borg, 1998) respectively, were recorded after every sprint to monitor the participants degree of exertion.

Upon completion of the peak power test all participants were required to continue cycling at a self-selected cadence and resistance for a minimum of 5 minutes, and for a self-selected period thereafter. All participants were then encouraged to perform self-selected stretches. Throughout the cool down period, and for a minimum of 10 minutes thereafter, all participants were visually and verbally monitored for abnormal responses in recovery, based upon the recommendations of Fletcher et al., (2001). All peak power outputs, absolute and normalised to body mass, were collated into Microsoft Excel (Microsoft Office Professional Plus 2010, Microsoft Corporation, Redmond, USA) alongside all anthropometrics and data acquired from the participant pre exercise screening form and participant cycling and physical activity background questionnaire.

7.2.4 Data analysis

To identify any differences in anthropometrics or peak power output between data collection sessions the mean absolute and relative differences were calculated in Microsoft Excel (Microsoft Office 2011, Microsoft Corporation, USA). To ensure the selection of suitable analysis procedures the parametric nature of all variables were first explored. A Shapiro-Wilks and Levene's test for equality of variance were conducted to determine the normality and homogeneity of variance, respectively, within SPSS (IBM SPSS Statistics 24.0). When separated by cycling discipline, several variables were normally distributed and demonstrated homogeneity of variance. However, because many variables demonstrated skewness and kurtosis, and the data set demonstrates high degrees of multicollinearity, the parametric nature was therefore accepted with caution. A one-way ANOVA with Games-Howell post hoc correction was then executed to explore the differences in group descriptives. Games-Howell was selected due to its suitability for use within unequal and small sample sizes (Field, 2009).

To determine the degree to which peak power output can be explained by changes in anthropometrics, partial least squares regression analysis (PLSR) was conducted. Originally proposed by Wold (1975) PLSR is a predictive method that combines elements of linear regression and factor analysis. Similar to principle component analysis (PCA), PLSR resolves the issues with multicollinearity and a greater number of predictors than observations (Wold et al., 1984; Abdi, 2010). PLSR reduces the predictor (x) and response (y) variables to principal components. The y-component scores are then predicted from the x-components creating several latent factors, which in turn are used to predict the raw y variable (Bastien et al., 2005). PLSR is reported to be more efficient than the PCA technique as it takes the response variable into account (Maitra & Yan, 2008).

PLSR was conducted within SPSS (IBM SPSS Statistics 24.0) using the ANACONA (https://www.continuum.io/downloads) Python powered open data science platform (4.3.0, Continuum Analytics LTD), following the instruction of Garson (2016). Anthropometrics were used as the x predictor variables divided into simple and, simple and complex, as comparison of two separate models is unadvised. The y response variable was peak power output (watts).

The mean root squared prediction error (RMSE) by leave one out cross-validation was calculated to determine the optimal (and most parsimonious) combination of latent factors. RMSE were calculated within MATLAB (MathsWorks Inc.) using libPLS (Li et al., 2014) MATLAB library source codes. The lower the RMSE the more optimal (and parsimonious) the combination of latent factors. Thus, the model with the lowest RMSE is typically regarded as the most optimal (MathWorks, 2017).

Due to the small sample size further validation of the models was not possible. Furthermore, typical difference testing between the two models was not feasible. Although the variables used within the creation of the PLSR models were nested the latent factors used to create them were not. It is possible that other analysis methods such as neural networks and top down induction decision trees (TDIDT) would prove highly informative within this investigation. However, as the reliability of these modelling methods is solely dependent upon training (Saxén & Pettersson, 2006) and thus a sufficiently large data set to facilitate training and avoid bias, such methods were not deemed suitable on this occasion.

To determine the importance of each anthropometric within the model the variable importance in projection statistic was exported (VIP) within the PLSR analysis in SPSS (IBM SPSS Statistics 24.0). VIP is the weighted sum of squares of the PLSR-weights, with the weights calculated from the amount of Y- variance of each PLSR component (Wold et al., 1993, 2001). VIPs ≥ 0.8 were considered to significantly contribute to the model and have high predictive power, based on the suggestions of Wold (1995). VIP's were calculated within MATLAB (2017a, MathsWorks Inc.) using libPLS (Li et al., 2014) MATLAB library source codes.

7.3 Results

Table 7.1 demonstrates the group descriptives. Sprint cyclists produced the highest peak power output, followed by mountain bike cyclists, time trial cyclists and endurance cyclists. Whilst the same differences between groups were demonstrated for peak power output when normalised to body mass, the degree of significance in the differences demonstrated was reduced.

Table 7.1. The mean ± standard deviations of the group descriptives for each cycling group.

Descriptive		All	Sprint	Endurance	Time Trial	Mountain Bike
No.		54	9	8	14	23
Age (years)		29 ± 9	28 ± 8	28 ± 11	27 ± 12	33 ± 7
Stature (cm)		180.2 ±8.4	181.0 ± 7.5	179.2 ± 7.8	179.0 ± 10.2	181.0 ± 8.3
Body mass (kg)		65.7 ± 10	80.2 ± 10.8	68.4 ± 10.9	72.0 ± 6.4 *M	78.9 ± 8 ^{*T}
Peak power output	(watts)	1724 ±330	1988 ± 291$^{*E\ *T}$	1400 ± 292 $^{*S\ *M}$	1595 ± 163 ^{*S}	1811 ± 323 ^{*E}
	(watts .BM (kg))	22.2 ±3.4	23.9 ± 2.2	20.6 ± 3.8	21.3 ± 2.6	22.7 ± 3.9
Swann Classification		3.26 1.77	4.10 0.98	4.96 1.32	3.79 1.93	2.01 1.15
Hours per week	Training	10.8 4.69	11.00 5.45	12.75 3.81	10.04 4.42	8.83 4.63
	Competing	2.53 2.16	2.75 1.75	3.00 1.71	3.21 2.55	1.87 2.12

Significantly different ($p \leq 0.05$) to: ^{*S}= sprint cyclists, ^{*E}= endurance cyclists, ^{*T}= time trial cyclists, ^{*M}= mountain bike cyclists.

The simple anthropometrics PLSR model and simple and complex anthropometrics PLSR models, for all cyclists and across all cycling disciplines, demonstrated varying degrees in which anthropometrics explains the variance in peak power output (Table 7.2), and VIP's for each anthropometrics (Figure 7.1, Figure 7.2, Figure 7.3, Figure 7.4 and Figure 7.5) for the sprint, endurance, time trail and mountain bike groups respectively).

Table 7.2: The cumulative R^2 (the R^2 for each latent factor included) and the adjusted R^2 for each PLSR model

Group	Model: Simple			Simple + Complex		
All	0.27	(0.27)	0.26	0.36	(0.27,0.06,0.03)	0.32
Sprint	0.35	(0.17, 0.18)	0.13	0.56	(0.14,0.18,0.23)	0.29
Endurance	0.30	(0.30)	0.19	0.31	(0.31)	0.20
Time Trial	0.63	(0.34, 0.29)	0.56	0.68	(0.30,0.33, 0.05, 0.01)	0.54
Mountain Bike	0.16	(0.16)	0.12	0.46	(0.16, 0.26,0.04)	0.38

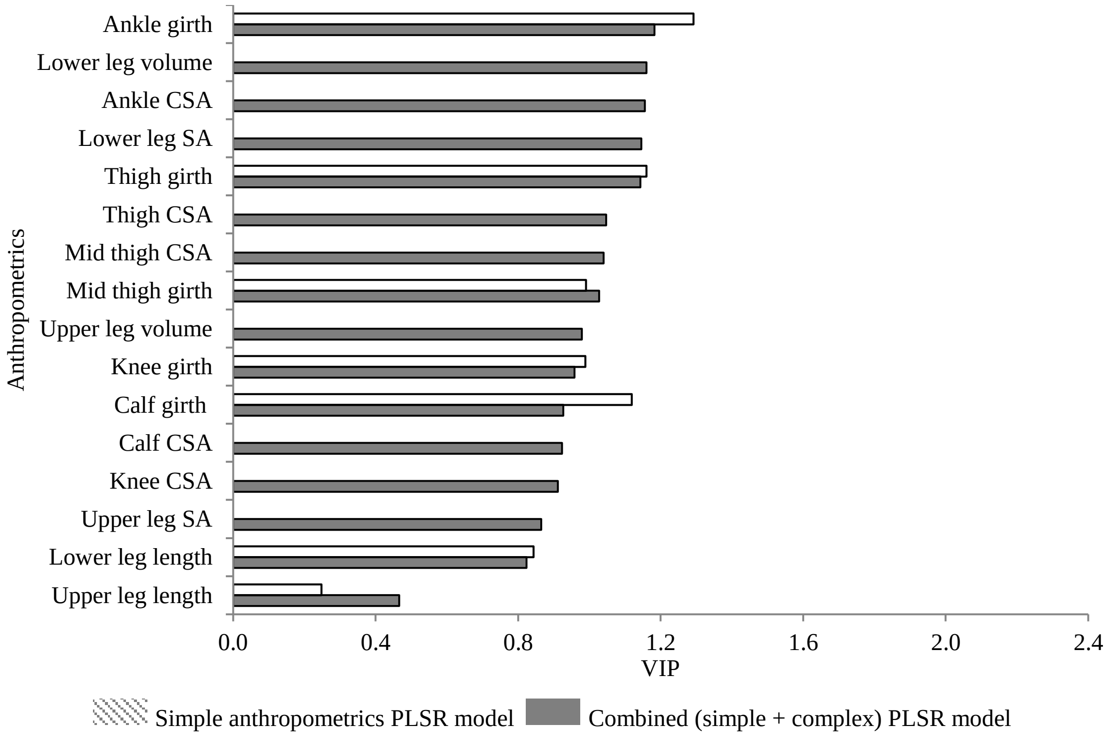


Figure 7.1: The VIP for anthropometrics of all cyclists for both PLSR models. 6/7 anthropometrics demonstrated VIP ≥ 0.8 within the simple anthropometrics PLSR model, and 15/16 (simple: 6/7, complex: 9/ 9) anthropometrics demonstrated VIP ≥ 0.8 within the simple and complex anthropometrics PLSR model.

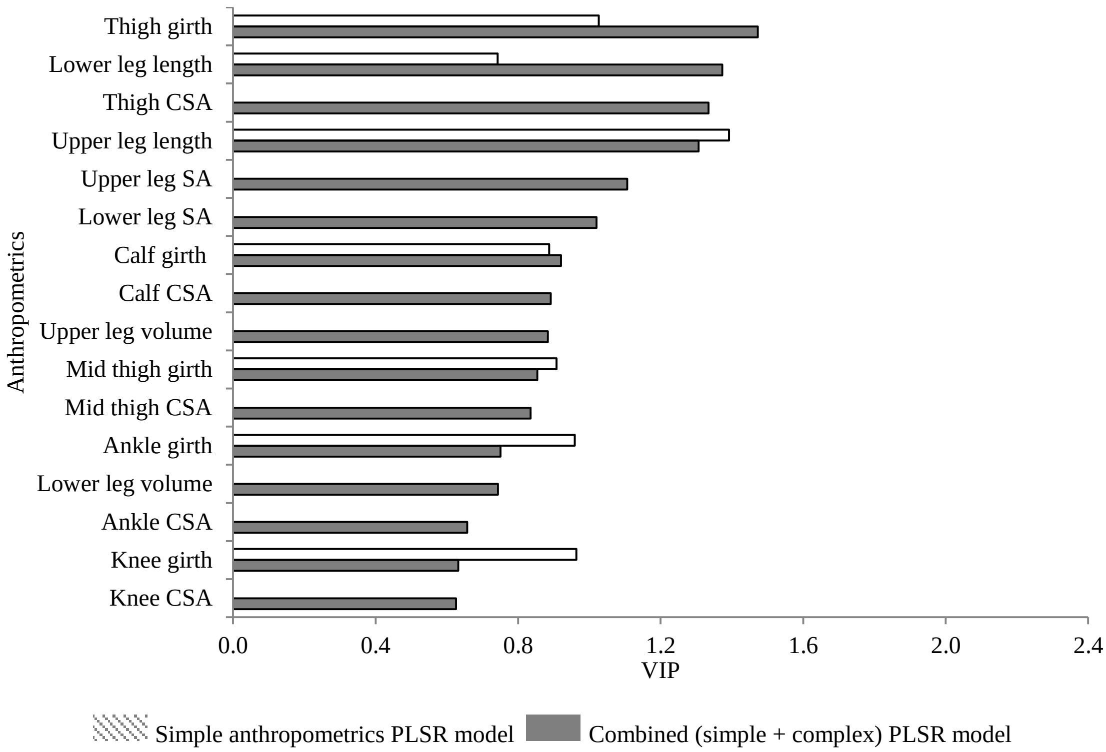


Figure 7.2: The VIP for anthropometrics of sprint cyclists for both PLSR models. 6/7 anthropometrics demonstrated VIP ≥ 0.8 within the simple anthropometrics PLSR model, and 11/16 (simple: 5/7, complex: 6/ 9) anthropometrics demonstrated VIP ≥ 0.8 within the simple and complex anthropometrics PLSR model.

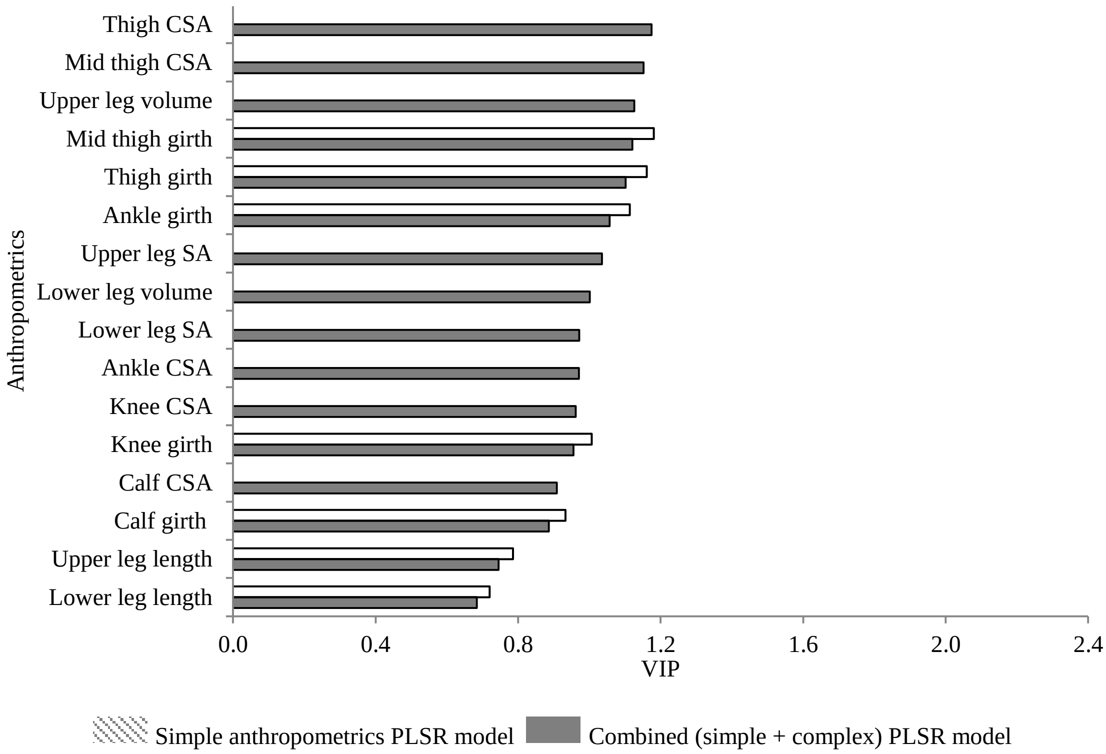


Figure 7.3: The VIP for anthropometrics of endurance cyclists for both PLSR models. 5/7 anthropometrics demonstrated VIP ≥ 0.8 within the simple anthropometrics PLSR model, and 14/16 (simple: 5/7, complex: 9/ 9) anthropometrics demonstrated VIP ≥ 0.8 within the simple and complex anthropometrics PLSR model.

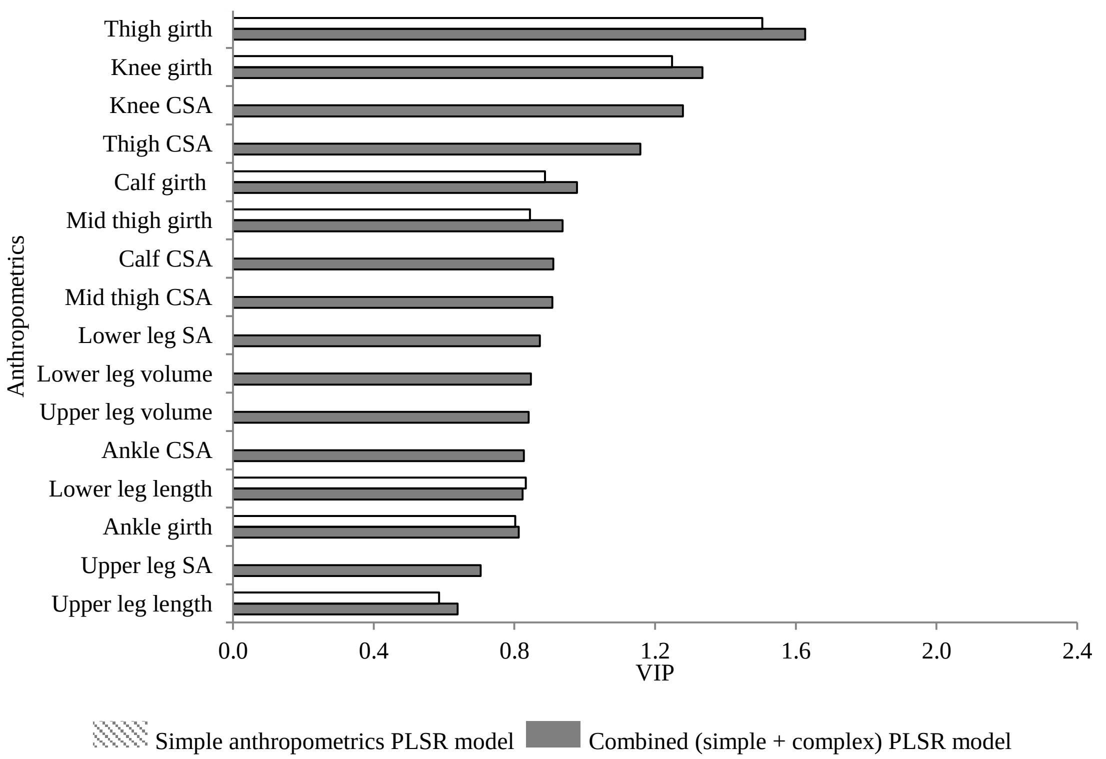


Figure 7.4: The VIP for anthropometrics of time trial cyclists for both PLSR models.6/7 anthropometrics demonstrated VIP ≥ 0.8 within the simple anthropometrics PLSR model, and 14/16 (simple: 6/7, complex: 8/ 9) anthropometrics demonstrated VIP ≥ 0.8 within the simple and complex anthropometrics PLSR model.

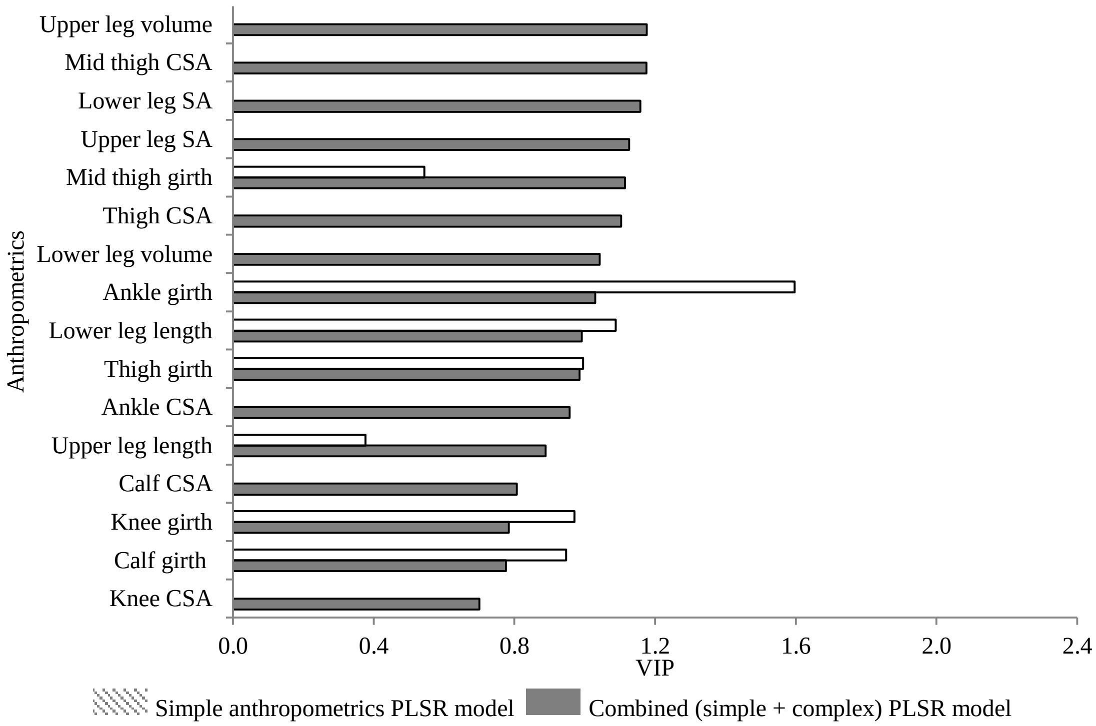


Figure 7.5: The VIP for anthropometrics of mountain bike cyclists for both PLSR models. 5/7 anthropometrics demonstrated VIP ≥ 0.8 within the simple anthropometrics PLSR model, and 13/16 (simple: 5/7, complex: 8/ 9) anthropometrics demonstrated VIP ≥ 0.8 within the simple and complex anthropometrics PLSR model.

7.4 Discussion

The aim of this investigation was to determine the importance of complex anthropometrics in explaining the variance in peak power output. 55 male volunteers were recruited and stratified into four groups: track and road sprint, road endurance, road time trial and mountain bike (cross-country and enduro) cyclists. 3D images of the lower body of each participant were captured using 3D surface imaging (3dMDbody5) from which simple and complex anthropometrics were exported. Peak power output was measured as the peak power output produced during four maximal 6 second sprints on an electronically braked ergometer. The anthropometrics and peak power output recorded were used to create PLSR models for simple anthropometrics and, simple and complex anthropometrics.

The results of this investigation suggest that in explaining the variance in peak power output in cyclists, the inclusion of complex anthropometrics improved the predictive capabilities of anthropometrics. This investigation reiterates the findings of Schranz et al., (2012) who explored the inclusion of complex anthropometrics in the assessment of self-reported 2000 m ergometer performance in junior male and female rowers. Examination of the regression models demonstrates that the predictive capability of both the simple, and simple and complex models varies between cycling disciplines.

This variation is aligned with the degree to which each cycling discipline is dependent upon the production of peak power, except for time trial cyclists which demonstrate the largest R^2 value in both the simple and, simple and complex PLSR models. It is possible that the differing results of these cycling sub disciplines are attributable to the differing experience levels or the absence of a familiarisation protocol. Although several investigations have reported the reduced importance of familiarisation of cycling based protocol with cycling trained individuals (Martin et al., 2000; Pekünlü, 2015; Wehbe et al., 2015), as discussed above, it is unclear if all participants were equally familiar in cycling against high resistances and producing peak power output. Although Schranz et al., (2012) also demonstrated differences between groups, based on sex, they did not discuss the potential causes for this. Consequently, the reason why the predictive capability of both the simple, and simple and complex PLSR models varies between cycling disciplines remains unclear. Irrespective of this, the results of this investigation demonstrated that the inclusion of complex anthropometrics increased the degree to which anthropometrics explained variance in peak power output. Consequently, future research into the predictive modelling, talent identification and athlete monitoring may wish to consider the use of complex anthropometrics.

Anthropometrics of the thigh; lean volumes, total volume and girths, have been reported to demonstrate positive relationship with peak power output (McCartney et al., 1983; Mclean & Parker, 1989; Dorel et al., 2005; Basset et al., 2014). The results of this investigation reiterate the findings of previous investigations, as of the seven anthropometrics that substantially contributed to the prediction of peak power output (VIP $\geq$ 0.8), for all cycling disciplines, five were of the upper leg; upper leg volume, mid-thigh girth, thigh CSA, mid-thigh girth and mid-thigh CSA. The anthropometrics of the lower leg that substantially contributed to the prediction of peak power output (VIP $\geq$ 0.8), for all cycling disciplines, were both complex anthropometrics: Lower leg surface area and lower leg CSA. This is supported by a previous investigation by Katch & Katch (1974) whom demonstrated that body mass, lower limb surface area and lower limb volume accounted for 46% of the variability in power output in sprint cycling. It is possible that the increased importance of the anthropometrics of the lower leg is associated with the transmission of force through the gastrocnemii during cycling. Although in cycling the majority of power is transmitted to the foot at the ankle joint during knee extension part of the quadriceps power output is transferred to the foot by the gastrocnemii and the achilles tendon (Driss & Vandewalle, 2013). Driss &

Vandewalle (2013) suggested that the force of the gastrocnemii determines the magnitude of the quadriceps power output that can be transmitted to the Achilles tendon and subsequently the foot. Irrespective, examination of the VIPs demonstrate that when predicting peak power output complex anthropometrics are as important as simple anthropometrics, and in some cases, can highlight relationships that are unidentifiable through simple anthropometrics alone.

Anthropometrics about the ankle and knee, and of length substantially contributed to the prediction of peak power output (VIP $\geq$ 0.8) in predominately all cycling discipline groups except sprint cycling. It is possible that these anthropometrics reflect the cyclists' skeletal frame size. As an individual's skeletal frame has been reported to influence an individual's capacity for muscle (Chumlea et al., 2002) and consequently strength (Malina & Bouchard, 1991); i.e. the larger an individual's skeletal frame the greater their capacity for muscle. Typically, skeletal frame measures are bone lengths and breadths, particularly the epicondyles of the femur for the lower body. However, as neither breadths nor body compositions were extracted within this investigation further research would be necessary to confirm these explanations.

Previous literature suggests that cyclists from short duration events, such as track sprinting are capable of producing the highest peak power output (Passfield et al., 2012). The results of this investigation support the current literature as sprint cyclists produced the highest peak power outputs, followed by mountain bike cyclists, time trial cyclists and endurance cyclists. However, the magnitude of peak power outputs reported within this investigation are greater than those reported by previous investigations (Vandewalle et al., 1987b; Davies & Sandstrom, 1989; Martin et al., 1997; Dorel et al., 2005). It is possible that this is due to the inclusion of inertial corrections, typically not included within anaerobic bike based tests. Exploration of the uncorrected measures confirms this, as inertia load correction added a mean of 570 $\pm$ 257 watts. Inertia correction includes the power generated to overcome the moment of inertia of the stationary flywheel. Several researchers have suggested the inclusion of this correction as it produces a more accurate measurement of peak power output as it is during this period in which peak power is reported to be exerted (Driss & Vandewalle, 2013). Continued validation of the Lode ergometers throughout this investigation reduces the concern that it could be a source of error from the ergometer itself.

7.4.1 Limitations

This study has limitations that require consideration. Firstly, because of the small sample sizes within this investigation, the degree to which these results are representative of the wider population groups remains unknown. Secondly, due to the analysis methods adopted it has not been possible to determine if the inclusion of complex anthropometrics altered the prediction power of the PLSR models to a statistically significant degree. Thirdly, although peak power production is a performance determinant of cycling performance, its importance to performance varies between cycling disciplines. Although the use of a consistent performance measure allowed comparison between groups, it cannot be classed as the most important measure of cycling performance for all disciplines. Fourthly, whilst attempts were made to ensure ecological validity of the performance measure, i.e. participant's bike setup and footwear, the bike was stationary and therefore is unlikely to be truly representative of cycling performance (Jobson et al., 2007). Finally, although applied kinanthropometry highlights the anthropometrics that are important in predicting performance, the stability of these anthropometrics over time remains unknown. Future research should focus upon the importance of complex anthropometrics in longitudinal kinanthropometric assessments of cyclists.

7.5 Conclusion

The results of this investigation demonstrated that the inclusion of complex anthropometrics increased the degree to which anthropometrics explained variance in peak power output. Thus the results suggest that complex anthropometrics complement simple anthropometrics in the prediction of peak power output in cyclists. Future anthropometric investigations may wish to consider extracting complex anthropometrics alongside simple anthropometrics in applied kinanthropometric investigations. Future research should focus on the importance of complex anthropometrics in longitudinal kinanthropometric assessments of cyclists.

Chapter 8 - The importance of complex anthropometrics in the longitudinal kinanthropometric assessment of cyclists

8.1 Introduction

The results of Chapter Seven demonstrated that the inclusion of complex anthropometrics increased the degree to which anthropometrics explained variation in peak power output. Although applied kinanthropometry highlights the anthropometrics important in predicting performance, the stability of these anthropometrics over time remains unknown. As outlined in Section 2.1.1, longitudinal kinanthropometry explores descriptive or applied kinanthropometry over a period of time. It provides understanding of the stability of anthropometrics over time and, similar to descriptive and applied, longitudinal kinanthropometry is useful in determining the anthropometrics that should be monitored in elite performance, in understanding the biomechanical and physiological ramifications of certain anthropometrics, and in the creation of talent identification criteria. Consequently, investigation into the importance of complex anthropometrics in monitoring anthropometric changes of cyclists over time was warranted.

This chapter reports an investigation into complex anthropometrics and longitudinal kinanthropometry. The aim of this investigation was to determine the importance of complex anthropometrics in monitoring anthropometric changes and peak power output of cyclists over time. The objectives were to;

- Identify and recruit a group of cyclists undergoing a power based training phase.
- Obtain 3D images of the lower body of the cyclists using 3D surface imaging
- Obtain a measurement of peak power output from all cyclists prior to and after the power based training phase.
- Extract simple and complex anthropometrics from the 3D images.
- Identify if anthropometrics or peak power output changed over the course of the power based training phase.
- Determine the degree to which simple and complex anthropometrics identified morphological changes over time, for all participants as a group and individually.
- Determine the degree to which changes in peak power output are reflected by changes in simple and complex anthropometrics.
- Determine the degree to which simple and complex anthropometrics explain variance in peak power output.

- Explore the extent to which the PLSR model created within Chapter Seven predicts the peak power output after the training phase.

8.2 Method

8.2.1 Participants

All participants recruited within this investigation were members of a mountain bike strength and conditioning club. This investigation followed the cyclists through an eight-week power based training phase as part of their normal strength and conditioning club training programme. Participants were required to meet the inclusion and exclusion criteria outlined in Section 5.2. Based on these criteria, eight male mountain bike cyclists were recruited (Figure 8.1). In addition to the documentation detailed in Section 5.2, all participants were required to complete a pre-exercise screening questionnaire prior to each data collection session, identical to that used within Section 7.2.3. The pre-exercise screening questionnaire was used to ensure suitability for participation in exercise, identify any changes in health and adherence to the pre-exercise guidance. As the training programme was part of the cyclists' normal strength and conditioning club training, and thereby already voluntary, consent and screening were only obtained for participation within the data collection sessions that monitored the effects of the training programme. All procedures and documents were approved by Sheffield Hallam University Research Ethics Committee (Appendix Seven).

Figure 8.1: The mean ± standard deviations of the group descriptives.

Descriptive		Value
n		8
Age (years)		34.1 ± 4.1
Stature (cm)		180.4 ± 7.6
Body mass (kg)		80.6 ± 5.9
Swann Classification		2.0 ± 0.9 (semi-elite)
Hours per week:	Training	7.1 ± 3.1
	Competing	2.0 ± 1.6
IPAQ		High

8.2.2 Training programme

This investigation followed the cyclists through an eight-week power based training phase. A power based training programme was selected for monitoring due to the high correlation between peak power output to muscle size (Hopker et al., 2010; Dellanini et al., 2004; Martin, Davidson & Pardyjak, 2007) and thereby potentially between peak power output and body size (Olds, 2009), as previously discussed in Section 1.1 and

Section 7.2.2. In a single week the training programme consisted of two 1.5 hour strength and conditioning sessions (one at Sheffield Hallam University and one completed within their own time) and one 1 hour bike based interval training session (completed in their own time) (Appendix A.6.2). The training programme adopted a mixed methods approach in which a variety of loads and exercises were used in a periodised fashion to optimize power output, as recommended by previous investigations (Bompa & Haff, 2009; Cronin & Sleivert, 2005; Kawamori & Haff, 2004; Newton & Kraemer, 1994). Alongside adhering to the fundamental FITT principles of exercise training; frequency, intensity, type and time (Reimer, 1998). Each strength and conditioning session consisted of eight exercises, of a rotation of 26 exercises, performed for 4 - 5 repetitions in 4 - 5 sets (Appendix A.6.2).

All participants were required to repeat each set on both sides, when relevant. Furthermore, all participants were encouraged to perform each exercise at 75-90% of their 1RM and to increase their loads continually throughout the training program in an attempt to maximise power development, as recommended by previous investigations (Newton & Kraemer, 1994; Moss et al., 1997; Toji & Kaneko, 2004; Tricoli et al., 2005). Because the training programme adhered to suggestions from previous investigations and the fundamental principles of training it was hypothesised that the training programme was sufficient to induce change. Thus, the training programme monitored within this investigation was not written or influenced by the lead researcher (the author). To monitor adherence to the training programme participants were asked to keep a weekly record of their training and physical activity (Appendix A.7.3). To encourage adherence to the training phase weekly verbal and digital reminders were delivered to all participants. Adherence to the training program was 73.4% ± 10.2% across all participants.

8.2.3 Research protocol

All participants attended two data collections; pre and post (week 0 and week 8). During each data collection participants attended one 20 minute anthropometric data collection and a 45 minute peak power output test.

Anthropometrics collection

In line with the methods detailed in Section 5.3.3, during each anthropometric data collection participants had 12 anatomical locations (on each leg) manually palpated and marked. 3D images of the legs were then acquired using a 3dMDbody5 system and KinAnthroScan, from which 48 anthropometrics (32 size anthropometrics and 16 symmetry anthropometrics) were exported into excel, as detailed in Section 5.3.4. Anthropometrics of both the dominant and non-dominant sides, and symmetry anthropometrics were extracted within this investigation as it was hypothesised that the degree of symmetry demonstrated by cyclists may be one of the anthropometrics to vary over time.

Peak power output measurement

Immediately following the anthropometric data collection, all participants completed a peak power test on electromagnetically braked cycle ergometers (Lode Excalibur Sport with Pedal Force Measurement, Groningen, Netherlands). Although this is not a direct measure of mountain bike performance, a peak power test was selected as it is a direct measure of the primary intention of the training programme.

The peak power test conducted within this investigation was identical to that reported within Section 7.2.2. Briefly, participants completed a 5 minute warm up of submaximal cycling, followed by four six second all out seated sprints, from a stationary start, against four loads of BM(kg) (7.5%, 9%, 10.5%, 12%) in a randomly assigned order. This was followed by a 5 minute cool down at a self-selected cadence and resistance. Peak power output was recorded as the maximal peak power exerted over all sprints. This peak power test was selected for the reasons as outlined in Section 7.2.3. All data were collated into Microsoft Excel (Microsoft Office Professional Plus 2010, Microsoft Corporation, Redmond, USA) alongside all anthropometrics and data acquired from the screening documents.

During the peak power test all participants were required to wear exercise clothing of their choice, as specified in Section 5.3.1 and 7.2.3. As the type of footwear worn whilst cycling is believed to influence performance, all participants were required to wear the same cycling shoes and cleats for each data collection session, as reported in Section 7.2.3. Validation of each ergometer suggested the Lode ergometer demonstrated a small mean intra and inter-device error, as discussed in Section 7.2.3 and reported in Appendix Five, therefore participants were encouraged to use the same ergometer for each data collection session. Whilst this was possible on most occasions, on the occasions when using the same ergometer was not possible no correction to the data was applied due to the small magnitude of mean inter-device differences.

8.2.4 Data analysis

To identify any differences in anthropometrics or peak power output between data collection sessions the mean absolute and relative differences were calculated in Microsoft Excel (Microsoft Office 2011, Microsoft Corporation, USA). To ensure the selection of suitable statistical analysis procedures the parametric nature of all variables were first explored. A Shapiro-Wilks and Levene's test for equality of variance were conducted to determine the normality and homogeneity of variance, respectively, within SPSS (IBM SPSS Statistics 24.0). To identify the sphericity of the data set Mauchly's test of sphericity was conducted on all variables.

Correlation testing was conducted to determine the degree of correlation between the change in anthropometrics, the change in peak power output between data collections, and data collected from the screening documents (expertise categorisation score) and training diary (adherence). All correlation testing was conducted using a Pearson's or Spearman's correlation tests within SPSS (IBM SPSS Statistics 24.0), for parametric and nonparametric data respectively.

To determine if any statistically significant differences were present, a one-way repeated measures ANOVA or Friedman test was then executed within SPSS (IBM SPSS Statistics 24.0), for parametric and nonparametric data respectively. For parametric data, when the assumption of sphericity was violated the Greenhouse-Geisser correction was adopted. Greenhouse-Geisser was selected due to its suitability for use with small sample sizes (Field, 2009). Although one-way repeated measures ANOVA and the Friedman test increases the risk of type one error it was deemed more suitable than a one-way repeated measures MANOVA due to the high levels of multicollinearity and greater number of variables than participants.

To explore the sources of any significant differences highlighted, pairwise comparisons using a LSD correction was used. Whilst the LSD correction increases the risk of type one error its use was deemed necessary due to small magnitude of any differences. To accompany the interpretation of any differences, and reduce the risk of type two errors due to the small sample size, effect sizes between the data collection sessions for each anthropometric were also calculated. Effect sizes were calculated using Cohen's d

(1988) formula (Equation 3 and Equation 4), as outlined previously in Section 2.1.1. Cohen's d (1988) formula was selected because of its suitability for use with equal group sizes.

Although, as explained in Section 2.1.1, Cohen's d (1988) standardized effect sizes thresholds are criticised for their inappropriate use, as previous investigations using complex anthropometrics in cycling are sparse and the meaningful degree of difference one would hope to detect is unknown, they were deemed the most suitable for use within this investigation. However, to reduce the risk of type one errors and ensure any differences detected were attributable to true change; not attributable to the system's variability (MDC) identified in Chapter Four (0.67 cm in girths, 0.48 cm^2 in cross sectional areas, 67.85 ml in volumes and 0.99 cm^2 in surface areas), only large effect sizes $\leq$ -0.8 or $\geq$ 0.8 are reported as meaningful degrees of difference. For size anthropometrics, effect sizes $\leq$ -0.8 indicated that cyclists reduced in size between data collection sessions, and effect sizes $\geq$ 0.8 indicated that the cyclists increased in size between data collection sessions. For symmetry anthropometrics, $\leq$ -0.8 indicated that the cyclists symmetry increased (were less asymmetrical) between data collection sessions, and effect sizes $\geq$ 0.8 indicated that the cyclists symmetry decreased (were more asymmetrical) between data collection sessions.

In order to explore participants as individuals, plots of girth every 2 mm along the length of a segment were created. These were examined alongside the simple and complex anthropometrics.

To determine the degree to which peak power output can be explained by variance in anthropometrics PLSR models using simple and, simple and complex anthropometrics were created using the same methods as Section 7.2.4. Due to the small sample size and the absence of a training dataset, further validation of the model was not conducted. To determine the importance of each anthropometric within the model the VIP was exported from the PLSR analysis in SPSS (IBM SPSS Statistics 24.0), as detailed in Section 2.1.1 and used previously in Section 7.2.4 VIP $\geq$ 0.8 were considered to significantly contribute to the model and explain a degree of variance in peak power output, based on the suggestions of Wold (1995).

Peak power output was predicted for each cyclist using the PLSR model for mountain bike and all cyclists created within Chapter Seven and the anthropometrics from the post training phase data collection session to explore the degree to which complex anthropometrics can increase the predictive capability of anthropometrics. Whilst this data is not fully independent as the pre training phase data collection session data were included within the PLSR models created in Chapter Seven, exploration using this data was deemed suitable. Absolute (watts) and relative (%) mean and standard deviation of the differences between the measured and predicted peak power outputs were calculated to determine the error in each prediction.

8.3 Results

Statistical difference testing demonstrated no significant overall effect for time when all anthropometrics and peak power output were considered (Appendix Seven). No significant differences were demonstrated for any anthropometrics or peak power output between data collection sessions. This finding was reiterated by effect sizes (Appendix Seven), as neither anthropometric nor peak power output demonstrated meaningful effect sizes ($\leq$ -0.8 and $\geq$ 0.8). No statistically significant correlation ($p > 0.05$) between change in peak power output and anthropometrics, and adherence.

Correlation testing highlighted the change in ~8% (4/48, simple: 2/21, complex: 2/27) of anthropometrics to demonstrate a statistically significant ($p \leq 0.05$), medium to strong, positive correlation with the change in peak power output between data collection one and data collection three (Appendix Seven). These anthropometrics were; knee girth symmetry (r (6) = 0.84, p = 0.01), knee CSA symmetry (r (6) = 0.82, p = 0.01), mid-thigh girth symmetry (r (6) = 0.75, p = 0.03) and mid-thigh CSA symmetry (r (6) = 0.70, p = 0.05). Furthermore, ~6% (3/48, simple: 1/21, complex: 2/27) of anthropometrics demonstrated a statistically significant ($p \leq 0.05$) correlation with the Swann et al., (2014) categorisation score. These anthropometrics were; dominant knee girth (r (6) = -0.82, p = 0.01), dominant knee CSA (r (6) = -0.82, p = 0.01) and non-dominant lower leg volume (r (6) = 0.810, p = 0.03).

The results of this investigation demonstrated high inter-participant differences in the magnitude of change in anthropometrics, in addition to an absence of consistency in the relationship between change in the anthropometrics and the change in peak power. Consequently, exploration of participants as individuals was conducted by inspection of the raw data and girth plots (Figure 8.2 and Figure 8.3). It was noted that at no point was change identified by girth anthropometrics that was not also reflected by complex anthropometrics. Yet change in complex anthropometrics was demonstrated that was not reflected in girth anthropometrics. Furthermore it was highlighted that for some participants change at the location of girth anthropometrics was not representative over the change experienced throughout out the whole segment (Figure 8.2).

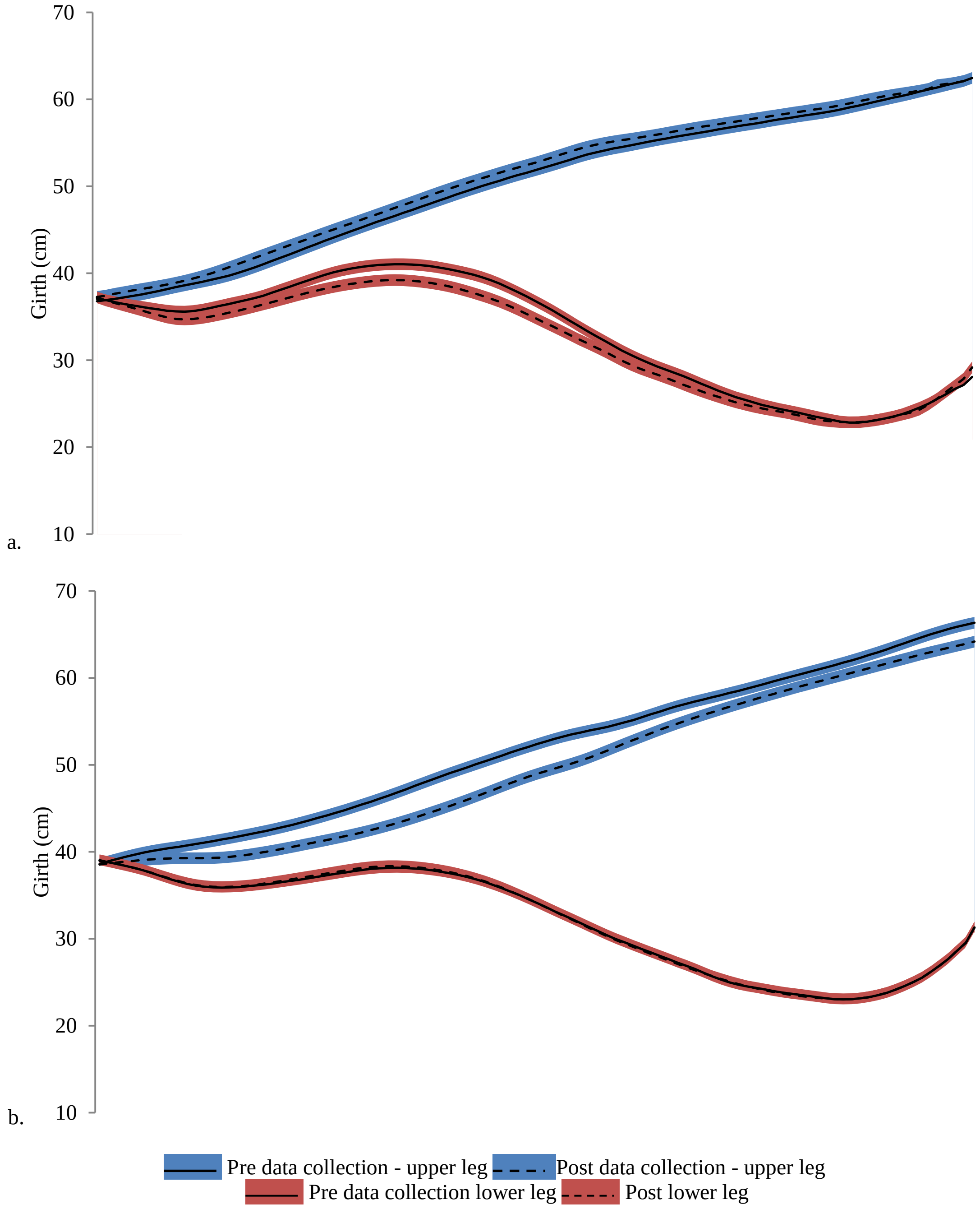


Figure 8.2: Girth (cm) plots and MDC of the 3dMDbody5 system (coloured band) for the dominant upper leg; from the knee to the upper thigh, and lower leg; from the knee to the ankle, for two participants (a & b) that demonstrated an increased peak power output

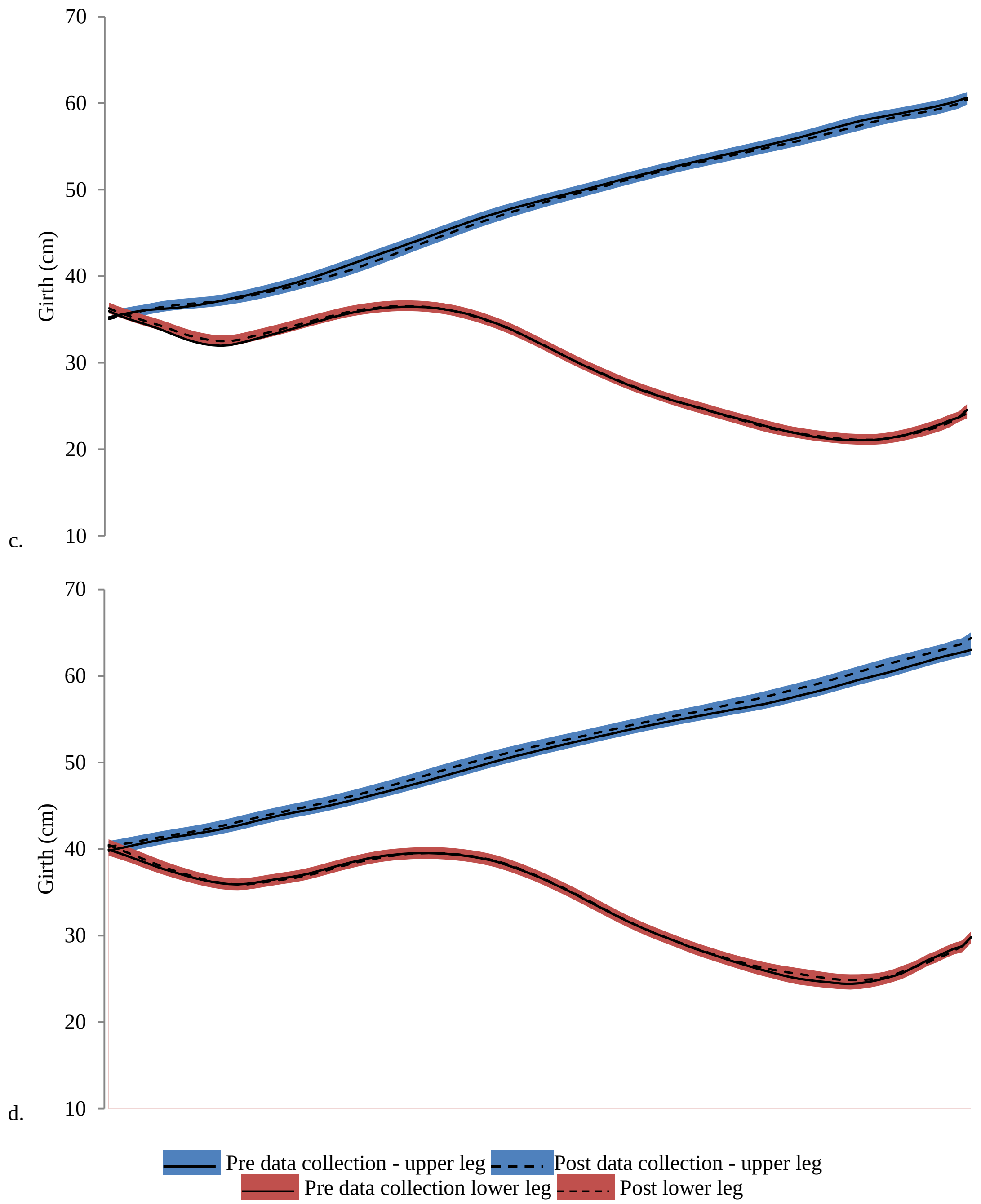


Figure 8.3: Girth (cm) plots and MDC of the 3dMDbody5 system (coloured band) for the dominant upper leg; from the knee to the upper thigh, and lower leg; from the knee to the ankle, for two participants that demonstrated a decrease (c) and no increase (d) in peak power output.

The PLSR models suggested that simple anthropometrics explained 76.0% and 64.6% of the variance in peak power output, for the pre and post data collection respectively as detailed in Table 8.1. Within this model 9/21 and 7/21 anthropometrics demonstrated VIP $\geq$ 0.8, for the pre and post data collection sessions respectively (Figure 8.4). 7/21 of the simple anthropometrics demonstrated meaningful VIP (VIP $\geq$ 0.8) for both the pre and post data collection sessions (Table 8.1). These included: thigh girth symmetry, dominant ankle girth, non-dominant ankle girth, dominant lower leg length, non-dominant lower leg length, dominant knee girth, and non-dominant knee girth.

Table 8.1: The cumulative R^2 (the R^2 for each latent factor included) and the adjusted R^2 for each PLSR model

Data collection	Model					
	Simple			Simple + Complex		
Pre	0.79	(0.79)	0.76	0.69	(0.69)	0.64
Post	0.70	(0.70)	0.65	0.63	(0.63)	0.56

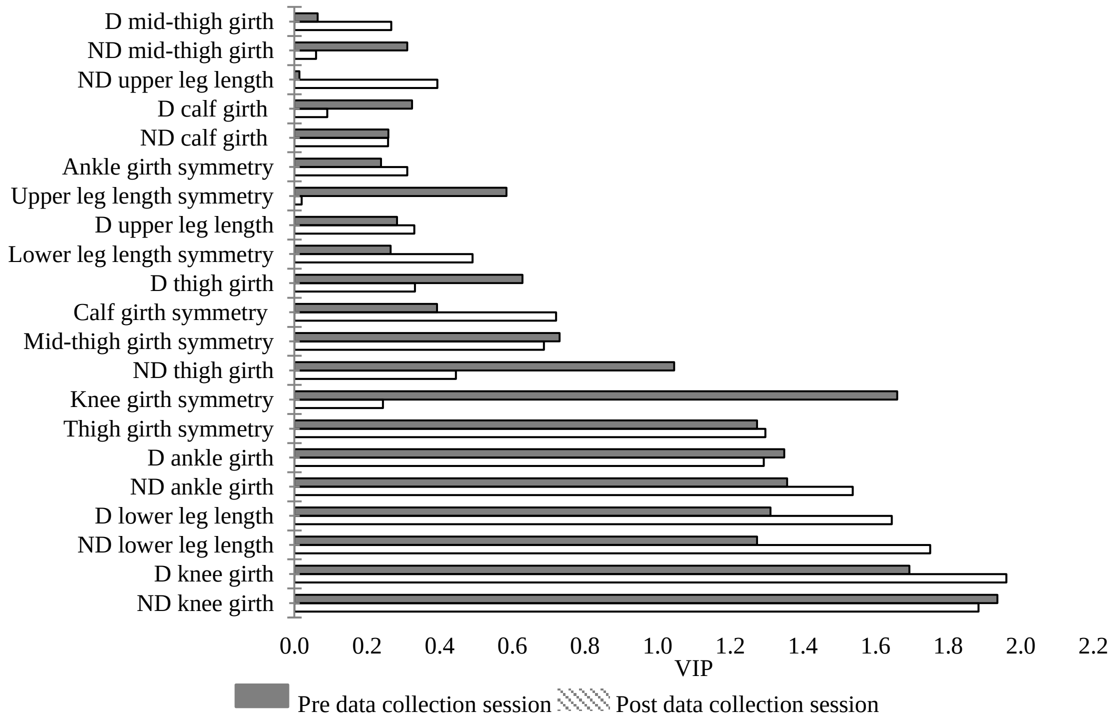


Figure 8.4: The VIP for anthropometrics of all cyclists for the pre and post data collection simple PLSR models.

The PLSR models suggested that simple and complex anthropometrics explained 63.7% and 56.4% of the variance in peak power output, for the pre and post data collection respectively as detailed in Table 8.1. Within this model ~42% (20/48, simple: 9/21, complex: 11/27) and ~33% (16/48, simple: 7/21, complex: 9/27) anthropometrics demonstrated VIP ≥ 0.8, as demonstrated in Figure 4 for the pre and post data collection respectively. 15/28 (simple: 6/21, complex: 7/27) anthropometrics demonstrated meaningful VIP (VIP ≥ 0.8) for both the pre and post data collection (Figure 8.5). These included: thigh girth symmetry, dominant ankle girth, dominant Ankle CSA, dominant lower leg volume, non-dominant lower leg volume, non-dominant ankle girth, dominant lower leg length, non-dominant ankle CSA, non-dominant lower leg length, dominant lower leg surface area, non-dominant lower leg surface area, dominant knee girth, dominant knee CSA, non-dominant knee CSA and non-dominant knee girth.

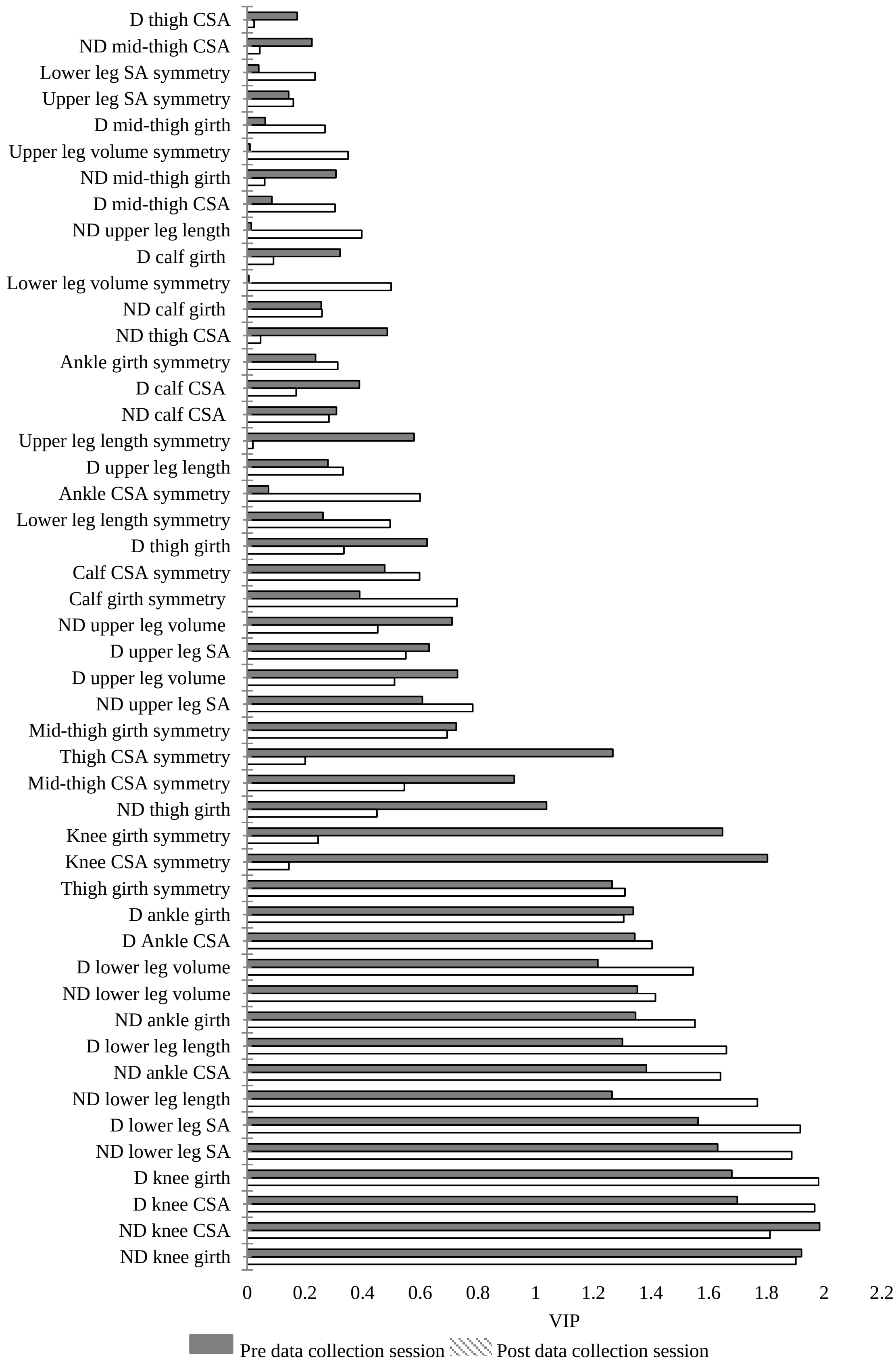


Figure 8.5: The VIP for anthropometrics of all cyclists for the pre and post data collection simple + complex PLSR models.

Anthropometrics acquired from the post training phase data collection session were used within the PLSR models for mountain bike and all cyclists created within Chapter

Seven. As illustrated in Figure 8.6, anthropometrics demonstrated very little predictive power and high inter-participant variability in the degree of accuracy of the predictions created by the PLSR models. However, overall (for 6/8 participants) the simple and complex PLSR models, in particular the mountain bike cyclists' specific model, demonstrated more accurate predictions of peak power output, alongside lower mean error in prediction (Table 8.2).

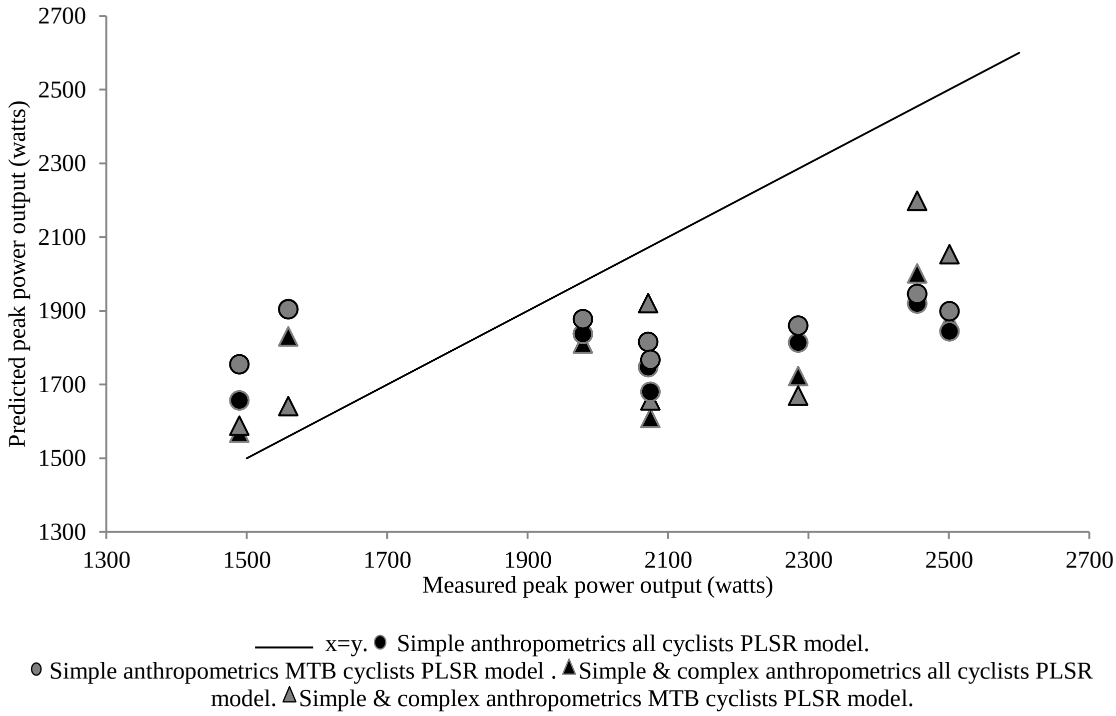


Figure 8.6: Prediction of peak power output (watts) using the models developed in Chapter Seven.

Table 8.2: Mean absolute and relative error and standard deviation for the prediction of peak power output using the models developed in Chapter Seven.

	PLSR model			
Mean error	Simple		Simple & Complex	
	All	MTB	All	MTB
Absolute (watts)	380.0 ± 175.6	351.9 ± 157.7	365.7 ± 192.9	273.4 ± 198.8
Relative (%)	18.0 ± 6.3	17.0 ± 6.1	17.02 ± 7.3	12.6 ± 8.1

8.4 Discussion

The aim of this investigation was to determine the importance of complex anthropometrics in monitoring anthropometric changes of cyclists over time. This investigation followed eight mountain bike cyclists through an eight-week power based training phase. When the results of this investigation were assessed as individual case studies, they demonstrated complex anthropometrics identified changes in anthropometrics as effectively as simple anthropometrics, and in some cases, identified change that would otherwise go unidentified by simple anthropometrics alone. As, at no point was change identified by girth anthropometrics that was not also reflected within complex anthropometrics. Yet change in complex anthropometrics was demonstrated that was not reflected in girth anthropometrics. This is because for some participants anthropometric change at the location of girth anthropometrics was representative of change throughout a segment, however for some participants this wasn't the case and anthropometric change at the location of girth anthropometrics was not representative of change experienced throughout out the segment. This investigation reiterates the advantages of 3D imaging systems as methods of acquiring anthropometrics within kinanthropometry. For example, the ability to acquire girth every 2 mm allowed the visual assessment of shape across the entire length of a segment - exploration of anthropometric change previously impractical and thereby unfeasible through traditional manual methods. Consequently kinanthropometrists, practitioners and sport and exercise scientists should consider the inclusion of complex anthropometrics within the longitudinally kinanthropometric assessment of cyclist, alongside exploring other methods of shape analysis to further bolster the battery of anthropometric analysis within kinanthropometry.

Examination of the dataset highlighted high inter-participant variability and small magnitude of change in anthropometrics and peak power output demonstrated by several cyclists within this investigation. Consequently, when group based results were assessed the benefits of complex anthropometrics were masked and simple and complex anthropometrics produced comparable findings. For example, no significant differences or meaningful effect sizes were demonstrated in any anthropometric or peak power output, thus simple and complex anthropometrics identified comparable differences in anthropometric change over time when all cyclists were assessed. The extent to which anthropometrics explained the variance in peak power output within the PLSR models was not increased by the inclusion of complex anthropometrics in either data collections session. Yet a comparable number of complex and simple anthropometrics remained relatively consistent in their ability to explain the variance in predicted peak power output within the PLSR models in both data collection sessions. An additional intention of this investigation was to explore the application of the PLSR models created in Chapter Seven, using the anthropometrics acquired from the post training phase data collection session. Within this investigation the simple and complex PLSR models, in particular the mountain bike cyclists' specific model, demonstrated more accurate predictions of peak power output, alongside lower mean error in prediction. Thus this finding does reiterate the finding of Chapter Two; that the peak power output demonstrates a relationship with anthropometrics in Mountain Bike cyclists. Whilst it falls beyond the remit of this investigation to determine if this relationship is attributable to correlation or causation, this finding does suggest that further work in predicting peak power output in cycling should consider both simple and complex anthropometrics.

There are several potential explanations for the inter-participant variability and the small magnitude of change in anthropometrics and peak power output demonstrated. Because the training programme adhered to suggestions from previous investigations and the fundamental principles of training, it was hypothesised that the training programme was sufficient to induce change. As the training programme content was theoretically grounded and designed to induce change based, as detailed in Section 8.2.2, and was of a similar duration to previous power and strength based training programmes that reported successful outcomes in cyclists (Rønnestad et al., 2010, 2017), it appears unlikely that the training programme did not induce change because of its content or duration. Whilst no statistically significant correlation between change in peak power output and anthropometrics, and adherence it is possible the training programme did not induce change because of insufficient adherence to the training programme. Adherence to the training program was only 73.4% ± 10.2%, despite monitoring of adherence and delivery of numerous reminders throughout the training phase. This is substantially lower than previous investigations that reported successful training programmes of similar durations for cyclists, such as 96 ± 4.5% (Rønnestad et al., 2017) and 97 ± 1.0% (Rønnestad et al., 2010). It is suggested low adherence to training programmes is attributable to individual factors; self-motivations, self-efficacy, exercise history, skills, and health behaviours, and environmental factors; cost, time barriers and, social and cultural supports (Dishman et al., 1980; Byerly et al., 1994; Sherwood & Jeffery, 2000). It is possible that the adherence demonstrated within this investigation is attributable to a combination of individual and environmental factors, particularly as data collection occurred during peak season. Consequently, this investigation suggests that further research takes adherence to the training programme and the individual and environmental factors that may influence adherence into greater consideration.

Few published investigations have explored the importance of complex anthropometrics in the longitudinal kinanthropometric assessment of cyclists. However, these predominantly suggest that complex anthropometrics can distinguish differences that are unidentifiable through simple anthropometrics alone within longitudinal kinanthropometric investigation. For example, Rønnestad et al., (2010) detailed that only thigh CSA demonstrated a correlation with increases in thigh strength in well-trained national level cyclists following a 12 week strength training intervention. Thus, the complex anthropometric of CSA could detect change that was undetectable through simple anthropometrics alone. Furthermore, Bullas et al., (2016) suggested that, in the longitudinal kinanthropometric assessment of the lower of body of an elite mountain bike cyclist, simple anthropometrics may misrepresent the magnitude of change in size and that 3D body measurement and complex anthropometrics; such as volume and surface area, may provide a more accurate representation of change through a body segment.

Anthropometrics of the thigh lean volume, total volume and girths, have been reported to demonstrate positive relationships with peak power output (McCartney et al., 1983; Mclean & Parker, 1989; Dorel et al., 2005; Basset et al., 2014). Several anthropometrics demonstrated stability in their importance in predicting peak power output between data collection sessions; and demonstrated meaningful VIP (VIP $\geq$ 0.8) for both the pre and post data collection session. The results of this investigation suggest a greater importance of lower leg anthropometrics as opposed to those of the upper leg. Although this is similar to the results presented in Chapter Seven, it remains unclear as to why anthropometrics of the lower leg appear to be of such importance in predicting peak power output. It is possible that this is attributable to the same reasons outlined in Section 7.4. Furthermore, anthropometrics of the knee appear to demonstrate increased importance within this investigation. It is possible that these anthropometrics reflect the cyclists' skeletal frame size as discussed in Section 7.4.

As detailed in Section 2.4.1, ISAK guidelines typically suggest anthropometrics are only acquired from the right-hand side of the body irrespective of the preferred side of the participant, unless considered impractical (e.g. due to injury) (Stewart et al., 2011). This is because the bias associated with side preference / dominance is believed to be less than manual measurement error (Martorell et al., 1988; Moreno et al., 2002). The results of this investigation found that only symmetry anthropometrics that demonstrated statistically significant correlation in change with the change in peak power output between data collection sessions. Further exploration of these differences highlighted an increase in the bias towards the dominant side, similar to the descriptive kinanthropometric profile of sprint cyclists reported in Chapter Six. As discussed in Section 6.4.2, several previous investigations have explored the asymmetries of cycling performance, particularly pedalling kinetics, kinematics and muscle recruitment (Daly & Cavanagh, 1975; Smak et al., 1999; Carpes et al., 2010). Bini (2011) suggested that at higher power (≥ 200 watts) pedalling asymmetries are exacerbated causing the dominant leg to receive greater neural drive and provide a greater contribution to power output. As the training programme, in particular the bike intervals, were directed to be performed at high intensity it is possible that the asymmetries in performance result in asymmetries in anthropometry. However, as the differences reported within this investigation fall below the MDC of the 3dMDbody5 system reported in Chapter Four (0.67 cm in girths, 0.48 cm^2 in cross sectional areas, 67.85 ml in volumes and 0.99 cm^2 in surface areas) it is possible these differences are attributable to variability of the 3dMDbody5 system and protocol.

8.3.1 Limitations

First, because of the small sample size, the degree to which these results are representative of the wider population groups is limited. As such, further work using larger sample sizes and cyclists from different cycling disciplines is necessary to confirm if these results are representative of the wider population groups and cyclists from other disciplines. Second, as discussed above, the small magnitude of change in peak power output demonstrated by the cyclists during the training programme limited the formation of stronger conclusions on the importance of complex anthropometrics. Therefore, further research to more clearly establish the importance of complex anthropometrics in longitudinal kinanthropometric investigations appears warranted.

8.4 Conclusion

The results of this investigation suggest that, in the assessment of longitudinal kinanthropometric assessment of cyclists, complex anthropometrics can identify changes in anthropometrics as effectively as simple anthropometrics and in some case can identify change that would otherwise go unidentifiable by simple anthropometrics alone. However, it appears that these benefits are masked when individuals are assessed as a group due to high degrees of inter-participant variability and the small magnitude of change in peak power experienced by the cyclists within this investigation.

Kinanthropometrists, practitioners and sport and exercise scientists should consider the inclusion of complex anthropometrics within the longitudinally kinanthropometric assessment of cyclist and prediction of peak power output in cycling. Future research should focus on further establishing the importance of complex anthropometrics in longitudinal kinanthropometric investigations using larger sample sizes, to confirm if these results are representative of wider population groups and cyclists from other disciplines, taking participants' adherence to training programmes or interventions into greater consideration to ensure the generation of change in peak power output.

Chapter 9 - Overall discussion

9.1 Introduction

The aim of this programme of research was to determine the importance of complex anthropometrics in the kinanthropometric assessment of cyclists. To fulfil this aim five objectives were identified. The research was motivated by previous literature that suggested complex anthropometrics, such as volume and area, can identify changes in body size and shape that might otherwise go unnoticed by simple anthropometrics (Rønnestad et al., 2010; Schranz et al., 2012) as well as providing a more realistic representation of the body (Daniell et al., 2013). A focus on cycling was adopted as it is a closed sport that is heavily influenced by the size and shape of the cyclist (Wolstencroft, 2002b; Dellanini et al., 2004; Chen et al., 2011) (Wolstencroft, 2002b; Dellanini et al., 2004; Chen et al., 2011). This is not merely due to the aerodynamic benefits of a smaller frontal area, but because power, which can be associated with muscle size (Dellanini et al., 2004; Hopker et al., 2010) and thereby body size, is a core determinant of sprint cycling performance which is important to success in the majority of disciplines and events (Faria et al., 2005b; Martin et al., 2007; Inoue et al., 2012). This chapter summarises the findings in relation to each objective, alongside the primary contributions to knowledge, practical implications, limitations of the research, potential areas for further research and overall conclusions.

9.2 Summary of work

9.2.1 Objective one: To synthesise information from across published literature and develop a critical understanding of the topic area and anthropometric measurement methods.

This was achieved in Chapter One through a literature review of sports kinanthropometry, complex anthropometrics, anthropometrics in cycling by cycling discipline and anthropometric measurement methods. Previous literature suggests complex anthropometrics, such as area and volume, can identify changes in body size and shape that are not detectable with traditional anthropometrics of lengths, breadths, skinfolds and girths. However, these investigations were limited and whilst optimal body dimensions are believed to be an important prerequisite of success in cycling, literature on the kinanthropometry assessment of cyclists is sparse and has predominantly focused solely on simple anthropometrics. Consequently, further research on the importance of complex anthropometrics within kinanthropometric assessment of cyclists and a greater understanding of the importance of lower body anthropometrics to cycling performance was warranted. Furthermore, the literature review suggested stereo photogrammetry imaging systems to be a suitable method for use within kinanthropometric assessments of cyclists. Although expensive, their high accuracy and repeatability provided confidence that any anthropometric differences, either between groups or over time, would not be masked by the system's variability.

9.2.2 Objective two: To validate the most suitable method of anthropometric measurement through comparison with established industry standards.

The 3dMDbody5 (3Q Technologies Inc., Atlanta, GA) surface imaging system was selected as the stereo photogrammetry system for validation. Chapter Three found the 3dMDbody5 system accuracy and repeatability to be compliant to industry standards (ISAK and ISO) when measuring validation objects of known dimensions. However, it was likely that the magnitude of error demonstrated by the 3dMDbody5 system would increase when measuring human participants due to factors such as hair, human movement and skin. Consequently, Chapter Four investigated the repeatability of the 3dMDbody5 system and its agreement with manual measurement when measuring human participants. The results of this investigation showed the 3dMDbody5 system to be highly repeatable and to demonstrate strong agreement with manual measurement, within established industry standards when measuring human participants. The 3dMDbody5 system's minimal clinically detectable differences of 0.67 cm, 0.48 cm^2, 67.85 ml and 0.99 cm^2 in girths, cross sectional area, volumes and surface areas, respectively were calculated using the data in Chapter Four. This established a quantifiable value of the systems variability for use in subsequent investigations. Consequently, the 3dMDbody5 system was deemed suitability valid and repeatable for use in subsequent investigations.

9.2.3 Objective three: To compare simple and complex anthropometrics in the descriptive kinanthropometric assessment of cyclists, by investigating the extent to which simple and complex anthropometrics can distinguish between non-cyclists and cyclists from different disciplines.

This was achieved within Chapter Six through an investigation into the importance of complex anthropometrics in distinguishing between population groups in cycling. Simple and complex anthropometries were collected from 25 male non-cyclists and 55 male cyclists from four cycling disciplines: track and road sprint, road endurance (> 50 miles), road time trial (< 50 miles) and mountain bike (cross-country and enduro). This created anthropometrics profiles, comprising simple and complex anthropometrics, of the lower body of non-cyclists and cyclists from the four cycling disciplines. The results of this investigation demonstrate complex anthropometrics can identify the differences between groups as effectively as simple anthropometrics, and in some cases, distinguish differences that are unidentifiable through simple anthropometrics alone.

9.2.4 Objective four: The fourth objective was to critically compare simple and complex anthropometrics in the applied kinanthropometric assessment of cyclists by determining to what degree simple and complex anthropometrics explain variance in cycling performance.

To address this objective, an investigation into the importance of complex anthropometrics in explaining variance in peak power output was conducted in Chapter Seven. This investigation collected simple and complex anthropometries and peak power output of 55 male cyclists from four cycling disciplines: track and road sprint, road endurance (> 50 miles), road time trial (< 50 miles) and mountain bike (cross-country and enduro). PLSR models and the extraction of VIP values showed that the degree to which anthropometrics explain variance in peak power output varies between cycling disciplines and that complex anthropometrics increased the degree to which anthropometrics explained variance in peak power output.

9.2.5 Objective five: To critically compare simple and complex anthropometrics in the longitudinal kinanthropometric assessment of cyclists by monitoring anthropometrics and cycling performance longitudinally, and assessing if the change in cycling performance related to changes in anthropometrics.

This was achieved within Chapter Eight, through an investigation to determine the importance of complex anthropometrics in monitoring anthropometric changes of cyclists over time. This investigation followed eight mountain bike cyclists through an eight-week power based training phase. Overall, participants experienced a small magnitude of change in anthropometrics and peak power output during the training programme. In identifying this change complex anthropometrics provided a comparable degree of understanding compared to simple anthropometrics. However, examination of participants as individuals demonstrated complex anthropometrics identified changes in morphology as effectively as simple anthropometrics, and in some cases, identified change that would have otherwise gone unidentified by simple anthropometrics alone. Analysis of individual participants using plots of girth every 2 mm highlighted the advantages of shape analysis. Consequently, it was concluded that, within this investigation, the benefits of complex anthropometrics were masked when individuals were assessed as a group due to high degrees of inter-participant variability and the small magnitude of change in peak power experienced by the cyclists within this investigation. Furthermore, using the PLSR models created in Chapter Seven, this investigation found that the inclusion of complex anthropometrics to simple anthropometrics improved the predictive capabilities of anthropometrics.

9.3. Contribution to knowledge

This programme of research extends the scope of the kinanthropometry discipline in its understanding of complex anthropometrics, consequently it has several contributions to knowledge. This research identified the minimal clinically detectable difference of the 3dMDbody5 imaging system, when measuring human participants, is 0.67 cm, 0.48 cm^2, 67.85 ml and 0.99 cm^2 in girths, cross sectional area, volumes and surface areas, respectively. Therefore, indicating the point at which any detected change of differences are truly attributable to differences in anthropometrics and not the system's variability. In the descriptive kinanthropometric assessment of cyclists, this programme of research demonstrated that complex anthropometrics distinguish between groups of cyclists and non-cyclists as effectively as simple anthropometrics, and in some cases can distinguish differences that are unidentifiable through simple anthropometrics alone. This work also created anthropometrics profiles, comprising of simple and complex anthropometrics, of the lower body of non-cyclists and cyclists from four cycling disciplines; sprint, endurance, time trail and mountain bike cycling. In addition this work demonstrates that individuals from these groups typically demonstrated different lower body anthropometric profiles. In the applied kinanthropometric assessment of cyclists, this research highlighted that complex anthropometrics increase the degree to which anthropometrics explained variance in peak power output. As a result, this work also established the degree to which anthropometrics explain variance in peak power output for four cycling disciplines; sprint, endurance, time trail and mountain bike cycling and that this varies between cycling discipline. As well as highlighted that complex anthropometrics improve the prediction of peak power output over that achieved through simple anthropometrics alone. In the longitudinal kinanthropometric assessment of cyclists, this programme of research demonstrated that complex anthropometrics can identify changes in anthropometrics as effectively as simple anthropometrics, and in some cases, can identify change that would otherwise go unidentifiable by simple anthropometrics alone.

9.4 Practical applications

The primary contributions to knowledge of this programme of research have several practical applications. This research suggests that in descriptive, applied and longitudinal kinanthropometric assessment of cyclists, complex anthropometrics complement simple anthropometrics, and in some cases, can distinguish differences / changes that are unidentifiable through simple anthropometrics alone. Consequently the results of this research suggests the inclusion of complex anthropometrics in future kinanthropometric assessment of cyclists will improve researchers', kinanthropometrists' and sport science practitioners' understanding of anthropometric changes and differences. Thus the results of this programme of research suggest researchers, kinanthropometrists and sport science practitioners to consider the inclusion of complex anthropometrics in the kinanthropometric assessment of cyclists. Furthermore, this work also adds to the understanding of complex anthropometrics within kinanthropometry.

This programme of research provides a more detailed understanding of the lower body anthropometric profiles of cyclists and the degree to which lower body anthropometrics explain the variance in peak power output in cyclists. This understanding will contribute towards creating a more coherent understanding of the anthropometrics of cyclists for use in applied and research contexts, particularly in determining the anthropometrics that should be monitored in performance, assisting in the creation of talent identification criteria and in the prediction of peak power output. This research also suggests cyclists from different cycling disciplines demonstrate different lower body anthropometric profiles and degrees to which anthropometrics explains the variance in peak power output. Thus, these results should be used to justify the separation of cyclists from different disciplines in future investigations and population based kinanthropometric surveys.

The findings of Chapter Three and Four provide a measurement of minimal clinically detectable difference of the 3dMDbody5 system, when measuring validation objects and human participants, for use in future investigations using this system. Due to the bespoke nature of many 3dMDbody5 imaging systems in configuration, lighting and camera focus, it is recommended that validation is conducted for each 3dMDbody5 imaging system. Irrespective, the findings of this research will provide an understanding surrounding the variability of 3dMDbody5 systems for future investigations and applications of this measurement method as, to the authors knowledge, no published investigation has previous explored the accuracy and repeatability of the 3dMDbody5 imaging system.

The results of this programme of research also advocate the use of 3D imaging systems as methods of acquiring anthropometrics - simple and complex - within kinanthropometry. 3D surface imaging was initially selected due to its high accuracy and repeatability, and the ability to collect both simple and complex anthropometrics. However, the use of a 3D imaging system provided several additional benefits. 3D imaging was quick and allowed retrospective or immediate analysis of data, particularly useful to confirm if large standard deviations in anthropometrics between data collection sessions were attributable to a digitising measurement error or true change. The method made the extraction of traditionally difficult anthropometrics, particularly those near intimate areas, easy to acquire as well as providing a visual tool to engage and interest participants. Furthermore, although not relevant within this body of work, 3D imaging systems have the ability to potentially further our understanding of shape and contour in kinanthropometric applications. Consequently, researchers, kinanthropometrists and sport science practitioners should consider the use of 3D imaging systems in kinanthropometric applications when possible.

Multiple leading kinanthropometrists (Olds, 2004; Stewart, 2010; Schranz et al., 2010; Schranz et al., 2012; Daniells, Olds & Tomkinson, 2013) have encouraged the use of 3D imaging technologies in kinanthropometry applications. Yet, the use of 3D technologies within kinanthropometry remains limited. The use of this measurement method has previously been restricted by the inaccessibility of the technology. However, the rapid market growth of 3D imaging systems has stimulated an increase in systems' performance, a decrease in costs and therefore an increase in accessibility suggests that it likely this technology will play an increasingly greater role within kinanthropometry. This programme of research provides further evidence that 3D imaging is a suitable method of acquiring anthropometrics within kinanthropometry. There would therefore seem to be a definite need for international governing bodies to incorporate this method into their standards and guidelines to ensure the use of this method is valid and consistent.

9.4 Limitations

Several limitations have been identified in each chapter of this programme of research. However, there are three that warrant the most consideration. Firstly, as the investigations of this programme of research investigated semi-competitive elite male cyclists of a relatively small sample size, the degree to which these findings are representative of the wider population is limited. Furthermore, as anthropometrics of only the lower body were collected and body composition measures were not acquired the importance of complex anthropometrics of the upper body and torso in the kinanthropometric assessment of cyclists and the extent to which any differences highlighted are attributable to differences in fat free mass, fat or bone remains unknown. However, to extend this research to the torso and upper body reconfiguration of the protocol would be necessary; validating the system for measurement of these segments, as it would be logistically difficult to capture all of these elements in a single session without a much larger (and therefore much more expensive) system. Secondly, this programme of research adopted a focus on peak power output as a measure of cycling performance. Whilst peak power production is a determinant of cycling performance and the use of a consistent performance measure allowed comparison between groups, its importance to performance varies between cycling disciplines. Thus, the extent to which anthropometrics relates to direct measures of cycling performance for each cycling discipline remains unknown. Finally, it is possible that the use of a relatively inaccessible 3D imaging system may limit the transferability and practical implications of the findings and recommendations reported within this body of work.

9.5 Future research

Several areas of further research have been highlighted through this programme of research. There are two areas that warrant the greatest attention. First, to address the limitations of this programme of research, future investigations should explore the importance of complex anthropometrics of the whole body using larger sample sizes, female athletes, athletes from different sport and / or athletes of varying expertise, in addition to determining the importance of anthropometrics to direct measurements of cycling performance. Second, future research should attempt to continue to extend the scope of the kinanthropometry discipline and 3D imaging by continuing to exploring low cost, accessible 3D imaging technologies and the barriers that may restrict the uptake of such systems within kinanthropometry, as well as investigating other methods of assessing body size using 3D imaging systems such as shape analysis.

9.6 Conclusions

The findings of this programme of research extend the scope of the kinanthropometry discipline. It has been demonstrated that in descriptive, applied and longitudinal kinanthropometric assessment of cyclists complex anthropometrics complement simple anthropometrics, and in some cases, can distinguish differences / changes that are unidentifiable through simple anthropometrics alone. Researchers, kinanthropometrists and sport science practitioners should consider the inclusion of complex anthropometrics in the kinanthropometric assessment of cyclists. Moreover, this programme of research has provided a more detailed understanding of cyclists' lower body that hopefully will contribute towards a more coherent understanding of the anthropometrics of cyclists.

Chapter 10 - References

[TC]2,2014. TC2-18 3D Body Scanner [online]. www.tc2.com. Available from: http://www.tc2.com/documents/tc218.

3dMD,2016. 3dMDTorso [online]. www.3dmd.com. Available from: www.3dmd.com.

3dMD,2017. Static-3dMD Sytstems [online]. www.3dmd.com. Available from: http://www.3dmd.com/3dmd-systems/#body.

Abbott, A., Collins, D., Martindale, R.J., & Sowerby, K.,2002. Talent identification and development: an academic review. Edinburgh: Sport Scotland.

Abdi, H.,2010. Partial least squares regression and projection on latent structure regression (PLS Regression). Wiley Interdisciplinary Reviews: Computational Statistics, 2, 97–106.

Accardo, J. & Chaudhry, M.A.,2014. Radiation exposure and privacy concerns surrounding full-body scanners in airports. Journal of Radiation Research and Applied Sciences, 7 (2), 198–200.

Ackland, T.R.,2006. Built for success: Homogeneity in elite athlete morphology. In: M. Marfell-Jones, A. Stewart, and T. Olds, eds. Kinanthropometry IX: Proceedings of the 9th International Conference of the International Society for the Advancement of Kinanthropometry. London: Routledge, 26–35.

Ackland, T.R., Lohman, T.G., Sundgot-borgen, J., Maughan, R.J., Meyer, N.L., Stewart, A.D., & Mu, W.,2012. Current status of body composition assessment in sport: review and position statement on behalf of the ad hoc Research Working Group on Body Composition Health and Performance, under the auspices of the IOC Medical Commission. Sports Medicine, 42 (3), 227–249.

Ackland, T.R. & Mazza, J.C.,1994. Introduction. In: J.E.L. Carter, T.R. Ackland, J. Mazza, and W.D. Ross, eds. Kinanthropometry in Aquatic Sports. Champaign, IL: Human Kinetics, 8–10.

ACSM,2013. *American College of Sports Medicine. ACSM's guidelines for exercise* testing and prescription. Baltimore: Lippincott Williams & Wilkins.

Al-Gindan, Y.Y., Hankey, C.R., Leslie, W., Govan, L., & Lean, M.E.J.,2014. Predicting muscle mass from anthropometry using magnetic resonance imaging as reference: a systematic review. Nutrition reviews, 72 (2), 113–26.

Aldridge, K., Boyadjiev, S.A., Capone, G.T., DeLeon, V.B., & Richtsmeier, J.T.,2005. Precision and error of three-dimensional phenotypic measures acquired from 3dMD photogrammetric images. American Journal of Medical Genetics, 138A (3), 247–53.

Alefs, B.G., den Hollander, R.J.M., Nennie, F.A., van der Houwen, E.H., Bruijn, M., van der Mark, W., & Noordam, J.C.,2010. Thorax biometrics from millimetre-wave images. Pattern Recognition Letters, 31 (15), 2357–2363.

ALGLIB,2014. Clustering [online]. ALGLIB. Available from: http://www.alglib.net/dataanalysis/clustering.php.

Apuzzo, N.D.,2009. Recent advances in 3D full body scanning with applications to fashion and apparel. In: A. Gruen and H. Kahmen, eds. Optical 3-D Measurement Techniques IX. Vienna.

Astrand, P.O. & Rodahl, K.,1977. Evaluation of physical work capacity on the basis of tests. In: P.O. Astrand and K. Rodahl, eds. Textbook of Work Physiology. New York: McGee Raw Hill, 333–365.

ASUS,2015. Xtion PRO LIVE [online]. www.asus.com. Available from: http://www.asus.com/uk/Multimedia/Xtion_PRO_LIVE/.

ASUS,2016. Asus Xtion Pro [online]. www.asus.com/3D-Sensor/Xtion_PRO. Available from: www.asus.com/3D-Sensor/Xtion_PRO.

Atkinson, G., Peacock, O., Gibson, A.S.C., & Tucker, R.,2007. Distribution of power output during cycling: Impact and mechanisms. Sports Medicine, 37 (8), 647–667.

Augustyn, C. & Peters, M.,1986. On the relation between footedness and handedness. Perceptual & Motor Skills, 63 (3), 1115–1118.

Ayalon, A., Inbar, O., & Bar-Or, O.,1974. Relationship among measurements of explosive strength and anaerobic power. In: R.C. Morehouse and C.A. Nelson, eds. International Series on Sport Sciences. Baltimore: University Press., 572–577.

Balmer, J., Potter, C.R., Bird, S.R., & Davison, R.R.C.R.,2005. Age-related changes in maximal power and maximal heart rate recorded during a ramped test in 114 cyclists age 15–73 years. Journal of Aging and Physical Activity, 13 (1), 75–86.

Basset, F.A., Billaut, F., & Joanisse, D.R.,2014. Anthropometric Characteristics Account for Time to Exhaustion in Cycling. International journal of sports medicine, 35 (13), 1084–1089.

Bastien, P., Vinzi, V.E., & Tenenhaus, M.,2005. PLS generalised linear regression. Computational Statistics and Data Analysis, 48 (1), 17–46.

BCC Research,2016. 3D Scanning: Technologies and Global Markets.

Beaton, D.E., Bombardier, C., Katz, J.N., & Wright, J.G.,2001. A taxonomy for responseness. Journal of Clinical Epidemiology, 54, 1204–1217.

Beunen, G. & Borms, J.,1990. Kinanthropometry: roots, development and future. Journal of Sport Science, 8, 1–15.

Bini, R.,2011. Effects of saddle position on pedalling technique and methods to assess pedalling kinetics and kinematics of cyclists and triathletes. Auckland University of Technology.

Bland, J.M. & Altman, D.G.,1999. Measuring agreement in method comparison studies. Statistical Methods in Medical Research, 8, 135–160.

Block, J.,2014. Block imaging your guide to medical imaging equipment – CT machine cost and price guide [online]. www.blockimaging.com. Available from: www.blockimaging.com.

Bogdanis, G.C.,1996. Effects of active recovery on power output during repeated maximal sprint cycling. European Journal of Applied Physiology and Occupational Physiology, 74 (5), 461–469.

Bong, Y.B., Merican, A.F., Azhar, S., Mokhtari, T., Mohamed, A.M., & Shariff, A.A.,2014. Three-Dimensional (3D) Anthropometry Study of the Malaysian Population. In: Proceedings of the 5th International Conference on 3D Body Scanning Technologies. Lugano, Switzerland, 167–173.

Borg, G.,1998. *Borg's perceived exertion and pain scales*. Champaign, IL: Human Kinetics.

Borkan, G.A., Hults, D.E., Gerzof, S.G., Robbins, A.H., Silbert, C.K., & Series, A.,1983. Age changes in body composition revealed by computed tomography. The Journals of Gerontology Biological Sciences and Medical Sciences, 38, 673–677.

Bragança, S., Carvalho, M., Xu, B., Arezes, P., & Ashdown, S.,2014. A Validation Study of a Kinect Based Body Imaging (KBI) Device System Based on ISO 20685 : 2010. In: Proceedings of 5th International Conference on 3D Body Scanning Technologies. Lugano, Switzerland.

Bray, M., Pomeroy, J., Knowler, W.C., Bersamin, A., Hopkins, S., Brage, S., Stanhope, K., Havel, P.J., & Boyer, B.B.,2013. Simple anthropometrics aremore correlated with health variables than are estimates of body composition in young people. Obesity, 21 (9), 435–438.

Bretschneider, T., Koop, U., Schreiner, V., Wenck, H., & Jaspers, S.,2009. Validation of the body scanner as a measuring tool for a rapid quantification of body shape. Skin research and technology: official journal of International Society for Bioengineering and the Skin (ISBS) and International Society for Digital Imaging of Skin (ISDIS) and International Society for Skin Imaging (ISSI), 15 (3), 364–9.

Brown, M.A., Carden, J.A., Coleman, R.E., McKinney, R., & Spicer, L.D.,1987. Magnetic field effects on surgical ligation clips. Magnetic Resonance Imaging, 5, 443–453.

Brunkhorst, L. & Kielstein, H.,2013. Comparison of anthropometric characteristics between professional triathletes and cyclists. Biology of Sport, 30 (4), 269–273.

Bullas, A., Choppin, S., Heller, B., Clarkson, S., & Wheat, J.,2014. Kinanthropometry applications of depth camera based 3D scanning systems in cycling : repeatability and agreement with manual methods. In: Proceedings of 5th International Conference on 3D Body Scanning Technologies. Lugano, Switzerland.

Bullas, A.M., Choppin, S., Heller, B., & Wheat, J.,2016. ISAK & digital 3D body measurement: A longitudinal case study from elite cycling. In: Kinanthropometry XV. Merida, Mexico, 215–217.

Byerly, P.N., Worrell, T., Gahimer, J., & Domholdt, E.,1994. Rehabilitation compliance in an athletic training environment. Journal of Athletic Training, 29 (4).

Cameron, N., Faulkner, F., & Tanner, J.M.,1986. The methods of auxological anthropology. In Eds Human Growth New York Plenum Press, 3, 3–46.

Capelli, C., Rosa, G., Butti, F., Ferretti, G., Veicsteinas, A., & di Prampero, P.E.,1993. Energy cost and efficiency of riding aerodynamic bicycles. European Journal of Applied Physiology & Occupational Physiology., 67 (2), 144–149.

Capelli, C., Rosa, G., Butti, F., Ferretti, G., Veicsteinas, A., di Prampero, P.E., Schena, F., Zamparo, P., DalMonte, A., Faina, M., & di Prampero, P.E.,1998. Energetics of best performances in track cycling. Medicine and Science in Sports and Exercise, 30 (2), 144–149.

Carpes, F.P., Mota, C.B., & Faria, I.E.,2010. On the bilateral asymmetry during running and cycling - A review considering leg preference. Physical Therapy in Sport, 11 (4), 136–142.

Carter, L.,2008. Kinanthropometry. In: J. Borms, ed. Directory of Sport Science: A journey through time: The changing face of ICSSPE. London: Human Kinetics, 137–154.

Chen, B.B., Shih, T.T.F., Hsu, C.Y., Yu, C.W., Wei, S.Y., Chen, C.Y., & Wu, C.H.,2011. Thigh muscle volume predicted by anthropometric measurements and correlated with physical function in the older adults. The Journal of Nutrition, Health & Aging, 15 (6), 433–8.

Chumlea, W.C., Wisemandle, W., Guo, S.S., & Siervogel, R.M.,2002. Relations between frame size and body composition and bone mineral status. The American Journal of Clinical Nutrition, 75 (6), 1012–1016.

Clarkson, S.A.,2015. The Use of Consumer Depth Cameras for Calculating Body Segment Parameters. Sheffield Hallam Univeristy.

Clarkson, S., Choppin, S., Hart, J., Heller, B., & Wheat, J.,2012. Calculating body segment inertia parameters from a single rapid scan using the Microsoft Kinect. In: Proceedings of 3rd International Conference on 3D Body Scanning Technologies. Lugano, Switzerland.

Clarkson, S., Wheat, J., Heller, B., & Choppin, S.,2014. Assessing the Suitability of the Microsoft Kinect for Calculating Person Specific Body Segment Parameters. 4th IEEE Workshop on Consumer Depth Cameras for Computer Vision, European Conference on Computer Vision, 372–385.

Clarkson, S., Wheat, J., Heller, B., & Choppin, S.,2015. Assessment of a Microsoft Kinect-based 3D scanning system for taking body segment girth measurements: a comparison to ISAK and ISO standards. Journal of Sports Sciences, 1–9.

Clarkson, S., Wheat, J., Heller, B., Webster, J., & Choppin, S.,2013. Distortion Correction of Depth Data from Consumer Depth Cameras. In: Proceedings of the 4th International Conference on 3D Body Scanning Technologies. Long Beach, CA.

Coelho-E-Silva, M.J., Malina, R.M., Simões, F., Valente-Dos-Santos, J., Martins, R. a, Vaz Ronque, E.R., Petroski, E.L., Minderico, C., Silva, A.M., Baptista, F., & Sardinha, L.B.,2013. Determination of thigh volume in youth with anthropometry and DXA: agreement between estimates. European Journal of Sport Science, 13 (5), 527–33.

Cohen, J.,1988. Statistical power analysis for the behavioral sciences. 2nd ed. Hillsdale, NY: Lawrence Erlbaum Associates.

Coleman, D.,2012. The physiological demands of road cycling. In: J. Hopker and S. Jobson, eds. Performance Cycling: The Science of Success. London: Bloomsbury.

Coleman, S.G.S.,1994. The measurment of maximal power output during short term cycling. Loughbrough University of Technology.

Coren, S., Porac, C., & Duncan, P.,1981. Lateral preference behaviors in preschool children and young adults. Child Development, 443–450.

Craig, N.P. & Norton, K.I.,2001. Characteristics of track cycling. Sports Medicine, 31 (7), 457–468.

Crisco, J.J. & McGovern, R.D.,1998. Efficient calculation of mass moments of inertia for segmented homogenous three-dimensional objects. Journal of Biomechanics, 31, 97–101.

Daanen, H.A.M., Haar, F.B., & Ter Haar, F.B.,2013. 3D whole body scanners revisited. Displays, 34 (4), 270–275.

Daanen, H.A.M. & Van De Water, J.,1998. Whole body scanners. Displays, 19, 111–120.

Daly, D.J. & Cavanagh, P.R.,1975. Asymmetry in bicycle ergometer pedalling. Medicine & Science in Sports & Exercise, 8 (3), 204–208.

Daly, M., Duma, S.M., & Stitzel, J.D.,2006. Retrospective identification of subject anthropometry using computed tomography of the leg. Biomedical sciences instrumentation, 42, 114–119.

Daniell, N., Olds, T., & Tomkinson, G.,2010. The importance of site location for girth measurements. Journal of Sport Science, 28 (7), 751–7.

Daniell, N., Olds, T., & Tomkinson, G.,2013. Volumetric differences in body shape among adults with differing body mass index values: An analysis using three-dimensional body scans. American Journal of Human Biology, 26 (2), 156–163.

Davies, C. & Sandstrom, E.,1989. Maximal mechanical power output and capacity of cyclists and young adults. European Journal of Applied Physiology and Occupational Physiology, 58 (8), 838–844.

Dellanini, L., Hawkins, D., Martin, B., & Stover, S.,2004. The effects of changing bone and muscle size on limb inertial properties and limb dynamics: a computer simulation. Computer Methods in Biomechanics and Biomedical Engineering, 7 (3), 167–76.

Dindaroğlu, F., Kutlu, P., Duran, G.S., Görgülü, S., & Aslan, E.,2015. Accuracy and reliability of 3D stereophotogrammetry: A comparison to direct anthropometry and 2D photogrammetry. The Angle Orthodontist.

Dishman, R.K., Ickes, W., & Morgan, W.P.,1980. Self motivation and adherence to habitual physical activity. Journal of Applied Social Psychology, 10 (2), 115–132.

Dorel, S., Hautier, C.A., Rambaud, O., Rouffet, D., Van Praagh, E., Lacour, J.R.R., & Bourdin, M.,2005. Torque and power-velocity relationships in cycling: Relevance to track sprint performance in world-class cyclists. International Journal of Sports

Medicine, 26 (9), 739–746.

Drinkwater, E., Hopkins, W.G., McKenna, M., Hunt, P., & Pyne, D.,2007. Modelling age and secular differences in fitness between basketball players. Journal of Sports Sciences, 25, 869–878.

Driss, T. & Vandewalle, H.,2013. The measurement of maximal (anaerobic) power output on a cycle ergometer: a critical review. BioMed research international.

Driss, T., Vandewalle, H., Le Chevalier, J.-M., & Monod, H.,2002. Force-velocity relationship on a cycle ergometer and knee-extensor strength indices. Canadian journal of applied physiology / Revue canadienne de physiologie appliquee, 27 (3), 250–262.

Ema, R., Wakahara, T., Yanaka, T., Kanehisa, H., & Kawakami, Y.,2016. Unique muscularity in cyclists' thigh and trunk: A cross-sectional and longitudinal study. Scandinavian Journal of Medicine & Science in Sports, 26 (7), 782–793.

Erasmus, L.J., Hurter, D., Naudé, M., Kritzinger, H.G., & Acho, S.,2004. A short overview of MRI artefacts. South African Journal of Radiology, 8 (2), 13–17.

Eston, R. & Reilly, T.,2009. Kinanthropometry and exercise physiology laboratory manual: tests, procedures and data. Volume 1: anthropometry. Third. London and New York: Routledge.

Fairclough, J.A., Mintowt-Czyz, W.J., Mackie, I., & Nokes, L.,1994. Abdominal girth: an unreliable measure of intra-abdominal bleeding. Injury, 16, 85–87.

Faria, E.W., Parker, D.L., & Faria, I.E.,2005a. The science of cycling: Physiology and training - Part 1. Sports Medicine, 35 (4), 285–312.

Faria, E.W., Parker, D.L., & Faria, I.E.,2005b. The science of cycling - Factors affecting performance - Part 2. Sports Medicine, 35 (4), 313–337.

Fawkner, S.,2013. Use of anthropometry-its importance and critical use in the assessment of growth. Journal of Sport Science, 31 (15), 1625–6.

Field, A.,2009. Discovering statistics using SPSS. London: Sage publications.

Fletcher, G.F., Balady, G.J., Amsterdam, E.A., Chaitman, B., Eckel, R., Fleg, J., Froelicher, V.F., Leon, A.S., Piña, I.L., Rodney, R., Simons-Morton, D.A., Williams, M.A., & Bazzarre, T.,2001. Exercise Standards for Testing and Training: A Statement for Healthcare Professionals From the American Heart Association. Circulation, 104 (14), 1694–1740.

Foley, J.P., Bird, S.R., & White, J. a,1989. Anthropometric comparison of cyclists from different events. British journal of sports medicine, 23 (1), 30–33.

Fourie, Z., Damstra, J., Gerrits, P.O., & Ren, Y.,2011. Evaluation of anthropometric accuracy and reliability using different three-dimensional scanning systems. Forensic science international, 207 (1–3), 127–34.

Gardner, A S., Martin, J.C., Martin, D.T., Barras, M., & Jenkins, D.G.,2007. Maximal torque- and power-pedaling rate relationships for elite sprint cyclists in laboratory and field tests. European journal of applied physiology, 101 (3), 287–92.

Garson, G.D.,2016. Partial Least Squares: Regression & Structural Equation Models.

Geng, J.,2011. Structured-light 3D surface imaging: a tutorial. Advances in Optics and Photonics, 3 (2), 128.

Gibson, R.S.,1990. Principles of Nutritional Assessment. Oxford, UK: Oxford University Press.

Glass, G. V, McGaw, B., & Smith, M.L.,1981. Meta-Analysis in Social Research. USA: Sage.

Gonzalez-Sosa, E., Vera-Rodriguez, R., Fierrez, J., & Ortega-Garcia, J.,2013. Body shape-based biometric recognition using millimeter wave images. 2013 47th International Carnahan Conference on Security Technology (ICCST), 1–5.

Grassi, B., Cerretelli, P., Narici, M. V, & Marconi, C.,1991. Peak anaerobic power in master athletes. European Journal of Applied Physiology and Occupational Physiology, 62 (6), 394–399.

Gregor, R.J. & Conconi, F.,2000. Road cycling. Oxford: Blackwell Science Inc.

Gregory, J.R.,2002. The Physiological and Physical Determinants of Mountain Bike Cross Country Cycling. University of Tasmania.

Haakonssen, E.C., Barras, M., Burke, L.M., Jenkins, D.G., & Martin, D.T.,2016. Body composition of female road and track endurance cyclists: Normative values and typical changes. European journal of sport science, 16 (6), 645–53.

Haas, J.D. & Flegal, K.M.,1981. Anthropometric measurements. Nutrition & Cancer: Etiology & Treatment, 123–140.

Haley, S.M. & Fragala-Pinkham, M.A.,2006. Interpreting change scores of tests and measures used in physical therapy. Physical Therapy, 86 (5).

Havlíček, J., Třebický, V., Valentova, J. V, Kleisner, K., Akoko, R.M., Fialová, J., Jash, R., Kočnar, T., Pereira, K.J., Štěrbová, Z., & Varella, M.A.,2017. Men's preferences for women's breast size and shape in four cultures. Evolution & Human Behavior, 38 (2), 217–226.

Hedges, L. V & Olkin, I.,1985. Statistical methods for meta-analysis. New York: Academic Press.

HERCA Group,2010. Facts and figures concerning the use of Full body scanners using X-Rays for security reason. HERCA.

Heuberger, R., Domina, T., & MacGillivray, M.,2007. Body scanning as a new anthropometric measurement tool for health-risk assessment. International Journal of Consumer Studies, 32 (1).

Hodges-Simeon, C.R., Sobraske, K.N., Samore, T., Gurven, M., & Gaulin, S.J.,2016. Facial Width-To-Height Ratio (fWHR) is not associated with adolescent testosterone levels. Plos One, 11 (4).

Hopker, J., Coleman, D., Jobson, S.A., & Passfield, L.,2012. Inverse relationship between $\dot{V}O_2$max and gross efficiency. Journal of Sports Medicine, 33, 789–794.

Hopker, J., Jobson, S., Carter, H., & Passfield, L.,2010. Cycling efficiency in trained male and female competitive cyclists. Journal of sports science & medicine, 9 (2), 332–7.

Human Solutions,2016. Vitronic Vitus [online]. www.human-solutions.com. Available from: www.human-solutions.com.

Impellizzeri, F.M. & Marcora, S.M.,2007. The physiology of mountain biking. Sports

Medicine, 37 (1), 59–71.

Inoue, A., Santos, T.M., Ike, M.O.B., & Ountry, C.R.,2012. Relationship between anaerobic cycling tests and mountain bike cross-country performance. The Journal of Strength and Conditioning Research, 26 (8), 1589–1593.

IOC,2017a. Cycling Track [online]. Available from: https://www.olympic.org/cycling-track.

IOC,2017b. Cycling Road [online]. Available from: https://www.olympic.org/cycling-road.

IPAQ,2002. International Physical Activity Questionnaire: Short - last 7 days self administered. For use with young and middle-aged sdults (15-69 years).

ISO,2010. ISO/DIS 20685-*1 : Ergonomics* - 3-D scanning methodologies for internationally compatible anthropometric databases - Part 1: Evaluation protocol for body dimensions extracted from 3-D body scans.

Jaafar, H., Attiogbé, E., Rouis, M., Vandewalle, H., & Driss, T.,2015. Reliability of Force-Velocity Tests in Cycling and Cranking Exercises in Men and Women. BioMed Research International.

Jeukendrup, A.E., Craig, N.P., & Hawley, J.A.,2000. The bioenergetics of World Class Cycling. Journal of Science and Medicine in Sport, 3, 414 –433,.

Jobson, S.A., Nevill, A.M., Palmer, G.S., Jeukendrup, A.E., Doherty, M., & Atkinson, G.,2007. The ecological validity of laboratory cycling: Does body size explain the difference between laboratory- and field-based cycling performance? Journal of Sports Sciences, 25 (1), 3–9.

Jones, A.M., Vanhatalo, A.T., & Doust, J.H.,2009. Kinanthropometry and exercise physiology laboratory manual: tests, procedures and data. In: R. Eston and T. Reilly, eds. Exericse Physiology. London: Taylor & Francis, 271–306.

Jones, P.R. & Pearson, J.,1969. Anthropometric determination of leg fat and muscle plus bone volumes in young male and female adults. The Journal of Physiology, 204 (2), 63–66.

Jones, P.R.M. & Riouxb, M.,1997. Three-dimensional surface anthropometry : to the human body applications. Optics and Lasers in Engineering, 28, 89–117.

Karges, J.R., Mark, B.E., Stikeleather, S.J., Worrell, W., & Worrell, T.W.,2003. Concurrent validity of upper-extremity volume estimates: comparison of calculated volume derived from girth measurements and water displacement volume. Physical therapy, 83 (2), 134–145.

Katch, V.L. & Katch, F.I.,1974. A simple antrhopometric method for calculating segmental leg limb volume. Research quarterly, 45 (2), 211–4.

Kaulesar Sukul, D.M.K.S., Den Hoed, P.T., Johannes, E.J., Van Dolder, R., & Benda, E.,1993. Direct and indirect methods for the quantification of leg volume: Comparison between water displacement volumetry, the disk model method and the frustum sign model method, using the correlation coefficient and the limits of agreement. Journal of Biomedical Engineering, 15 (6), 477–480.

Khoshelham, K. & Elberink, S.O.,2012. Accuracy and resoluation of Kinect depth data for indoor mapping applications. Sensors, 12 (2), 1437–1454.

Knapp, B.,1963. Skill in sport: the attainment of proficiency. London: Routledge & Kegan Paul.

Knechtle, B., Knechtle, P., Rosemann, T., & Senn, O.,2011. Personal best time and training volume, not anthropometry, is related to race performance in the ‘Swiss Bike Masters’ mountain bike ultramarathon. Journal of strength and conditioning research / National Strength & Conditioning Association, 25 (5), 1312–1317.

Knechtle, B., Wirth, A., Knechtle, P., & Rosemann, T.,2009. Moderate association of anthropometry, but not training volume, with race performance in male ultraendurance cyclists. Research quarterly for exercise and sport, 80 (3), 563–568.

Koley, S. & Jain, V.K.,2013. Correlations of maximal oxygen consumption with selected anthropometric and physical characteristics in elite Indian cyclists. Annals of Biological Research, 4 (4), 134–138.

Kouzaki, M. & Masani, K.,2008. Reduced postural sway during quiet standing by light touch is due to finger tactile feedback but not mechanical support. Experimental brain research, 188 (1), 153–8.

Ku, P.X., Noor, A.A.O., & Wan, A.B.W.A.,2014. Balance control in lower extremity amputees during quiet standing: a systematic review. Gait & Posture, 39 (2), 672–682.

Kulkarni, D., Ranjan, S., Chitodkar, V., Gurjar, V., Ghaisas, C. V, & Mannikar, A. V,2011. SIZE INDIA – Anthropometric size measurement of Indian population (Report No. 2011-26-0108).

Kyle, C.R.,1989. The aerodynamics of helmets and handlebars. Cycling Science, 1, 22–25.

Lackner, J., Rabin, E., & DiZio, P.,2001. Stabilization of posture by precision touch of the index finger with rigid and flexible filaments. Experimental Brain Research, 139 (4), 454–464.

Lafortune, M.A. & Cavanagh, P.R.,1983. Effectiveness and efficiency during bicycle riding. In: H. Matsui and K. Kobayashi, eds. Biomechanics VIIB: International Series on Sports Science 4B. 928–936.

Lakens, D.,2013. Calculating and reporting effect sizes to facilitate cumulative science: A practical primer for t-tests and ANOVAs. Frontiers in Psychology, 4, 1–12.

Lane, C. & Harrell, W.,2008. Completing the 3-dimensional picture. American Journal of Orthodontics and Dentofacial Orthopedics, 133 (4), 612–620.

Lavoie, N.F., Mahony, M.D., & Marmelic, L.S.,1978. Maximal oxygen uptake on a bicycle ergometer without toe stirrups and with toe stirrups versus a treadmill. Canadian Journal of Applied Physiology, 3, 99–102.

Lee, H., Martin, D.T., Anson, J.M., Grundy, D., & Hahn, A.G.,2002. Physiological characteristics of successful mountain bikers and professional road cyclists. Journal of Sport Science, 20 (12), 1001–1008.

Lee, J., Kawale, M., Merchant, F. a, Weston, J., Fingeret, M.C., Ladewig, D., Reece, G.P., Crosby, M. a, Beahm, E.K., & Markey, M.K.,2011. Validation of stereophotogrammetry of the human torso. *Breast cancer : basic and clini*cal research, 5, 15–25.

Lerch, T., MacGillivray, M., & Domina, T.,2007. 3D laser scanning: A model of multidisciplinary research. Journal of Textile and Apparel, Technology and Management, 5 (4), 1–8.

Li, H.D., Xu, Q.S., & Liang, Y.Z.,2014. libPLS: An Integrated Library for Partial Least Squares Regression and Discriminant Analysis.

Littlefield, T.R., Kelly, K.M., Cherney, J.C., Beals, S.P., & Pomatto, J.K.,2004. Technical strategies: development of a new three-dimensional cranial imaging system. Journal of Craniofacial Surgery, 15 (1), 175–181.

Lode,2017. Excalibur-Sport [online]. Lode.com. Available from: www.lode.com.

Lombardo, M.P.,2012. On the evolution of sport. Evolutionary Psychology, 10, 1–28.

LucÍa, A., Hoyos, J.E., PÉrez, M., & Chicharro, J.L.,2000. Heart rate and performance parameters in elite cyclists: a longitudinal study. Medicine & Science in Sports & Exercise, 32 (10), 1777–1782.

Ludbrook, J.,1997. Comparing measurment methods. Clinical and Experimental Pharmacology and Physiology, 24, 193–203.

Ludbrook, J.,2010. Linear regression analysis for comparing two measurers or methods of measurement: But which regression? Clinical and Experimental Pharmacology and Physiology, 37 (7), 692–699.

Ludbrook, J.,2012. A primer for biomedical scientists on how to execute model II linear regression analysis. Clinical & Experimental Pharmacology & physiology, 39 (4), 329–35.

Lufkin,2016. Anthropometric tape measure [online]. www.lufkintool.com. Available from: www.lufkintool.com.

Macintosh, B.R., Rishaug, Æ.P., & Svedahl, Æ.K.,2003. Assessment of peak power and short-term work capacity, 572–579.

Maitra, S. & Yan, J.,2008. Principle component analysis and partial least squares: Two dimension reduction techniques for regression. Applying Multivariate Statistical Models., 15 (79), 79–90.

Malina, R.M. & Bouchard, C.,1991. Growth, Maturation and Physical Activity.

Champaign / Human Kinetics.

Van der Mark, W., Burghouts, G., Den Dekker, E., Ten Kate, T., & Schavemaker, J.,2007. 3D scene reconstruction with a handheld stereo camera. COGnitive systems with Interactive Sensors (COGIS). California, USA.

Martin, J., Wagner, B., & Coyle, E.,1997. Inertial-load method determines maximal cycling power in a single exercise bout. Medicine & Science in Sports & Exercise, 29 (11), 1505–1512.

Martin, J.C., Davidson, C.J., & Pardyjak, E.R.,2007. Understanding sprint-cycling performance : The integration of muscle power, resistance, and modeling aspects of muscle power. International Journal of Sports Physiology and Performance, 2 (5), 5–21.

Martin, J.C., Diedrich, D., & Coyle, E.F.,2000. Time course of learning to produce maximum cycling power. International Journal of Sports Medicine, 21 (7), 485–487.

Martin, P.E., Mungiole, M., Marxke, M.W., & Longhill, J.M.,1989. The use of magnetic resonance imaging for measuring segmental inertial properties. Journal of Biomechanics, 22, 361–376.

Martorell, R., Mendoza, F., Mueller, W.H., & Pawson, I.G.,1988. Which side to Measure: Right or Left? In: T.G. Lohmann, A.F. Roche, and R. Martorell, eds. Anthropometric Standardization Reference Manual. New York: Human Kinetics, 87–91.

Mathur, S., Takai, K.P.R., Macintyre, D.L., & Reid, D.,2008. Estimation of Thigh Muscle Mass With Magnetic Resonance Imaging in Older Obstructive Pulmonary Disease. Physical Therapy, 88 (2), 219–230.

MathWorks,2017. Partial Least Squares Regression and Principal Components Regression [online]. MathWorks.com. Available from: https://uk.mathworks.com/help/stats/examples/partial-least-squares-regression-and-principal-components-regression.html?prodcode=ML.

Maylia, E., Fairclough, J.A., Nokes, L.D.M., & Jones, M.D.,1999. Can thigh girth be measured accurately? A preliminary investigation. Journal of Sport Rehabilitation, 8, 43–49.

Mayrovitz, H.N., Macdonald, J., Davey, S., Olson, K., & Washington, E.,2007. Measurement decisions for clinical assessment of limb volume changes in patients with bilateral and unilateral limb edema. Physical Therapy, 87 (10), 1362–8.

McCartney, N., Heigenhauser, G.J., & Jones, N.L.,1983. Power output and fatigue of human muscle in maximal cycling exercise. Journal of Applied Physiology, 55, 218 – 224.

McGawley, K. & Bishop, D.,2006. Reliability of a 5 x 6-s maximal cycling repeated-sprint test in trained female team-sport athletes. European journal of applied physiology, 98 (4), 383–393.

McGee, R., Birkbeck, J., & Silva, P.A.,1985. Physical development of hyeractive boys. Developmental Medicine and Child Neurology, 27 (3), 364–368.

McGregor, A.H., Anderton, L., & Gedroyc, W.M.,2002. The trunk muscles of elite oarsmen. British Journal of Sports Medicine, 36, 214–221.

McKinnon, J.G., Wong, V., Temple, W.J., Galbraith, C., Ferry, P., Clynch, G.S., & Clynch, C.,2007. Measurement of limb volume: laser scanning versus volume displacement. Journal of Surgical Oncology, 96 (5), 381–8.

Mckinnon, L. & Istook, C.L.,2002. Body scanning: The effects of subject respiration and foot positioning on the data integrity of scanned measurements. Journal of Fashion Marketing and Management, 6 (2), 103–121.

McLachlan, F.,2016. Gender Politics, the Olympic Games, and Road Cycling: A Case for Critical History. The International Journal of the History of Sport, 33 (4), 469–483.

McLean, B.D. & Ellis, L.,1992. Body mass, thigh volume and vertical jumping ability as predictors of short-term cycle ergometer performance in junior cyclists. Excel, 3, 149–153.

Mclean, B.D. & Parker, A.W.,1989. An anthropometric analysis of elite austrialian track cylists. Journal of Sport Science, 7 (3), 247–255.

McNair, P.J., Depledge, J., Brettkelly, M., & Stanley, S.N.,1996. Verbal encouragement: effects on maximum effort voluntary muscle action. British Journal of Sport Medicine, 30, 243–245.

Mendez-Villanueva, A., Bishop, D., & Hamer, P.,2007. Reproducibility of a 6-s maximal cycling sprint test. Journal of science and medicine in sport / Sports Medicine Australia, 10 (5), 323–6.

Microsoft,2016. Microsoft Kinect for Xbox One [online]. www.xbox.com. Available from: www.xbox.com/en-US/xbox-one/accessories/kinect.

Mok, K.M., Kristianslund, E., & Krosshaug, T.,2013. The effect of thigh skin marker cluster configuration on knee valgus measurement in vertical drop jumping: an implication to ACL injury risk factor study. In: XXIV Congress of the International Society of Biomechanics. Natal, Brazil.

Moller, A.P.,1993. Patterns of fluctuating asymmetry in sexual ornaments\npredict female choice. Journal of Evolutionary Biology, 6, 481–491.

Moreno, L. A, Rodríguez, G., Guillén, J., Rabanaque, M.J., León, J.F., & Ariño, A,2002. Anthropometric measurements in both sides of the body in the assessment of nutritional status in prepubertal children. European journal of clinical nutrition, 56 (12), 1208–1215.

Mornieux, C., Stapelfeldt, B., Collhofer, A., & Belli, A.,2008. Effects of pedal type and pull-up action during cycling. International Journal of Sports Medicine, 29 (10), 817–822.

Moussa, E., Zouhal, H., Vincent, S., Proiux, J., Delamarche, P., & Gratas-Delamarche, A.,2003. Effect of sprint duration (6 s or 30 s) on plasma glucose regulation in untrained male subjects. Journal of Sports Medicine & Physical Fitness, 43 (4), 546–553.

Ng, K., Ahmad, A.C., Nizam, M.S., & Abdullah, B.J.J.,2003. Magnetic Resonance Imaging : Health Effects and Safety. In: Proceedings of the International Conference on Non-Ionizing Radiation at UNITEN (ICNIR2003): Electromagnetic Fields and Our Health. 1–15.

NHS,2015. CT Scan [online]. NHS. Available from: www.nhs.com.

Nicholls, M.E., Thomas, N.A., Loetscher, T., & Grimshaw, G.M.,2013. The Flinders Handedness survey (FLANDERS): a brief measure of skilled hand preference. Cortex, 49 (10), 2914–2926.

Norton, K. & Olds, T.,2001. Morphological Evolution of Athletes Over the 20th Century Causes and Consequences. Sports Medicine, 31 (11), 763–783.

Norton, K., Olds, T., Oliveira, S., & Craig, N.,2002. Anthropometry and sports performance. In: K. Norton and T. Olds, eds. Anthropometrica: A textbook of body measurement for sports and health courses. Australia: University of New South Wales Press, 289–391.

Novak, A.R. & Dascombe, B.J.,2004. Physiological and Performance characteristics of Elite Mountain Bike Cyclists. Journal of Science and Cycling, 3 (3), 9–16.

Occiptal,2015. Homepage [online]. www.occiptal.com. Available from: http://occipital.com/.

Olds, T.,2004. The rise and fall of anthropometry. Journal of Sport Science, 22 (4), 319–20.

Olds, T.,2009. Anthropometry. In: R.J. Maughan, ed. The Encyclopaedia of Sports Medicine. 131–148.

Olds, T. & Honey, F.,2006. The use of 3D whole-body scanners in anthropometry. In: M. Marfell-Jones, A. Stewart, and T. Olds, eds. Kinanthropometry IX: Proceedings of the 9th International Conference of the International Society for the Advancement of Kinanthropometry. London: Routledge, 1–14.

Oosterhuis, H.,2016. Cycling, modernity and national culture. Social History, 41 (3), 233–248.

Parkin, S., Nowicky, A. V, Rutherford, O.M., & McGregor, A.H.,2001. Do oarsmen have asymmetries in the strength of their back and leg muscles? Journal of Sports Sciences, 19, 521–526.

Passfield, L., Walker, M., & Barrett, P.,2012. The physiological demands of off road cycling disciplines. In: J. Hopker and S. Jobson, eds. Performance Cycling: The Science of Success. London: Bloomsbury.

Pauw, K. De, Roelands, B., Cheung, S.S., Geus, B. De, Rietjens, G., & Meeusen, R.,2013. Guidelines to classify subject groups in sport science research. International Journal of Sports Physiology and Performance, 8, 111–122.

Pearsall, D. & Reid, J.,1994. The Study of Human Body Segment Parameters in Biomechanics: A Historical Review and Current Status Report. Sports Medicine, 18 (5), 126–140.

Pearsall, D.J., Reid, J.G., & Livingston, L.A.,1996. Segmental inertial parameters of the human trunk as determined from computed tomography. Annals of Biomedical Engineering, 24, 198–210.

Pekünlü, E.,2015. A large number of short sprints is required to avoid practice based improvement effect during the assessment of cycling peak power. Isokinetics & Exercise Science, 23 (2), 133–142.

Percoco, G. & Galantucci, L.M.,2010. Photogrammetric 3D body scanner for low cost textile mass customization. In: International Conference on 3D Body Scanning Technologies Conference. Lugano, Switzerland.

Perrin, M., Guex, J.J., & Perrin, M.,2000. Edema and leg volume: methods of assessment. Angiology, 51 (1), 9–12.

Pesce, M., Galantucci, L.M., Percoco, G., & Lavecchia, F.,2014. multi camera 3D scanning system for quality measurement of non-static subjects. In: Poceedings of the 3rd CIRP Global Web Conference A low-cost.

Pfister, G.,2010. Women in Sport – Gender Relations and Future Perspectives. Sport in Society, 13 (2), 234–248.

Pirnay, F. & Crielaard, J.M.,1979. Mesure de la puissance anaerobic alactique /Measure of anaerobic alactic power. Medicine de Sport, 53, 13–16.

Rábago, C.A., Dingwell, J.B., & Wilken, J.M.,2015. Reliability and minimum detectable change of temporal-spatial, kinematic, and dynamic stability measures during perturbed gait. PloS one, 10 (11).

Reilly, T.,2008. The international face of sports science through the window of the Journal of Sports Sciences--with a special reference to kinanthropometry. Journal of Sport Science, 26 (4), 349–63.

Rikowski, A. & Grammer, K.,1999. Human body odour, symmetry and attractiveness. In: Proceedings of the Royal Society of London Biological Sciences. 869–874.

Robinette, K.M.,2013. 3D Body Scanning , Past and Future. In: Proceedings of the 4th International Conference on 3D Body Scanning Technologies. Lugano, Switzerland.

Robinette, K.M., Daanen, H., & Nrc, E.P.,1994. *The CAESAR project : A 3*-D surface anthropometry survey.

Robinson, A., M, M., Zoub, L., Brown, S., & Evenden, A.,2012. Improving the quality of measurements through the implementation of customised standards. In: Proceedings of 3rd International Conference on 3D Body Scanning Technologies. Lugano, Switzerland, 16–17.

Rogers, M. & Olds, T.,2004. 3D anthropometry-applications to health and exercise science. Sport Health, 22 (3), 21.

Rønnestad, B.R., Hansen, E.A., & Raastad, T.,2010. Effect of heavy strength training on thigh muscle cross-sectional area, performance determinants, and performance in well-trained cyclists. European Journal of Applied Physiology, 108 (5), 965–975.

Rønnestad, B.R., Hansen, J., & Nygaard, H.,2017. 10 weeks of heavy strength training improves performance-related measurements in elite cyclists. Journal of Sport Science, 35 (14), 1435–1441.

Ross, W.D., Hebbelink, M., Van Gheluwe, B., & Lemmens, M.L.,1972. Kinanthropometrie et l'appreciation de l'erreur de mesure. Kinanthropologie, 4, 23–34.

Rosscraft,2016. Rosscraft Centurion anthropometry kit [online]. www.rosscraft.ca. Available from: www.rosscraft.ca/tools.

Santos, A.M.C., Welsman, J.R., De Ste Croix, M.B.A., & Armstrong, N.,2002. Age and sex related differences in optimal peak power. Pediatric Exercise Science, 14, 202–212.

Saxén, H. & Pettersson, F.,2006. Method for the selection of inputs and structure of feedforward neural networks. Computers & Chemical Engineering, 30 (6), 1038–1045.

Schranz, N., Tomkinson, G., Olds, T, & Daniell, N.,2010. Three-dimensional anthropometric analysis : Differences between elite Australian rowers and the general population. Journal of Sport Sciences, 28 (5), 459–469.

Schranz, N., Tomkinson, G., Olds, T, Petkov, J., & Hahn, A.G.,2012. Is three-dimensional anthropometric analysis as good as traditional anthropometric analysis in predicting junior rowing performance? Journal of sports sciences, 30 (12), 1241–1248.

Schreiner, P.J., Pitkaniemi, J., Pekkanen, J., & Salomaa, V. V,1995. Reliability of near-infrared interactance body fat assessment relative to standard anthropometric techniques. Journal of Clinical Epidemiology, 48, 1361–1367.

SDS,2016. L3 SafeView ProVision [online]. www.sds.l-3com.com. Available from: www.sds.l-3com.com.

Sherwood, N.E. & Jeffery, R.W.,2000. The behavioral determinants of exercise: implications for physical activity interventions. Annual Review of Nutrition, 20 (1), 21–44.

Sicotte, M., Ledoux, M., Zunzunegui, M. V, Aboubacrine, A.S., Nguyen, V.K., Aboubacrine, S.A., Nguyen, V.K., & BMC,2010. Reliability of anthropometric measures in a longitudinal cohort of patients initiating ART in West Africa. BMC Medical Research Methodology, 10 (1), 102–111.

Siemans,2016a. Siemans SOMATOM Perspective CT Scanner [online]. www.healthcare.siemens.com. Available from: www.healthcare.siemens.com.

Siemans,2016b. Siemans MAGNETOM Aera MRI Scanner [online]. www.healthcare.siemens.com. Available from: www.healthcare.siemens.com.

Sims, R.E.E., Marshall, R., Gyi, D.E.E., Summerskill, S.J.J., Case, K., & Repository, I.,2012. Collection of anthropometry from older and physically impaired persons: Traditional methods versus TC2 3-D body scanner. International Journal of Industrial Ergonomics, 42 (1), 65–72.

Singh, D.,1995. Female health, attractiveness, and desirability for relationships: Role of breast asymmetry and waist-to-hip ratio. Ethology and Sociobiology, 16 (6), 465–481.

Skals, S., Ellena, T., Subic, A., Mustafa, H., & Pang, T.Y.,2016. Improving fit of bicycle helmet liners using 3D anthropometric data. International Journal of Industrial Ergonomics, 55, 86–95.

Smak, W., Neptune, R.R., & Hull, M.L.,1999. The influence of pedaling rate on bilateral asymmetry in cycling. Journal of Biomechanics, 32 (9), 899–906.

Smith, J.L. & McManus, A.,2009. A Review on Transitional Implications for Retiring Elite Athletes: What Happens When the Spotlight Dims? The Open Sports Sciences Journal, 1 (1), 45–49.

Soderberg, G.L., Ballantyne, B.T., & Kestel, L.L.,1996. Reliability of lower extremity girth measurements after anterior cruciate ligament reconstruction. Physiotherapy, 1 (1), 7–16.

SoftKinect,2015. Homepage [online]. www.softkinetic.com. Available from: http://www.softkinetic.com/.

Sonnenschein, E.G., Kim, M.Y., Pasternack, S., Toniolo, P.G., Pasternack, B.S., & Toniolo, P.G.,1993. Sources of variability in waist and hip measurements in middle-aged women. American Journal of Epidemiology, 138 (5), 301–309.

Stewart, A.D.,2010. Kinanthropometry and body composition: a natural home for three-dimensional photonic scanning. Journal of Sport Science, 28 (5), 455–7.

Stewart, A.D., Marfell-Jones, M., Olds, T., & De Ridder, H.,2011. International standards of anthropometric assessment. 3rd ed. ISAK.

Stratford, P.W., Binkley, J.M., Riddle, D.L., & Guyatt, G.H.,1998. Sensitivity to change of the Roland-Morris Back Pain Questionnaire: part 1. Physical Therapy, 78, 1186–1196.

Sutton, L. & Stewart, A.D.,2012. Body composition: professional practice and an interdisciplinary toolkit. In: A.D. Stewart and L. Sutton, eds. Body Composition in Sport, Exercise and Health. Oxon, UK, 187–208.

Swann, C., Moran, A., & Piggott, D.,2014. Defining elite athletes: Issues in the study of expert performance in sport psychology. Psychology of Sport and Exercise, 16, 3–14.

Taiwo, I.A. & Akinde, O.R.,2012. Predictability of offspring birth weight using simple parental anthropometrics in a government hospital in Lagos, Nigeria. International Journal of Medicine and Biomedical Research, 1 (3), 206–214.

Takahashi, M., Fujii, M., Naemura, M., & Satoh, S.I.,2013. Human gesture recognition system for TV viewing using time-of-flight camera. Multimedia Tools & Applications, 62 (3), 761–783.

Tan, C.-W., Coutts, F., & Bulley, C.,2013. Measurement of lower limb volume: agreement between the vertically oriented perometer and a tape measure method. Physiotherapy, 99 (3), 247–51.

Tanner, J.M.,1964. Physique of the olympic athlete. London: Allen & Unwin.

Tanner, R. & Gore, C.,2013. Physiological tests for elite athletes. London: Human Kinetics.

Tate, J. & Shierman, G.,1977. Toe clips: how they increase pedalling efficiency. Bicycling, 18 (57).

Thaler, L., Schütz, A. C., Goodale, M. A., & Gegenfurtner, K.R.,2013. What is the best fixation target? The effect of target shape on stability of fixational eye movements. Vision Research, 76, 31–42.

Thompson, B.,2007. Effect sizes, confidence intervals, and confidence intervals for effect sizes. Psychology in the Schools, 44 (5), 423–432.

Tomkinson, G.R. & Olds, T.S.,2000. Physiological correlates of bilateral symmetry in humans. International Journal of Sports Medicine, 21 (8), 545–550.

Tomkinson, G.R., Popović, N., & Martin, M.,2003. Bilateral symmetry and the competitive standard attained in elite and sub-elite sport. Journal of Sport Science, 21 (3), 201–11.

Tothill, P. & Stewart, A.D.,2002. Estimation of thigh muscle and adipose tissue volume using magnetic resonance imaging and anthropometry. Journal of Sport Science, 20 (7), 563–76.

Treleaven, P.,2004. Sizing us up. IEEE Spectrum, 28–31.

Treleaven, P. & Wells, J.,2007. 3D Body Scanning and Healthcare. IEEE Computer Society, 28–34.

Trimensional,2015. Homepage [online]. www.trimensional.com. Available from: httpwww.trimensional.com.

Trujillo-Ortiz & Hernandez-Walls, R.,2010. MatLAB file - gmregress: Geometric Mean Regression (Reduced Major Axis Regression).

Tzou, C.-H.J., Artner, N.M., Pona, I., Hold, A., Placheta, E., Kropatsch, W.G., & Frey, M.,2014. Comparison of three-dimensional surface-imaging systems. Journal of plastic, rec*onstructive & aesthetic surgery : JPRAS*, 67 (4), 489–97.

Üçok, K., Gökbel, H., & Okudan, N.,2005. The load for the Wingate test: According to the body weight or lean body mass. European Journal of General Medicine, 2 (1), 10–13.

Ulijaszek, S. & Komlos, J.,2010. From a History of Anthropometry to Anthropometric History. In: N.C.G. Mascie-Taylor, A. Yasukouchi, and S. Ulijaszek, eds. Human Variation: From the Laboratory to the Field. 183–198.

Ulijaszek, S.J. & Kerr, D. a,1999. Anthropometric measurement error and the assessment of nutritional status. British Journal of Nutrition, 82, 165–177.

Ulijaszek, S.J. & Mascie-Taylor, C.G.N.,2005. Anthropometry: The Individual and the Population. Cambridge: Cambridge University Press.

Ustinova, K.I. & Perkins, J.,2011. Gaze and viewing angle influence visual stabilization of upright posture. Brain and behavior, 1 (1), 19–25.

Vaeyens, R., Lenoir, M., Williams, A.M., & Philippaerts, R.M.,2008. Talent identification and development programmes in sport: current models and future directions. Sports Medicine, 38 (9), 703–714.

Vandewalle, H., Pérès, G., Heller, J., & Monod, H.,1985. All out anaerobic capacity tests on cycle ergometers. European Journal of Applied Physiology and

Occupational Physiology, 54 (2), 222–229.

Vandewalle, H., Peres, G., Heller, J., Panel, J., & Monod, H.,1987a. Applied Physiology Force-velocity relationship and maximal power on a cycle ergometercorrelation with the height of a vertical jump. European Journal of Applied Physiology, 56, 650–656.

Vandewalle, H., Peres, G., Heller, J., Panel, J., & Monod, H.,1987b. Force-velocity relationship and maximal power on a cycle ergometer: Correlation with the height of a vertical jump. European Journal of Applied Physiology, 56, 650–656.

Vargas, N., Robergs, R., & Klopp, D.,2015. Optimal loads for a 30-s maximal power cycle ergometer test using a stationary start. European journal of applied physiology, 115 (5), 1087–1094.

Wang, J., Gallagher, D., Thornton, J.C., Yu, W., Horlick, M., & Pi-sunyer, F.X.,2006. Validation of a 3-dimensional photonic scanner for the measurement of body volumes, dimensions, and percentage body fat. The American journal of clinical nutrition, 83 (4), 809–16.

Wang, R., Choi, J., & Medioni, G.,2012. Accurate Full Body Scanning from a Single Fixed 3D Camera. In: 2012 Second International Conference on 3D Imaging, Modeling, Processing, Visualization & Transmission. Seattle, USA.

Wehbe, G.M., Gabbett, T.J., Hartwig, T.B., & Mclellan, C.P.,2015. Reliability of a cycle ergometer peak power test in running-based team sport athletes: a technical report. Journal of Strength & Conditioning Research, 29, 2050–2055.

Weinberg, S.M. & Kolar, J.C.,2005. Three-dimensional surface imaging: limitations and considerations from the anthropometric perspective. Journal of Craniofacial Surgery, 16 (5), 847–851.

Weinberg, S.M., Naidoo, S., Govier, D.P., Martin, R.A., Kane, A.A., & Marazita, M.L.,2006. Anthropometric precision and accuracy of digital three-dimensional photogrammetry: Comparing the Genex and 3dMD imaging systems with one another and with direct anthropometry. The Journal of Craniofacial Surgery, 17 (3), 477–483.

Wells, J.C.K., Treleaven, P., & Cole, T.J.,2007. BMI compared with 3-dimensional body shape: the UK national sizing survey. American Journal of Clinical Nutrition, 85 (2), 419–425.

Westesson, P.L.,1993. Reliability and validity of imaging diagnosis of temporomandibular joint disorder. Advances in Dental Research, 7 (2), 137–151.

White, J.A., Quinn, G., Al-Dawalibi, M., & Mulhall, J.,1979. A technical report submitted to the British Cycling Federation with special reference to the *evaluation of the road squad's winter training programme (Nov 1978*- Feb 1979).

White, J.A., Quinn, G., Al-Dawalibi, M., & Mulhall, J.,1982. Seasonal changes in cyclists' performance. Part I. British Journal of Sport Medicine, 16 (1), 4–12.

White, J.A., Quinn, G., Mulhall, J., Al-Dawalibi, M., & Mulhall, J.,1982. Seasonal changes in cyclists' performance. Part II. British journal of sports medicine, 16 (1), 13–21.

Wilkie, D.R.,1960. Man as a source of mechanical power. Ergonomics, 3, 1–8.

Wold, S.,1995. PLS for multivariate linear modelling. In: H. Van De Waterbeemd and W. Weinheim, eds. QSAR: Chemometric methods in molecular design. Germany & New York, USA: VCH Publishers, 185–218.

Wold, S., Johansson, E., & Cocchi, M.,1993. PLS-partial least squares projections to latent structures. 3D QSAR in drug design., 1, 523–550.

Wold, S., Ruhe, A., Wold, H., & Dunn III, W.J.,1984. The collinearity problem in linear regression - The partial least squares (PLS) approach to generalized inverses. SIAM Journal on Scientific and Statistical Computing, 5 (3), 735–743.

Wold, S., Sjöström, M., & Eriksson, L.,2001. PLS-regression: a basic tool of chemometrics. Chemometrics and intelligent laboratory systems, 58 (2), 109–130.

Wolstencroft, E.,2002a. *Talent Identification and Development : An Academic Review*. Edinburgh.

Wolstencroft, E.,2002b. Talent identification and development: an academic review. sportscotland.

Wrede, R.,2010. *Schaum's Outline of Advanced Calculus*. Third. New York: Schaum's

Outlines.

Wu, G., Siegler, S., Allard, P., Kirtley, C., Leardini, A., Rosenbaum, D., Whittle, M., D'Lima, D.D., Cristofolini, L., Witte, H., Schmid, O., & Stokes, I.,2002. ISB recommendation on definitions of joint coordinate system of various joints for the reporting of human joint motion - Part I: ankle, hip, and spine. Journal of Biomechanics, 35 (4), 543–548.

Yazdi, M. & Beaulieu, L.,2007. Artifacts in Spiral X-ray CT Scanners : Problems and Solutions. World Academy of Science, Engineering and Technology, 1 (11), 77–81.

Yeadon, M.R.,1990. The simulation of aerial movement–II. A mathematical inertia model of the human body. Journal of Biomechanics, 23 (1), 67–74.

Zuk, M. & Pezowicz, C.,2015. Kinematic analysis of a six-degrees-of-freedom model based on IBS recommendation: a repeatability analysis and comparison with conventional gait model. Applied Bionics and Biomechanics.

Zwane, P.E., Sithole, M., & Hunter, L.,2010. A preliminary comparative analysis of 3D body scanner, manually taken girth body measurements and size chart measurements. International Journal of Consumer Studies, 34, 265–271.

Chapter 11 - Appendices

Appendix 1 - Ethical approval for the investigation presented in Chapter Four.

A.1.1 Research ethics approval

17.3 Participant information sheet (this should be addressed directl to the participant (ie you will etc) and in a language they will understand)	✓
17.4 Informed consent form	✓
17.5 Pre-screening questionnaire	✓
17.6 Collaboration evidence/support correspondence from the organisation consenting to the research (this must be on letterhea paper and signed) See sections 9 & 10.	n/a
17.7 CRB Disclosure certificate or where not available **CRB application form**	n/a
17.8 Clinical Trails form (FIN 12)	n/a

18. Signature Principal Investigator	Once this application is approved, I will undertake the research study as approved. If circumstances necessitate that changes are made to the approved protocol, I will discuss these with my Project Supervisor. If the supervisor advises that there should be a resubmission to the Sport and Exercise Research Ethics Review Group, I agree that no work will be carried out using the changed protocol until approval has been sought and formally received. [signature] Date 13/11/2014 Principal Investigator signature Name: ALICE MAY BULLAS
19. Approval Project Supervisor to sign **either** box A **or** box B as applicable (refer to	**Box A:** I confirm that the research proposed is based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Review Group 'Ethics Procedures for Research with Humans as Participants' document, and therefore does not need to be submitted to the HWB Sport and Exercise Research Ethics Review Group. In terms of ethics approval, I agree the 'minor' procedures proposed

Page 11 of 14 Version 1 March 2011

Appendix I and the flowchart in appendix VI of the ethics guidelines)	here and confirm that the Principal Investigator may proceed with the study as designed. ____________________ Date 13/1/14 Project Supervisor signature Name Jon Wheat
	Box B: I confirm that the research proposed is <u>not</u> based solely on 'minor' procedures, as outlined in Appendix 1 of the HWB Sport and Exercise Research Ethics Review Group 'Ethics Procedures for Research with Humans as Participants' document, and therefore <u>must</u> be submitted to the HWB Sport and Exercise Research Ethics Review Group for approval. I confirm that the appropriate preparatory work has been undertaken and that this document is in a fit state for submission to the HWB Sport and Exercise Research Ethics Review Group. ____________________ Date __________ Project Supervisor signature Name ______________________________
20. Signature Technician	I confirm that I have seen the full and approved application for ethics approval and technical support will be provided. ____________________ Date __________ Technician signature Name ______________________________

A.1.2 Participant consent form

Sheffield Hallam University

Participant Informed Consent Form

The validity and repeatability of a 3D scanning system.

Please answer the following questions by ticking the response that applies

	YES	NO
1. I have read the Information Sheet for this study and have had details of the study explained to me.	☐	☐
2. My questions about the study have been answered to my satisfaction and I understand that I may ask further questions at any point.	☐	☐
3. I understand that I am free to withdraw from the study at any time, without giving a reason for my withdrawal or to decline to answer any particular questions in the study without any consequences to my future treatment by the researcher.	☐	☐
4. I agree to provide information to the researcher under the conditions of confidentiality set out in the Information Sheet.	☐	☐
5. I wish to participate in the study under the conditions set out in the Information Sheet.	☐	☐
6. I consent to the information collected for the purposes of this research study, once anonymised (so that I cannot be identified), to be used for any other research purposes.	☐	☐

Participant's Signature: ____ **Date:** __________

Participant's Name (Printed): ________________________________

Contact details: ____

____

Researcher's Name (Printed): ________________________________

Researcher's Signature: ____________________________________

Researcher's contact details:
The Centre for Sports Engineering Research
Sheffield Hallam University |Faculty of Health & Wellbeing |Room A210 Collegiate Hall |Collegiate Crescent |Sheffield S10 2BP
Email: a.bullas@shu.ac.uk | Tel: +44 (0)114 225 5867

Please keep your copy of the consent form and the information sheet together.

Participant Informed Consent Form 1

A.1.3 Use of images consent form

Sheffield Hallam University

Participant Consent - Use of Images

The validity and repeatability of a 3D scanning system.

Photographs taken of you would be used to add interest and exemplify the research findings. For example, they may be used as illustrations in website summaries, research reports, summary leaflets, newspapers articles and/or conference presentations. They will not be used in any way that would show you in a bad light.

To be completed by the participant:

	YES	NO
1. I agree to have my photograph taken.	☐	☐
2. I understand that my questionnaire responses will not be linked to the photograph(s).	☐	☐
3. I understand that my name will not be linked to the photograph(s).	☐	☐
4. I understand that I will not be given credit for my appearance in photograph(s).	☐	☐
5. I give the project team permission to:		
- put my photograph(s) on websites	☐	☐
- use my photograph(s) in printed material (e.g. reports, leaflets, newspaper articles, news releases)	☐	☐
- use my photograph(s) in presentations (e.g. at conferences or seminars)	☐	☐

Signature of participant: ______________________________ **Date:** ____________

Name of participant (block letters): ______________________________

Signature of investigator: ______________________________ **Date:** ____________
(Name, address, contact number of investigator)

Participant Consent Form for Use of Images 1

A.1.4 Participant screening form

Sheffield Hallam University

Participant Screening Form

The validity and repeatability of a 3D scanning system.

Please answer the following questions by ticking the response that applies

	YES	NO
1. I am over the age of 18 years.	☐	☐
2. I am able to stand unassisted for a minimum of 40 minutes.	☐	☐
3. I am able to stand on one leg assisted for a minimum of 5 minutes.	☐	☐
4. I know of no reason I know of as to why my ability to maintain my balance, on one or both legs should be inhibited.	☐	☐

Participant's Signature: ____ **Date:** __________

Participant's Name (Printed): ___________________________________

Researcher's Name (Printed): __________________________________

Researcher's Signature: ______________________________________

Participant Screening Form 1

Appendix 2 - Definitions for each anthropometric

Table A.1: Definitions for each anthropometric

Simple / Complex	Size / Symmetry	Dimension type	Measurement	Unit	Definition
Simple	Size	Length	Lower leg length	cm	The vertical distance between the centre point between the most superior point on the medial border of the head of the tibia (Stewart et al., 2011, p. 48) and of the most superior point on the lateral border of the head of the tibia (Stewart et al., 2011, p. 43), and the centre point of the inferior aspect of the distal tip of the lateral malleolus and the inferior aspect of the distal tip of the medial malleolus (Stewart et al., 2011, p. 49).
Simple	Size	Girth	Calf girth	cm	The maximal girth of the lower leg (Stewart et al., 2011, p. 87) , perpendicular to the long axis.
Complex	Size	Area	Calf CSA	m^2	The CSA at the maximal girth of the lower leg (Stewart et al., 2011, p. 87) , perpendicular to the long axis.
Simple	Size	Girth	Ankle girth	cm	The smallest girth of the lower leg (Stewart et al., 2011, p. 88) , perpendicular to the long axis.
Complex	Size	Area	Ankle CSA	m^2	CSA at the smallest girth of the lower leg (Stewart et al., 2011, p. 88) , perpendicular to the long axis.
Complex	Size	Volume	Lower leg volume	ml	Volume of the area enclosed by the most superior point on the medial border of the head of the tibia (Stewart et al., 2011, p.48). and of the most superior point on the lateral border of the head of the tibia (Stewart et al. 2011, p.43), and the inferior aspect of the distal tip of the lateral malleolus and the inferior aspect of the distal tip of the medial malleolus (Stewart et al., 2011, p.49).
Complex	Size	Area	lower leg SA	m^2	Surface area enclosed by the most superior point on the medial border of the head of the tibia (Stewart et al., 2011, p.48) and of the most superior point on the lateral border of the head of the tibia (Stewart et al., 2011, p.43), and the inferior aspect of the distal tip of the lateral malleolus and the inferior aspect of the distal tip of the medial malleolus (Stewart et al., 2011, p.49).

Simple	Size	Length	upper leg length	cm	The vertical distance between the centre point between the most superior point on the medial border of the head of the tibia (Stewart et al., 2011:p.48) and of the most superior point on the lateral border of the head of the tibia (Stewart et al., 2011, p.43) and the gluteal fold .
Simple	Size	Girth	knee girth	cm	Girth about the most superior point on the medial border of the head of the tibia (Stewart et al., 2011, p. 48) and of the most superior point on the lateral border of the head of the tibia (Stewart et al., 2011, p. 43) , perpendicular to the long axis.
Complex	Size	Area	Knee CSA	m^2	CSA encompassed by the most superior point on the medial border of the head of the tibia (Stewart et al., 2011, p. 48) and of the most superior point on the lateral border of the head of the tibia (Stewart et al., 2011, p. 43) , perpendicular to the long axis.
Simple	Size	Girth	Mid-thigh girth	cm	Girth at the midpoint of the upper leg length, perpendicular to the long axis.
Complex	Size	Area	Mid-thigh CSA	m^2	CSA at the midpoint of the upper leg length, perpendicular to the long axis.
Simple	Size	Girth	Thigh girth	cm	Girth of the thigh 1cm distal to the gluteal fold, perpendicular to the long axis (Stewart et al., 2011, p. 85).
Complex	Size	Area	Thigh CSA	m^2	CSA of the thigh 1cm distal to the gluteal fold, perpendicular to the long axis (Stewart et al., 2011, p. 85).
Complex	Size	Volume	Upper leg volume	ml	The volume enclosed by the most superior point on the medial border of the head of the tibia (Stewart et al., 2011:p.48), the most superior point on the lateral border of the head of the tibia (Stewart et al., 2011, p.43) and the gluteal fold .
Complex	Size	Area	Upper leg SA	m^2	The surface area enclosed by the most superior point on the medial border of the head of the tibia (Stewart et al., 2011:p.48), the most superior point on the lateral border of the head of the tibia (Stewart et al., 2011, p.43) and the gluteal fold .
Simple	Symmetry	Length	Lower leg length symmetry	%	The percentage difference between the dominant and non-dominant lower leg length.

Simple	Symmetry	Girth	calf girth symmetry	%	The percentage difference between the dominant and non-dominant calf girth.
Complex	Symmetry	Area	Calf CSA symmetry	%	The percentage difference between the dominant and non-dominant calf CSA.
Simple	Symmetry	Girth	Ankle girth symmetry	%	The percentage difference between the dominant and non-dominant ankle girth.
Complex	Symmetry	Area	Ankle CSA symmetry	%	The percentage difference between the dominant and non-dominant ankle CSA.
Complex	Symmetry	Volume	Lower leg volume symmetry	%	The percentage difference between the dominant and non-dominant lower leg volume.
Complex	Symmetry	Area	Lower leg SA symmetry	%	The percentage difference between the dominant and non-dominant lower leg surface area.
Simple	Symmetry	Length	Upper leg length symmetry	%	The percentage difference between the dominant and non-dominant upper leg length.
Simple	Symmetry	Girth	Knee girth symmetry	%	The percentage difference between the dominant and non-dominant knee girth.
Complex	Symmetry	Area	Knee CSA symmetry	%	The percentage difference between the dominant and non-dominant knee CSA.
Simple	Symmetry	Girth	Mid-thigh girth symmetry	%	The percentage difference between the dominant and non-dominant mid-thigh girth.
Complex	Symmetry	Area	Mid-thigh CSA symmetry	%	The percentage difference between the dominant and non-dominant mid-thigh CSA.
Simple	Symmetry	Girth	Thigh girth symmetry	%	The percentage difference between the dominant and non-dominant thigh girth.
Complex	Symmetry	Area	Thigh CSA symmetry	%	The percentage difference between the dominant and non-dominant thigh CSA.
Complex	Symmetry	Volume	Upper leg volume symmetry	%	The percentage difference between the dominant and non-dominant upper leg volume.

Complex	Symmetry	Area	Upper leg SA symmetry	%	The percentage difference between the dominant and non-dominant upper leg surface area.

Appendix 3 - Ethical approval for the investigation presented in Chapter Six.

A.3.1 Research ethics approval

3.	If you answered NO to question 2, do you have explicit permission to use these materials as data? *If YES, please show evidence to your supervisor. PI should retain permission.*	n/a
4.	If you answered NO to question 3, is it because: A. you have not yet asked permission B. you have asked and not yet received and answer C. you have asked and been refused access.	**A/B/C**
Note	*You will only be able to start the research when you have been granted permission to use the specified material.*	

Adherence to SHU policy and procedures

Personal statement	
I can confirm that: – I have read the Sheffield Hallam University Research Ethics Policy and Procedures – I agree to abide by its principles.	
Student / Researcher/ Principal Investigator (as applicable)	
Name: Alice May Bullas	Date:21/12/15
Signature: UPDATED 03/01/15.	
Supervisor or other person giving ethical sign-off	
I can confirm that completion of this form has not identified the need for ethical approval by the FREC or an NHS, Social Care or other external REC. The research will not commence until any approvals required under Sections 3 & 4 have been received.	
Name: Jon Wheat	Date: 21/12/15
Signature: 03/01/15.	
Additional Signature if required:	
Name: ~~Jon Wheat~~	Date:
Signature:	

Please ensure the following are included with this form if applicable, tick box to indicate:

	Yes	No	N/A
Research proposal if prepared previously	☐	☒	☐
Any recruitment materials (e.g. posters, letters, etc.)	☒	☐	☐
Participant information sheet	☒	☐	☐

Research Ethics Checklist (SHUREC1) 7 V4 October 2015

A.3.2 Participant consent & screening form

Sheffield Hallam University | Centre for Sports Engineering Research

Study Code: CS00

CycleSize - The importance of complex anthropometric measures.

Consent & Screening Form (Over 18)

Please answer the following questions by ticking the response that applies.	**YES**	**NO**
1. I have read the relevant Information Sheet and understand the protocol.	☐	☐
2. My questions about the study have been answered to my satisfaction and I understand that I may ask further questions at any point.	☐	☐
3. I agree to provide information to the researcher under the conditions of confidentiality set out in the Information Sheet.	☐	☐
4. I understand that my participation is completely voluntary and that I have the right to withdraw both myself and my data at any time, before, during or after the study (up to the date of publication) without reason or consequence.	☐	☐
5. I wish to participate in this study under the conditions set out in the Information Sheet.	☐	☐
6. I consent to the data collected (including images), once anonymised, being used for any research purposes (e.g. reports, leaflets, newspaper articles, news releases, presentations, journal articles) deemed necessary by the researcher.	☐	☐
7. I meet the inclusion criteria outlined in the Information Sheet.	☐	☐
8. I know of no reason why I should not participate within this study.	☐	☐
9. I am free from, and have never experienced, any disease or illness that may have influenced physical growth / development, any major lower limb trauma and am able to stand unaided.	☐	☐
10. I would care to receive a copy of the body measurements. (If *Yes* please provide your email address) ……………………………………………………………………	☐	☐

Participant's Consent

Name (printed): …………………………………….. Signature: ……………………………………………..

Age (years): ………… Date: DD/MM/YYYY Contact details:……………………………………..

Researcher's Details

Name: Ms. Alice M Bullas Signature: ………………………………………

Contact Details: a.bullas@shu.ac.uk / +44 (0)114 225 5867

Please retain a copy of your consent form and information for your personal records.

A.3.3 Participant physical activity background questionnaire

Sheffield Hallam University | Centre for Sports Engineering Research

Cycle Size

3D Body Scanning Research

Participant Physical Activity Background Questionnaire

Participant code:	Date of Birth: DD/MM/YYYY	Age: YY.MM
Sex: M / F	Dominant Hand: R / L	Dominant Leg: R / L
Nationality:	Ethnicity:	UK Shoe size: ....

Training Club & Location:

....

Elite Sport Experience:

Have you ever competed at an elite level (defined as regional level competition and above)? (Please circle) Yes/ No

If yes, please detail: ....

....

Cycling Experience:

How many years' experience / training do you have of each disciplines do you have? And what is your main cycling discipline? (Please circle)

BMX	Cyclo-cross	Track	Speedway	Road	Mountain	Other: ....
00	00	00	00	00	00	00

Within this discipline, what is your main competitive event? ....

What type of cyclist would you class yourself as? (Please circle)

Sprint	Hill Climb	Endurance	Time Trial	Recreational	Other:...............

Are you affiliated to any club / team?

....

Cycling Level of Performance (in the main cycling discipline detailed above):

What is your current highest level of performance? (Please circle)

Regional / University (competitions within a region/ area)	Talent development schemes / programme	National (competitions between regions)	International (National representation)

Please detail: ....

1

How long have you been competing at this level? 00 Years & 00 Months

How would you describe your current level of success? (Please circle)
(Success would be described as achieving 1st- 3rd place within a competition).

Local	Regional / University	National	Occasional International success	Frequent International success

Please give an example of this success: ……………………………………………………………

On average, how many hours per week do you spend training? 00 Hours & 00 Minutes.

On average, how many hours per week do you spend competing? 00 Hours & 00 Minutes.

Please circle where you would fall on this table:

Variable/score	1	2	3	4	
A. Athlete's highest standard of performance	Regional level; university level; semi-professional; 4th tier leagues or tours	Involved in talent development; 3rd tier professional leagues or tours	National level; selected to represent nation; 2nd tier professional leagues or tours	International level; top tier professional leagues or tours	**Within-sport comparison**
B. Success at the athlete's highest level	Success at regional, university, semi-professional, or 3rd/4th tier	National titles or success at 2nd/3rd tier	Infrequent success at international level or top tier	Sustained success in major international, globally recognised competition	
C. Experience at the athlete's highest level	<2 years	2-5 years	5-8 years	8+ years	
D. Competitiveness of sport in athlete's country	Sport ranks outside top 10 in county; small sporting nation	Sport ranks 5-10 in country; small-medium sporting nation	Sport ranks top 5 in country; medium-large sporting nation	National sport; large sporting nation	**Between-sports comparison**
E. Global competitiveness of sport	Not Olympic sport; World championships limited to few countries; limited national TV audience	Occasional Olympic sport; World championships limited to a few counties; limited international TV audience	Recent Olympic sport with regular international competition; semi-global TV audience	Regular Olympic sport with frequent major international competition; global TV audience	

IPAQ (International Physical Activity Questionnaire):

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week** **[**No vigorous physical activities ***Skip to question 3***]

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week** **[**No moderate physical activities ***Skip to question 5***]

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

   _____ **days per week** **[**No walking ***Skip to question 7***]

6. How much time did you usually spend **walking** on one of those days?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **weekday**?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

Appendix 4 - Ethical approval for the investigation presented in Chapter Seven.

A.4.1 Research ethics approval

Personal statement	
I confirm that: • **this research will conform to the principles outlined in the Sheffield Hallam University Research Ethics policy** • **this application is accurate to the best of my knowledge**	
Principal Investigator: Ms. Alice May Bullas	
Signature	
Date	6/05/16.
Supervisor: Dr. Jon Wheat	
Signature	
Date	6/05/16.
Other signature	
Signature	
Date	

Please ensure the following are included with this form if applicable, tick box to indicate:

	Yes	**No**	**N/A**
Research proposal if prepared previously	☐	☒	☐
Any recruitment materials (e.g. posters, letters, etc.)	☒	☐	☐
Participant information sheet	☒	☐	☐
Participant consent form	☒	☐	☐
Details of measures to be used (e.g. questionnaires, etc.)	☒	☐	☐
Outline interview schedule / focus group schedule	☐	☐	☒
Debriefing materials	☐	☐	☒
Health and Safety Project Safety Plan for Procedures	☒	☐	☐
Data Management Plan*	☒	☐	

If you have not already done so, please send a copy of your Data management Plan to rdm@shu.ac.uk. It will be used to tailor support and make sure enough data storage will be available for your data.

Application for Research Ethics Approval (SHUREC2B) 10 V3 June2015

A.4.2 Participant consent & screening form

Sheffield Hallam University | Centre for Sports Engineering Research

Cycle Size

3D Body Scanning Research

Participant Consent & Screening Form (Over 18)

Please answer the following questions by ticking the response that applies.

	YES	NO
1. I have read the Information Sheet for this study and have had details of the study explained to me.	☐	☐
2. My questions about the study have been answered to my satisfaction and I understand that I may ask further questions at any point.	☐	☐
3. I agree to provide information to the researcher under the conditions of confidentiality set out in the Information Sheet.	☐	☐
4. I understand that my participation is completely voluntary and that I have the right to withdraw myself and my data at any time, before, during or after the study without reason, questioning or consequence.	☐	☐
5. I wish to participate in the study under the conditions set out in the Information Sheet.	☐	☐
6. I consent to the data and images collected, once anonymised (so that I cannot be identified), being used for any research purposes associated with this project (e.g. reports, leaflets, newspaper articles, news releases, presentations, journal articles).	☐	☐
7. I meet the inclusion criteria outlined in the Information Sheet:		
a. Male	☐	☐
b. Aged 18-45 years	☐	☐
c. Able to stand unaided	☐	☐
d. Free from, and have never experienced any disease, illness or major injury / trauma that may have influenced physical growth / development.	☐	☐
e. Agree to adhere / have adhered to the pre-protocol guidelines (restricted exercise, caffeine intake etc.)	☐	☐
8. I know of no reason why I should not participate within this research study.	☐	☐
9. I do not have an aversion to flashing or strobe lights.	☐	☐
10. I do not have any imbedded / internal electrical devices (e.g. pace maker etc.)	☐	☐
11. I would care to receive a copy of my data. (If *Yes* please provide your email address) ………………………………………………………………………………	☐	☐

Participant Consent

Name (Printed): …………………………………… Signature: …………………………………………

Date: DD/MM/YYYY Contact Number: 00000000000

Researcher's Details

Name: Ms. Alice M Bullas Signature: ………………………………………

Contact Details: Email: a.bullas@shu.ac.uk, Tel: +44 (0)114 225 5867

A.4.3 Participant physical activity background questionnaire

Sheffield Hallam University | Centre for Sports Engineering Research

Cycle Size

3D Body Scanning Research

Participant Physical Activity Background Questionnaire

Participant code: …………………	Date of Birth: DD/MM/YYYY	Age: YY.MM
Sex: M / F	Dominant Hand: R / L	Dominant Leg: R / L
Nationality: …………………………	Ethnicity: …………………………	UK Shoe size: …………………

Training Club & Location:

……………………………………………………………………………………………

Elite Sport Experience:

Have you ever competed at an elite level (defined as regional level competition and above)? (Please circle) Yes/ No

If yes, please detail: ...………………………………………………………………………………..……..

……………………………………..…………………………………………….…………………………

Cycling Experience:

How many years' experience / training do you have of each disciplines do you have? And what is your main cycling discipline? (Please circle)

BMX	Cyclo-cross	Track	Speedway	Road	Mountain	Other: …..………
00	00	00	00	00	00	00

Within this discipline, what is your main competitive event? ………………………………………….

What type of cyclist would you class yourself as? (Please circle)

Sprint	Hill Climb	Endurance	Time Trial	Recreational	Other:…..……….

Are you affiliated to any club / team?

………………………………..…………………………………..

Cycling Level of Performance (in the main cycling discipline detailed above):

What is your current highest level of performance? (Please circle)

Regional / University (competitions within a region/ area)	Talent development schemes / programme	National (competitions between regions)	International (National representation)

Please detail: ………………………………………………………………………………………….

1

How long have you been competing at this level? 00 Years & 00 Months

How would you describe your current level of success? (Please circle)
(Success would be described as achieving 1^{st}- 3^{rd} place within a competition).

Local	Regional / University	National	Occasional International success	Frequent International success

Please give an example of this success: ……………………………………………………………

On average, how many hours per week do you spend training? 00 Hours & 00 Minutes.

On average, how many hours per week do you spend competing? 00 Hours & 00 Minutes.

Please circle where you would fall on this table:

Variable/score	1	2	3	4	
A. Athlete's highest standard of performance	Regional level; university level; semi-professional; 4^{th} tier leagues or tours	Involved in talent development; 3^{rd} tier professional leagues or tours	National level; selected to represent nation; 2^{nd} tier professional leagues or tours	International level; top tier professional leagues or tours	**Within-sport comparison**
B. Success at the athlete's highest level	Success at regional, university, semi-professional, or $3^{rd}/4^{th}$ tier	National titles or success at $2^{nd}/3^{rd}$ tier	Infrequent success at international level or top tier	Sustained success in major international, globally recognised competition	
C. Experience at the athlete's highest level	<2 years	2-5 years	5-8 years	8+ years	
D. Competitiveness of sport in athlete's country	Sport ranks outside top 10 in county; small sporting nation	Sport ranks 5-10 in country; small-medium sporting nation	Sport ranks top 5 in country; medium-large sporting nation	National sport; large sporting nation	**Between-sports comparison**
E. Global competitiveness of sport	Not Olympic sport; World championships limited to few countries; limited national TV audience	Occasional Olympic sport; World championships limited to a few counties; limited international TV audience	Recent Olympic sport with regular international competition; semi-global TV audience	Regular Olympic sport with frequent major international competition; global TV audience	

IPAQ (International Physical Activity Questionnaire):

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week** [No vigorous physical activities ***Skip to question 3***]

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week** [No moderate physical activities ***Skip to question 5***]

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

   _____ **days per week** [No walking ***Skip to question 7***]

6. How much time did you usually spend **walking** on one of those days?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **weekday**?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

A.4.4 Advanced participant pre-exercise screening form

Sheffield Hallam University | Centre for Sports Engineering Research

CycleSize Study 2- Complex Anthropometrics & Peak Power.

[Advanced] Participant Pre-Exercise Screening Form (Over 18)

For most people physical activity provides a basis for good health and an enhanced quality of life. However, there are a small number of people who may be at risk when exercising and for this reason we ask that you complete this form so that we may give you the highest level of care possible. Please be as detailed as possible. All information will remain confidential.

First Name:..................... Last Name:..................... Date of Birth: DD/MM/YYYY

Do you currently have, or have had in the past, any of the following?

	Yes / No	Details:
A heart condition		
Diabetes Type I		
Diabetes Type II		
High cholesterol		
Asthma or breathing difficulties		
Fainting or dizzy spells		
Increased bleeding or haemophilia		
Cystic Fibrosis		
High blood pressure		
Epilepsy or seizures		
Sudden shortness of breath		

In the last 6 months have you experienced any of the following while exercising?

	Yes / No	Details:
Muscular, joint or bone pain or injury?		
Unexplained coughing		
Shortness of breath		
Chest pain		
Dizziness / faintness		

Have you ever been recommended to only do exercise prescribed by a doctor? Yes / No Details:

Are you taking any medication or supplements? Yes / No Details:

1

Do you know of any reason why you should not participate in this study?	Yes / No	Details:

I, ……………………………………………………………………, hereby acknowledge that the information provided above regarding my health is, to the best of my knowledge, correct. I understand that participating in physical activity carries a risk, and I accept all responsibility for that risk.

Signature: ……………………………… Date: DD/MM/YYYY Contact Number: 00000000000

Emergency Contact Details

Name (Printed): ……………………………… Relationship to participant:……………………..……...

Contact No. (Home): 00000000000 Contact No. (Mobile):00000000000

Note:

If the participant ANSWERED '**YES**' to any of the questions, please seek guidance from the participants GP or appropriate allied health professional prior to the participant undertaking physical activity/exercise.

If the participant ANSWERED '**NO**' to all of the questions, and you have no other concerns about the participants health, they may proceed to undertake light-moderate intensity physical activity/exercise

A.4.5 On the day participant pre-exercise screening form

Sheffield Hallam University | Centre for Sports Engineering Research

Cycle Size

3D Body Scanning Research

Participant Pre-Exercise Screening Form (Over 18)

For most people physical activity provides a basis for good health and an enhanced quality of life. However, there are a small number of people who may be at risk when exercising and for this reason we ask that you complete this form so that we may give you the highest level of care possible. Please be as detailed as possible. All information will remain confidential.

First Name:..................... Last Name:..................... Date of Birth: DD/MM/YYYY

Do you currently have, or have had in the past, any of the following?

	Yes / No	Details:
A heart condition		
Diabetes Type I		
Diabetes Type II		
High cholesterol		
Asthma or breathing difficulties		
Fainting or dizzy spells		
Increased bleeding or haemophilia		
Cystic Fibrosis		
High blood pressure		
Epilepsy or seizures		
Sudden shortness of breath		

In the last 6 months have you experienced any of the following while exercising?

	Yes / No	Details:
Muscular, joint or bone pain or injury?		
Unexplained coughing		
Shortness of breath		
Chest pain		
Dizziness / faintness		

Have you ever been recommended to only do exercise prescribed by a doctor? Yes / No Details:

Are you taking any medication or supplements? Yes / No Details:

Have you drunk any caffeinated or high Yes / No Details:

1

(>12%) carbohydrate drinks in the last four hours?
Do you know of any reason why you should not participate in this study? Yes / No Details:

What exercise have you undertaken in the last 48 hours?

Activity:	Intensity:	Duration:

What have you consumed in the last 48 hours?

Meal:	Details:
Yesterday's Breakfast @ 0:00:	
Yesterday's Lunch @ 0:00:	
Yesterday's Dinner @ 0:00:	
Yesterday's Snacks @ 0:00:	
Today's Breakfast @ 0:00:	
Today 's Lunch @ 0:00:	
Today 's Dinner @ 0:00:	
Today 's Snacks @ 0:00:	

I, ………………………………………………………………., hereby acknowledge that the information provided above regarding my health is, to the best of my knowledge, correct. I understand that participating in physical activity carries a risk, and I accept all responsibility for that risk.

Signature: ……………………………… Date: DD/MM/YYYY Contact Number: 00000000000

Emergency Contact Details

Name (Printed): ……………………………… Relationship to participant:……………………..……...

Contact No. (Home): 00000000000 Contact No. (Mobile):00000000000

Note:

If the participant ANSWERED '**YES**' to any of the questions, please seek guidance from the participants GP or appropriate allied health professional prior to the participant undertaking physical activity/exercise.

If the participant ANSWERED '**NO**' to all of the questions, and you have no other concerns about the participants health, they may proceed to undertake light-moderate intensity physical activity/exercise

Appendix 5 - Lode verification.

A.5.1 Lode verification programme.

Table 11.1: Rpm (30-120) and watts (50-900) for the Lode verification programme.

RPM [/min]	Power [watt]			
	1	2	3	4
30	50	100	150	-
40	50	100	150	200
50	100	150	200	250
60	150	200	250	300
70	200	250	300	400
80	200	300	400	500
90	300	400	500	600
100	400	500	600	700
110	500	600	700	800
120	600	700	800	900
120	900	800	700	600
110	800	700	600	500
100	700	600	500	400
90	600	500	400	300
80	500	400	300	250
70	400	300	250	200
60	300	250	200	150
50	250	200	150	100
40	200	150	100	50
30	150	100	50	-

A.5.2 Lode verification programme results

Table 11.2: Mean error and standard deviation for each Lode bike and verifications session.

Verification session	Lode bike			
	1		2	
	watts	%	watts	%
1	-7.2 ± 10.3	-1.3 ± 2.8	-7.6 ± 5.7	-2.1 ± 1.2
2	-7.6 ± 5.7	-2.1 ± 1.2	-11.5 ± 10.7	-2.8 ± 2.7
3	-9.2 ± 10.5	-1.9 ± 2.7	-17.2 ± 12.1	-4.6 ± 2.4
All	-8.0 ± 1.1	-1.7 ± 0.4	-12.1 ± 4.8	-3.2 ± 1.3
Mean for both bikes	-10.1± 3.8	-2.5 ± 1.2		

Appendix 6 - Ethical approval for the investigation presented in Chapter Eight.

A.6.1 Research ethics approval

6. Are there any potential risks to your health and wellbeing associated with either (a) the venue where the research will take place and/or (b) the research topic itself?

☒ None that I am aware of
☐ Yes (Please outline below)

7. Does this research project require a health and safety risk analysis for the procedures to be used?

☒ Yes
☐ No

(If YES the completed Health and Safety Project Safety Plan for Procedures should be attached)

ADHERENCE TO SHU POLICY AND PROCEDURES

Personal statement	
I confirm that: • **this research will conform to the principles outlined in the Sheffield Hallam University Research Ethics policy** • **this application is accurate to the best of my knowledge**	
Principal Investigator: Ms. Alice May Bullas	
Signature	AMBullas
Date	15/03/16.
Supervisor: Dr. Jon Wheat	
Signature	
Date	15/3/16.
Other signature	
Signature	
Date	

Please ensure the following are included with this form if applicable, tick box to indicate:

	Yes	**No**	**N/A**
Research proposal if prepared previously	☐	☒	☐
Any recruitment materials (e.g. posters, letters, etc.)	☒	☐	☐
Letter of collaboration			

Application for Research Ethics Approval (SHUREC2B) 11 V3 June2015

A.6.2 Training plan

	Instead of us setting your colour intensity, you can do it based on how youre feeling. Move when you're tierd work when you're ready!																							
COLOUR KEY	Session 1						Session 2						Session 3						Session 4					
2 = Black	Soreness			Tierdness			Soreness			Tierdness			Soreness			Tierdness			Soreness			Tierdness		
3-4 = Red	(1-5)=			(1-5)=			(1-5)=			(1-5)=			(1-5)=			(1-5)=			(1-5)=			(1-5)=		
5-6 = Blue (or flow)	Total =			Colour =			Total =			Colour =			Total =			Colour =			Total =			Colour =		
7-10 = Flow	Squat				Leg Press				TBDL				Step Ups				Bench Pull Wrestle				Bench Press Wrestle			
1 % of 1RM	90%	80%	75%	<70%	90%	80%	75%	<70%	90%	80%	75%	<70%	90%	80%	75%	<70%	90%	80%	75%	<70%	90%	80%	75%	<70%
Lower (Kg)	84	74	64	40	220	192	166	110	120	106	90	60	36	32	28	18	45	40	30	20	50	45	30	20
Upper (Kg)	106	84	74	64	276	220	192	166	150	120	106	90	46	36	32	28	76	45	40	30	60	50	45	30
Training Phase:	Derek - Light nights, dust and loam, with a spring in our step is how we roam!																							
Choose session	Session 1 - Date:						Session 2 - Date:						Session 3 - Date:						Session 4 - Date:					
Flow	Reps w/up			Load(kg)			Reps w/up			Load(kg)			Reps w/up			Load(kg)			Reps w/up			Load(kg)		
Lateral Hops	5es	X					5es	X					5es	X					5es	X				
Lateral Squats	5es	X					5es	X					5es	X					5es	X				
Anti Rotation Press	8es	X					8es	X					8es	X					8es	X				
Step Ups	5es	X					5es	X					5es	X					5es	X				
Squat / Leg Press / TBDL	5						5						5						5					
Mountain Climbers	8es	X					8es	X					8es	X					8es	X				
TRX Row	8	X					8	X					8	X					8	X				
Push Up Variation	8	X					8	X					8	X					8	X				
Natural	Reps w/up			Load(kg)			Reps w/up			Load(kg)			Reps w/up			Load(kg)			Reps w/up			Load(kg)		
Seated Box Jumps	5	X					5	X					5	X					5	X				
Step Ups	5es	X					5es	X					5es	X					5es	X				
Kneeling Banded MB Throw	5es	X					5es	X					5es	X					5es	X				
Landmine Squat to Press	5						5						5						5					
Squat / Leg Press / TBDL	5						5						5						5					
Disabled Dogs	1L	X					1L	X					1L	X					1L	X				
Bench Pull Wrestle	5s+5	Bar					5s+5	Bar					5s+5	Bar					5s+5	Bar				
Bench Push Wrestle	5s+5	Bar					5s+5	Bar					5s+5	Bar					5s+5	Bar				
Notes >																								

	Instead of us setting your colour intensity, you can do it based on how youre feeling. Move when you're tierd work when you're ready!																							
COLOUR KEY	Session 1						Session 2						Session 3						Session 4					
2 = Black	Soreness			Tierdness			Soreness			Tierdness			Soreness			Tierdness			Soreness			Tierdness		
3-4 = Red	(1-5)=			(1-5)=			(1-5)=			(1-5)=			(1-5)=			(1-5)=			(1-5)=			(1-5)=		
5-6 = Blue (or flow)	Total =			Colour =			Total =			Colour =			Total =			Colour =			Total =			Colour =		
7-10 = Flow	Squat				Leg Press				TBDL				Step Ups				Bench Pull Wrestle				Bench Press Wrestle			
2 % of 1RM	90%	80%	75%	<70%	90%	80%	75%	<70%	90%	80%	75%	<70%	90%	80%	75%	<70%	90%	80%	75%	<70%	90%	80%	75%	<70%
Lower (Kg)	84	74	64	40	220	192	166	110	120	106	90	60	36	32	28	18	45	40	30	20	50	45	30	20
Upper (Kg)	106	84	74	64	276	220	192	166	150	120	106	90	46	36	32	28	76	45	40	30	60	50	45	30
Training Phase:	Derek - Light nights, dust and loam, with a spring in our step is how we roam!																							
Choose session	Session 1 - Date:						Session 2 - Date:						Session 3 - Date:						Session 4 - Date:					
Flow	Reps w/up			Load(kg)			Reps w/up			Load(kg)			Reps w/up			Load(kg)			Reps w/up			Load(kg)		
Box Jumps	4	X					4	X					4	X					4	X				
SL RDL	4es	X					4es	X					4es	X					4es	X				
Landmine Rotations	4es	X					4es	X					4es	X					4es	X				
Step Ups	4es	X					4es	X					4es	X					4es	X				
Squat / Leg Press / TBDL	5						5						5						5					
Partner Planks	8	X					8	X					8	X					8	X				
Landmine Pulls	8						8						8						8					
Lying MB Throw	8						8						8						8					
Natural	Reps w/up			Load(kg)			Reps w/up			Load(kg)			Reps w/up			Load(kg)			Reps w/up			Load(kg)		
Depth Jump	3	X					3	X					3	X					3	X				
Lunge to Step Up	3es	X					3es	X					3es	X					3es	X				
Landmine Rotations	4es	X					4es	X					4es	X					4es	X				
Banded Squat	8						8						8						8					
Squat / Leg Press / TBDL	4						4						4						4					
Partner Leg Throw	8	X					8	X					8	X					8	X				
Explosive Prowler Pull	4						4						4						4					
Prowler Push Throw	4						4						4						4					
Notes >																								

Blue Steel Derek Intervals

Turbo

Non-Optional Session 1

From Monday...	Week	Work Interval	Work Intensity	Recovery Interval	Recovery Intensity	Number of Repeats	Number of Sets	Recovery Between Sets	Total Session Time	Tick When Completed	Session Toughness	Session Notes
18/04/2016	1	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	3	1	n/a	9min			
25/04/2016	2	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	4	1	n/a	12min			
02/05/2016	3	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	5	1	n/a	15min			
09/05/2016	4	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	6	1	n/a	18min			
16/05/2016	5	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	7	1	n/a	21min			
23/05/2016	6	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	8	1	n/a	24min			
30/05/2016	7	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	9	1	n/a	27min			
06/06/2016	8	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	10	1	n/a	30min			
13/06/2016	9	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	10	1	n/a	30min			
20/06/2016	10	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	3	1	n/a	9min			

Optional Session 2

From Monday...	Week	Work Interval	Work Intensity	Recovery Interval	Recovery Intensity	Number of Repeats	Number of Sets	Recovery Between Sets	Total Session Time	Tick When Completed	Session Toughness	Session Notes
18/04/2016	1	15s	100+ RPM & 7-8/10	15s	Easy spin	10	2	2min easy spin	12min			
25/04/2016	2	15s	100+ RPM & 7-8/10	15s	Easy spin	10	2	2min easy spin	12min			
02/05/2016	3	15s	100+ RPM & 7-8/10	15s	Easy spin	10	2	2min easy spin	12min			
09/05/2016	4	15s	100+ RPM & 7-8/10	15s	Easy spin	10	2	2min easy spin	12min			
16/05/2016	5	30s	100+ RPM & 7-8/10	30s	Easy spin	10	2	2min easy spin	22min			
23/05/2016	6	30s	100+ RPM & 7-8/10	30s	Easy spin	10	2	2min easy spin	22min			
30/05/2016	7	30s	100+ RPM & 7-8/10	30s	Easy spin	10	2	2min easy spin	22min			
06/06/2016	8	30s	100+ RPM & 7-8/10	30s	Easy spin	10	2	2min easy spin	22min			
13/06/2016	9	15s	115+ RPM & 8/10	15s	Easy spin	10	2	2min easy spin	12min			
20/06/2016	10	0	0	0	0	0	0	0	0			

Instruction Sheet

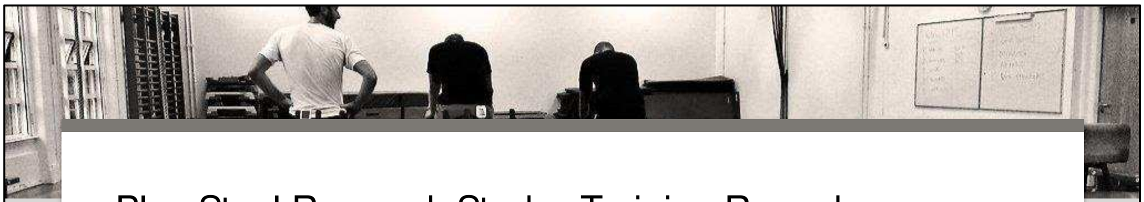
Turbo

Non-Optional Session 1

From Monday...	Week	Work Interval	Work Intensity	Recovery Interval	Recovery Intensity	Number of Repeats	Number of Sets	Recovery Between Sets	Total Session Time	Tick When Completed	Session Toughness	Session Notes
18/04/2016	1	5s	Big gear, slight uphill, max effort	2min 55s	Easy spin or flow	3	1	n/a	9min			
^ There are 4 weeks of training before we come back to see how everyone is getting on. ^ That's just 4 interval sessions between now and then! (8 if you do the optional ones too).		^ This is your work duration.	^ This is your interval intensity. Don't be tempted to work harder (or easier) as this is carefully thought out. Remember you are trying to maintain the same high quality across all intervals.	^ This is how long you have to recover.	^ If doing the session on the turbo, recover with an easy spin. If outside, spin easy, or gently pump a flow trail.	^ Number of times you go through the Work and Recovery cycle per Set.	^ Number of Sets per Session.	^ How long to Recover between Sets.	^ Total session time (not including Warm Up or Cool Down).	^ Tick off each Session as you do it. It really helps to see them getting done.	^ Rate your Session out of 10. Use the Intensity Scale as a guide. Hopefully it will closely match the Intensities prescribed!	^ Make any comments about the Session here. For example, say if you did it on the trainer or outside.

INTENSITY SCALE	
RPE	**Description**
10	YEOWCH!!
9	DREADFUL
8	BAD PLACE
7	PROPER HARD
6	
5	HARD
4	SORT OF HARD
3	MODERATE
2	EASY
1	REALLY EASY
0	REST

A.6.3 Training diary



Blue Steel Research Study - Training Record

Here is a weekly questionnaire for you to ; ll in. It will take approximately 1min 29s. Please do it as it's really important. It's also a great way for you to evaluate your week and reGect on what went well / what didn't go to plan.

Ta!

* Required

Week No. *

Your answer

Name: *

Your answer

Which days have you done an S&C programme? *

This could be a coached session or home programme

- ☐ Friday
- ☐ Saturday
- ☐ Sunday
- ☐ Monday
- ☐ Tuesday
- ☐ Wednesday
- ☐ Thursday (yesterday)
- ☐ I haven't done any

Which days have you done on the bike intervals? *

Please only let us know about the intervals we've suggested as part of the home programme

- ☐ Friday
- ☐ Saturday
- ☐ Sunday
- ☐ Monday
- ☐ Tuesday
- ☐ Wednesday
- ☐ Thursday (yesterday)
- ☐ I haven't done any

How many hours did you ride each day?

This could be commuting or any style of bicycle riding (please round to the nearest hour)

	30min	1hr	2hr	3hr	4hr	5hr	6hr	7hr+
Friday	○	○	○	○	○	○	○	○
Saturday	○	○	○	○	○	○	○	○
Sunday	○	○	○	○	○	○	○	○
Monday	○	○	○	○	○	○	○	○
Tuesday	○	○	○	○	○	○	○	○
Wednesday	○	○	○	○	○	○	○	○
Thursday (yesterday)	○	○	○	○	○	○	○	○

Have you done any other exercise / training / sport this week?

Your answer

Have you raced this week? *

◯ Yes

◯ No

If you did race, where was it and how did you do?

Your answer

Please rate how tired you are feeling *

	1	2	3	4	5	
Fresh as a daisy	◯	◯	◯	◯	◯	Totally worn out

Please rate how much muscle soreness you have *

	1	2	3	4	5	
None! Feel great	◯	◯	◯	◯	◯	DOMS from hell!

Please rate how energetic / lively / happy you're feeling *

	1	2	3	4	5	
Flat as a cold pancake	◯	◯	◯	◯	◯	Like a spring chicken (or Jolley on a good day!)

Please share with us any further comments about this past week below.

You may want to let us know if you've had any major changes at work / home or crashes or successes :-)

Your answer

SUBMIT

Never submit passwords through Google Forms.

A.6.4 Participant consent & screening form

Sheffield Hallam University | Centre for Sports Engineering Research

CycleSize Study 3- Complex Anthropometric in Kinanthropometry of Sprint Cycling.

Participant Consent Form

Please answer the following questions by ticking the response that applies.

	YES	NO
1. I have read the Information Sheet for this study and have had details of the study explained to me.	☐	☐
2. My questions about the study have been answered to my satisfaction and I understand that I may ask further questions at any point.	☐	☐
3. I agree to provide information to the researcher under the conditions of confidentiality set out in the Information Sheet.	☐	☐
4. I understand that my participation is completely voluntary and that I have the right to withdraw myself and my data at any time, before, during or after the study without reason, questioning or consequence.	☐	☐
5. I wish to participate in the study under the conditions set out in the Information Sheet.	☐	☐
6. I meet the inclusion criteria outlined in the Information Sheet:		
a. Male	☐	☐
b. Aged 18-45 years	☐	☐
c. Able to stand unaided	☐	☐
d. Free from, and have never experienced any disease, illness or major injury / trauma that may have influenced physical growth / development.	☐	☐
e. Agree to adhere / have adhered to the pre-protocol guidelines (restricted exercise, caffeine intake etc.)	☐	☐
7. I know of no reason why I should not participate within this research study.	☐	☐
8. I consent to take responsibility for informing the lead investigator (Alice Bullas) of any changes in my health.	☐	☐
9. I consent to the data and any images collected, once anonymised (so that I cannot be identified), being used for any research purposes associated with the principal investigators doctoral studies (e.g. reports, leaflets, newspaper articles, news releases, presentations, journal articles).	☐	☐

10. Please tick one:
- ☐ I consent for Blue Steel to receive an anonymised copy of my data…
- ☐ I consent for Blue Steel to have unlimited access of my data …
- ☐ I do not consent for Blue Steel to have access of my data …

… in reports, publications, and presentations (provided in a report (.pdf) by email, up to one month after the final data collection session).

	YES	NO
11. I would care to receive a copy of my data. (If *Yes* please provide your email address) ………………………………………………………………………………	☐	☐

Sheffield Hallam University | Centre for Sports Engineering Research

Participant Consent

Name (Printed): …………………………………….. Signature (initials if digital): ……………………..

Date: DD/MM/YYYY Contact Number: 00000000000

Researcher's Details

Name: Ms. Alice M Bullas

Contact Details: Email: a.bullas@shu.ac.uk, Tel: +44 (0)114 225 5867

A.6.5 Participant physical activity background questionnaire

Sheffield Hallam University | Centre for Sports Engineering Research

CycleSize Study 3 - Investigating the role of body measures in monitoring physical changes induced by training.

Participant Physical Activity Background Questionnaire

Participant code: ……………… Date of Birth: DD/MM/YYYY Age: YY.MM

Sex: M / F Dominant Hand: R / L Dominant Leg: R / L

Nationality: …………………… Ethnicity: …………………… UK Shoe size: ………………

Height: Weight:

Preferred pedal type: ☐ Flat ☐ Clip (please detail brand) …………………………………………

Training Club & Location: Blue Steel Strength & Conditioning Club, Sheffield Hallam Uni.

Elite Sport Experience:

Have you ever competed at an elite level (defined as regional level competition and above)? (Please circle) Yes/ No

If yes, please detail: ……………………………………………………………………………………...……..
………

Cycling Experience:

How many years' experience / training do you have of each disciplines do you have? And what is your main cycling discipline? (Please circle)

BMX	Cyclo-cross	Track	Speedway	Road	Mountain	Other: …………
00	00	00	00	00	00	00

Within this discipline, what is your main competitive event? …………………………………………

What type of cyclist would you class yourself as? (Please circle)

Sprint	Hill Climb	Endurance	Time Trial	Recreational	Other:……………

Are you affiliated to any club / team?
……………………………..……………………………………..

Cycling Level of Performance (in the main cycling discipline detailed above):

What is your current highest level of performance? (Please circle)

Regional / University (competitions within a region/ area)	Talent development schemes / programme	National (competitions between regions)	International (National representation)

Please detail: ………………………………………………………………………………………………

1

How long have you been competing at this level? 00 Years & 00 Months

How would you describe your current level of success? (Please circle)
(Success would be described as achieving 1st- 3rd place within a competition).

Local	Regional / University	National	Occasional International success	Frequent International success

Please give an example of this success: ……………………………………………………………

On average, how many hours per week do you spend training? 00 Hours & 00 Minutes.

On average, how many hours per week do you spend competing? 00 Hours & 00 Minutes.

Please circle where you would fall on this table:

Variable/score	1	2	3	4	
A. Athlete's highest standard of performance	Regional level; university level; semi-professional; 4th tier leagues or tours	Involved in talent development; 3rd tier professional leagues or tours	National level; selected to represent nation; 2nd tier professional leagues or tours	International level; top tier professional leagues or tours	**Within-sport comparison**
B. Success at the athlete's highest level	Success at regional, university, semi-professional, or 3rd/4th tier	National titles or success at 2nd/3rd tier	Infrequent success at international level or top tier	Sustained success in major international, globally recognised competition	
C. Experience at the athlete's highest level	<2 years	2-5 years	5-8 years	8+ years	
D. Competitiveness of sport in athlete's country	Sport ranks outside top 10 in county; small sporting nation	Sport ranks 5-10 in country; small-medium sporting nation	Sport ranks top 5 in country; medium-large sporting nation	National sport; large sporting nation	**Between-sports comparison**
E. Global competitiveness of sport	Not Olympic sport; World championships limited to few countries; limited national TV audience	Occasional Olympic sport; World championships limited to a few counties; limited international TV audience	Recent Olympic sport with regular international competition; semi-global TV audience	Regular Olympic sport with frequent major international competition; global TV audience	

2

IPAQ (International Physical Activity Questionnaire):

Think about all the **vigorous** activities that you did in the **last 7 days**. **Vigorous** physical activities refer to activities that take hard physical effort and make you breathe much harder than normal. Think *only* about those physical activities that you did for at least 10 minutes at a time.

1. During the **last 7 days**, on how many days did you do **vigorous** physical activities like heavy lifting, digging, aerobics, or fast bicycling?

   _____ **days per week** **[**No vigorous physical activities ***Skip to question 3***]

2. How much time did you usually spend doing **vigorous** physical activities on one of those days?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

Think about all the **moderate** activities that you did in the **last 7 days**. **Moderate** activities refer to activities that take moderate physical effort and make you breathe somewhat harder than normal. Think only about those physical activities that you did for at least 10 minutes at a time.

3. During the **last 7 days**, on how many days did you do **moderate** physical activities like carrying light loads, bicycling at a regular pace, or doubles tennis? Do not include walking.

   _____ **days per week** **[**No moderate physical activities ***Skip to question 5***]

4. How much time did you usually spend doing **moderate** physical activities on one of those days?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

Think about the time you spent **walking** in the **last 7 days**. This includes at work and at home, walking to travel from place to place, and any other walking that you have done solely for recreation, sport, exercise, or leisure.

5. During the **last 7 days**, on how many days did you **walk** for at least 10 minutes at a time?

   _____ **days per week** **[**No walking ***Skip to question 7***]

6. How much time did you usually spend **walking** on one of those days?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

The last question is about the time you spent **sitting** on weekdays during the **last 7 days**. Include time spent at work, at home, while doing course work and during leisure time. This may include time spent sitting at a desk, visiting friends, reading, or sitting or lying down to watch television.

7. During the **last 7 days**, how much time did you spend **sitting** on a **weekday**?

   _____ **hours per day**
   _____ **minutes per day** ☐ Don't know/Not sure

3

A.6.6 Advanced pre-exercise screening form

Sheffield Hallam University | Centre for Sports Engineering Research

CycleSize Study 3 - Investigating the role of body measures in monitoring physical changes induced by training.

[Advanced] Participant Pre-Exercise Screening Form

For most people physical activity provides a basis for good health and an enhanced quality of life. However, there are a small number of people who may be at risk when exercising and for this reason we ask that you complete this form so that we may give you the highest level of care possible. Please be as detailed as possible. All information will remain confidential.

First Name:..................... Last Name:..................... Date of Birth: DD/MM/YYYY

Do you currently have, or have had in the past, any of the following?

	Yes / No	Details:
A heart condition		
Diabetes Type I		
Diabetes Type II		
High cholesterol		
Asthma or breathing difficulties		
Fainting or dizzy spells		
Increased bleeding or haemophilia		
Cystic Fibrosis		
High blood pressure		
Epilepsy or seizures		
Sudden shortness of breath		

In the last 6 months have you experienced any of the following while exercising?

	Yes / No	Details:
Muscular, joint or bone pain or injury?		
Unexplained coughing		
Shortness of breath		
Chest pain		
Dizziness / faintness		

Have you ever been recommended to only do exercise prescribed by a doctor? Yes / No Details:

Are you taking any medication or supplements? Yes / No Details:

1

Do you know of any reason why you should not participate in this study?	Yes / No	Details:

I, ……………………………………………………………., hereby acknowledge that the information provided above regarding my health is, to the best of my knowledge, correct. I understand that participating in physical activity carries a risk, and I accept all responsibility for that risk.

Signature (initials if digital): ………………………………
Date: DD/MM/YYYY
Contact Number: 00000000000

Emergency Contact Details

Name (Printed): ……………………………… Relationship to participant:…………………………..……...

Contact No. (Home): 00000000000 Contact No. (Mobile):00000000000

Note:

If the participant ANSWERED '**YES**' to any of the questions, please seek guidance from the participants GP or appropriate allied health professional prior to the participant undertaking physical activity/exercise.

If the participant ANSWERED '**NO**' to all of the questions, and you have no other concerns about the participants health, they may proceed.

A.6.7 On the day pre-exercise screening form

CycleSize Study 3 - Investigating the role of body measures in monitoring physical changes induced by training.

[On The Day] Participant Pre-Exercise Screening Form

For most people physical activity provides a basis for good health and an enhanced quality of life. However, there are a small number of people who may be at risk when exercising and for this reason we ask that you complete this form so that we may give you the highest level of care possible. Please be as detailed as possible. All information will remain confidential.

First Name:...................... Last Name:...................... Date of Birth: DD/MM/YYYY

Do you currently have, or have had in the past, any of the following?

	Yes / No	Details:
A heart condition		
Diabetes Type I		
Diabetes Type II		
High cholesterol		
Asthma or breathing difficulties		
Fainting or dizzy spells		
Increased bleeding or haemophilia		
Cystic Fibrosis		
High blood pressure		
Epilepsy or seizures		
Sudden shortness of breath		

In the last 6 months have you experienced any of the following while exercising?

	Yes / No	Details:
Muscular, joint or bone pain or injury?		
Unexplained coughing		
Shortness of breath		
Chest pain		
Dizziness / faintness		

Have you ever been recommended to only do exercise prescribed by a doctor? Yes / No Details:

Are you taking any medication or supplements? Yes / No Details:

Have you drunk any caffeinated or high (>12%) carbohydrate drinks in the last Yes / No Details:

four hours?
Do you know of any reason why you should not participate in this study? Yes / No Details:

What exercise have you undertaken in the last 48 hours?

Activity:	Intensity:	Duration:

What have you consumed in the last 48 hours?

Meal:	Details:
Yesterday's Breakfast @ 0:00:	
Yesterday's Lunch @ 0:00:	
Yesterday's Dinner @ 0:00:	
Yesterday's Snacks @ 0:00:	
Today's Breakfast @ 0:00:	
Today 's Lunch @ 0:00:	
Today 's Dinner @ 0:00:	
Today 's Snacks @ 0:00:	

What is your most recent time trail result?
(Please detail the route) ……………………..…………………… …………… …………….

I, ……………………………………………………………….., hereby acknowledge that the information provided above regarding my health is, to the best of my knowledge, correct. I understand that participating in physical activity carries a risk, and I accept all responsibility for that risk.

Signature (initials if digital): ……………………..
Date: DD/MM/YYYY

Contact Number: 00000000000

Emergency Contact Details	
Name (Printed):	Relationship to participant:.................................
Contact No. (Home): 00000000000	Contact No. (Mobile):00000000000

Note:

If the participant ANSWERED '**YES**' to any of the questions, please seek guidance from the participants GP or appropriate allied health professional prior to the participant undertaking physical activity/exercise.

If the participant ANSWERED '**NO**' to all of the questions, and you have no other concerns about the participants health, they may proceed.

A.6.8 Letter of collaboration

Miss A L Carter
104 Oldfield Road
Stannington
Sheffield
S6 6DW

To whom it may concern,

I would like to formally express my interest in Alice-May Bullas' study: Complex anthropometrics in kinanthropometry of sprint cycling (Study 3). I would be happy to be a part of this and on behalf of Blue Steel Conditioning would be a willing collaborator.

Yours truly,

Miss A Carter

Appendix 7 - Results table from Chapter Eight.

Table 11.3: The mean ± standard deviations of each variable for each data collection session.

Variable	Data collection		Difference		Effect Size
	Pre	Post	Absolute	Relative	(d)
ND upper leg length (cm)	29.8 ± 1.8	30.0 ± 1.7	-0.0 ± 0.4	-0.1 ± 1.3	-0.01
ND thigh girth (cm)	61.6 ± 3.2	61.9 ± 2.9	0.3 ± 2.0	0.5 ± 3.3	0.09
ND thigh CSA (cm^2)	266.5 ± 21.8	267.8 ± 23.1	1.3 ± 4.2	0.5 ± 1.6	0.06
ND upper leg volume (ml)	5913.7 ± 440.4	5903.0 ± 346.4	-10.7 ± 218.1	-0.2 ± 3.7	-0.03
ND upper leg SA (cm^2)	1481.4 ± 83.3	1488.2 ± 73.7	6.9 ± 23.8	0.5 ± 1.6	0.09
ND knee girth (cm)	38.0 ± 1.9	38.1 ± 1.9	0.1 ± 0.5	0.2 ± 1.2	0.05
ND knee CSA (cm^2)	109.7 ± 11.0	109.9 ± 11.0	0.1 ± 1.7	0.1 ± 1.6	0.01
ND mid-thigh girth (cm)	50.2 ± 2.1	50.5 ± 2.1	0.3 ± 0.4	0.6 ± 0.7	0.14
ND mid-thigh CSA (cm^2)	198.9 ± 15.9	200.9 ± 16.1	2.1 ± 3.0	1.0 ± 1.5	0.13
D upper leg length (cm)	29.3 ± 2.2	29.3 ± 2.0	0.1± 0.4	0.3 ± 1.3	0.04
D thigh girth (cm)	61.3 ± 2.8	61.3 ± 2.8	0.1 ± 1.2	0.1 ± 1.9	0.02
D thigh CSA (cm^2)	269.3 ± 22.6	270.6 ± 22.8	1.3 ± 8.2	0.5 ± 3.0	0.06
D upper leg volume (ml)	5901.6 ± 427.4	5890.0 ± 432.0	-11.7 ± 252.7	-0.2 ± 4.3	-0.03
D upper leg SA (cm^2)	1459.9 ± 91.2	1464.7 ± 90.1	4.8 ± 41.3	0.3 ± 2.8	0.05
D knee girth (cm)	38.2 ± 1.6	38.3 ± 1.7	0.1 ± 0.7	0.3 ± 1.9	0.07
D knee CSA (cm^2)	110.4 ± 9.5	111.3 ± 9.8	0.9 ± 4.3	0.8 ± 3.9	0.09
D mid-thigh girth (cm)	50.7 ± 2.4	50.5 ± 2.2	-0.21± 1.4	-0.4 ± 2.7	-0.09
D mid-thigh CSA (cm^2)	203.8 ± 19.0	202.3 ± 17.8	-1.6 ± 10.8	-0.8 ± 5.3	-0.09
Upper leg length symmetry (%)	3.1± 2.6	2.2 ± 2.2	-0.9 ± 1.2	-28.6 ± 40.2	-0.36
Thigh girth symmetry (%)	1.5 ± 1.4	1.8 ± 23	0.3 ± 3.1	21.2 ± 206.6	0.17
Thigh CSA symmetry (%)	1.63± 1.4	2.5 ± 1.7	0.8 ± 2.5	50.1 ± 154.5	0.53
Upper leg volume symmetry (%)	2.0 ± 1.6	2.3 ± 2.2	0.3 ± 2.8	12.7 ± 137.5	0.14
Upper leg SA symmetry (%)	2.6 ± 2.4	2.7 ± 2.9	0.1 ± 2.8	3.5 ± 109.0	0.03
Knee girth symmetry (%)	1.3 ± 1.0	1.4 ± 1.5	0.1 ± 1.6†	9.8 ± 124.3	0.10
Knee CSA symmetry (%)	2.4 ± 1.6	2.6 ± 2.9	0.2 ± 3.3†	9.3 ± 138.2	0.10
Mid-thigh girth symmetry (%)	1.2 ± 1.2	1.5 ± 1.4	0.3 ± 1.4†	21.0 ± 117.8	0.20
Mid-thigh CSA symmetry (%)	2.5 ± 2.3	3.2 ± 2.8	0.7 ± 2.7†	26.5 ± 105.4	0.27
ND lower leg length (cm)	42.8 ± 2.7	42.7 ± 2.6	-0.1 ± 0.4	-0.3 ± 0.9	-0.05
ND calf girth (cm)	37.7 ± 1.9	37.7 ± 2.0	0.0 ± 0.4	-0.0 ± 1.1	0.00
ND calf CSA (cm^2)	112.3 ± 11.81	112.2 ± 12.5	-0.1 ± 2.7	-0.0 ± 2.4	0.00
ND lower leg volume (ml)	3386.5 ± 322.4	3368.2 ± 333.2	-18.3 ± 43.2	-0.5 ± 1.3	-0.06

ND lower leg SA (cm^2)	1338.5 ± 90.4	1332.6 ± 90.4	-5.9 ± 11.1	-0.4 ± 0.8	-0.07
ND ankle girth (cm)	22.4 ± 1.2	22.4 ± 1.0	-0.0 ± 0.4	-0.1 ± 1.7	-0.03
ND ankle CSA (cm^2)	38.2 ± 4.0	37.8± 3.0	-0.4 ± 1.9	-1.1 ± 5.0	-0.12
D lower leg length (cm)	42.6 ± 2.7	42.7 ± 2.6	0.0± 0.2	0.1 ± 0.4	0.01
D calf girth (cm)	38.0 ± 2.3	38.0 ± 1.9	0.0± 0.8	0.0 ± 2.1	0.00
D calf CSA (cm^2)	113.9 ± 14.2	113.8 ± 11.6	-0.1 ± 5.1	-0.1 ± 4.5	-0.01
D lower leg volume (ml)	3406.6 ± 358.0	3403.6 ± 332.5	-3.0 ± 96.9	-0.1 ± 2.9	-0.01
D lower leg SA (cm^2)	1339.4 ± 94.9	1340.4 ± 91.8	1.0 ± 15.9	0.1 ± 1.2	0.01
D ankle girth (cm)	22.3 ± 1.2	22.4 ± 1.3	0.1 ± 0.2	0.4 ± 1.0	0.07
D Ankle CSA (cm^2)	37.6 ± 4.2	38.0± 4.6	0.3 ± 0.8	0.9 ± 2.2	0.08
Lower leg length symmetry (%)	1.2 ± 1.0	0.7 ± 0.9	-0.5 ± 0.6	-39.2 ± 51.1	-0.49
Calf girth symmetry (%)	1.3 ± 1.0	0.9 ± 1.2	-0.4 ± 1.8	-33.3 ± 133.6	-0.39
Calf CSA symmetry (%)	2.6 ± 2.0	1.6 ± 2.3	-1.0 ± 3.3	-37.7 ± 127.5	-0.46
Lower leg volume symmetry (%)	2.0 ± 1.5	2.0 ± 1.4	0.1 ± 2.3	2.7 ± 114.5	0.04
Lower leg SA symmetry (%)	1.4 ± 0.9	1.5 ± 1.0	0.0 ± 1.3	0.8 ± 90.3	0.01
Ankle girth symmetry (%)	1.0 ± 1.1	1.4 ± 1.6	0.3 ± 1.7	33.5 ± 170.4	0.25
Ankle CSA symmetry (%)	2.7 ± 3.2	3.4 ± 4.4	0.8 ± 4.4	28.41± 164.8	0.20
Peak power output (watts)	1972.3 ± 331.1	2051.9 ± 375.0	79.1 ± 201.8	4.0 ± 10.2	0.23

*= statistically significant difference between data collection sessions.
†= statistically significant correlation in the change between data collection sessions and the change in peak power output between data collection sessions.