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Comparison of Complex and Simple Anthropometrics in the Descriptive Anthropometric Assessment of Male Cyclists

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Resumen

Introducción: Comparar la importancia de la antropometría superficial compleja (áreas y volúmenes) y simple (largos y perímetros) en la valoración antropométrica descriptiva del tren inferior de ciclistas masculinos de diferentes disciplinas. **Método:** utilizando un sistema de imágenes de superficie 3D 3dMDBody5 y un software personalizado (KinAnthroScan), antropometría de la parte inferior del cuerpo de 23 no ciclistas masculinos y 57 ciclistas masculinos de élite de diferentes disciplinas ciclistas: sprint (pista y ruta (colina)), resistencia (carretera, > 50 millas), contrarreloj (carretera, < 50 millas) y bicicleta de montaña (cross-country y enduro). **Resultados:** Varias medidas antropométricas difirieron entre los grupos de ciclistas y cuando se compararon con el grupo de no ciclistas; el grupo de velocidad demostró la mayor magnitud de diferencia con otras disciplinas ciclistas y el grupo de no ciclistas, mientras que los grupos de contrarreloj y bicicleta de montaña demostraron la menor. La antropometría compleja fue capaz de distinguir entre grupos con tanta eficacia como la antropometría simple y, en algunos casos, pudo distinguir diferencias que no eran identificables solo con antropometría simple. **Conclusiones:** Los investigadores, antropometristas y profesionales deben considerar la recopilación y el uso de antropometría compleja para mejorar la comprensión de las diferencias antropométricas dentro de la antropometría descriptiva, además de tener cuidado al investigar grupos de ciclistas de diferentes disciplinas debido a sus diferentes perfiles antropométricos, clasificándolos por disciplina cuando posible.

Palabras Clave: Imágenes de superficie 3D, Antropometría, Escaneo Corporal, Ciclismo, Medida Corporal.

Abstract

Introduction: Compare the importance of complex (areas and volumes) and simple (lengths and girths) surface anthropometrics in the descriptive anthropometric assessment of the lower body of male cyclists from different disciplines. **Method:** Using a 3dMDBody5 3D surface imaging system and bespoke software (KinAnthroScan), anthropometrics of the lower body of 23 male non-cyclists and 57 elite male cyclists from different cycling disciplines: sprint (track and road (hill)), endurance (road, > 50 miles), time trial (road, < 50 miles) and mountain bike (cross-country and enduro) were collected. **Results:** Several anthropometrics differed between cycling groups and when compared to the non-cyclists group; the sprint group demonstrated the largest magnitude of difference with other cycling disciplines and the non-cyclists group, whereas the time trial and mountain bike groups demonstrated the least. Complex anthropometrics were able to distinguish between groups as effectively as simple anthropometrics, and in some cases, were able to distinguish differences that were unidentifiable through simple anthropometrics alone. **Conclusions:** Researchers, anthropometrists and practitioners should consider the collection and use of complex anthropometrics to improve the understanding of anthropometric differences within descriptive anthropometry, alongside adopting caution when researching groups of cyclists from different disciplines due to their differing anthropometric profiles - categorising them by discipline when possible.

Keywords: 3D Surface Imaging, Anthropometry, Body Scanning, Cycling, Body Measurement.

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Introducción

Anthropometrics - anatomical dimensional measurements - are fundamental in sport and exercise science and medicine. They are used to optimise the fit between humans and environments or equipment, evaluate the impact of exercise, nutrition, human growth, ageing and the processes of illness and disease, and explore how size and shape can affect the demands of a sporting performance, and how athletes meet those demands (Olds, 2009). Furthermore, knowledge of anthropometrics is used to optimise training, assist in the monitoring and prevention of injury, examine the impact of training on growth and maturation, and in the early identification of athletic potential (Borms, 2008; Olds, 2009). Norton & Olds (2001) suggest that the collection, analysis and understanding of anthropometrics is vital in understanding the evolution of sport, as athletes' morphology adapts in response to modifications of the rules, technologies and structure of a sport. Within each of these contexts, whilst anthropometrics are not the only concept worthy of attention, many believe they are fundamentally important (Koley & Jain, 2013; Wolstencroft, 2002).

Traditionally, research and practice has focused on simple anthropometrics of lengths, breadths, girths, mass and compound measurements; e.g. BMI and somatotype. The popularity of simple anthropometrics can be attributed to requiring only low cost, accessible and portable equipment such as tape measures and callipers, and the availability of standardised training and measurement protocols from several international scientific associations including the International Society for the Advancement of Kinanthropometry (ISAK), the American College of Sports Medicine (ACSM) and the World Health Organisation (WHO). However, it has been suggested that complex anthropometrics - such as areas and volumes, also referred to as '3D' or 'new' anthropometrics, provide a more comprehensive representation of the size and shape of the body (Rønnestad et al., 2010; Schranz et al., 2012), by identifying changes in body size and shape that might otherwise go unnoticed by simple anthropometrics (Daniell et al., 2013). Previously the scarcity of research in this field has been attributed to measurement difficulties (Olds, 2004; Olds & Honey, 2006; Sicotte et al., 2010), the high cost and inaccessibility of 3D surface imaging systems, and the inaccuracies of predictive equations using manual measurements. However, the increasing usefulness of 3D surface imaging in entertainment, fashion, ergonomics, and health has bolstered the market (Allied Market Research, 2022), driving down prices and increasing accessibility. However, few studies have explored complex anthropometrics, with the majority of studies focusing on the accuracy and repeatability of 3D surface imaging systems and the measurements (simple and complex) they extract (Ballester et al., 2018; Bullas, et al., 2016; Clarkson et al., 2014, 2015; Kordi et al., 2019; Kordi et al., 2018) ,as opposed to the usefulness of such measures in anthropometric assessments.

Cycling performance is influenced by the morphology of the cyclist (Dellanini et al., 2004; Haakonssen et al., 2015). In general, smaller bodies produce a smaller frontal area, thereby a reduction in aerodynamic drag, in addition mean external power output during cycling is related to muscle force which, in turn, is related to muscle size and thereby body size (Dellanini et al., 2004). Typically, cyclists from disciplines in which high power production is a major determinant of performance are associated with mesomorphic somatotypes and shorter limbs (Astrand & Rodahl, 1977; Hopker et al., 2012), due to the increased muscle volume required to generate large external power outputs (Tanner, 1964). However, as the importance of high peak power reduces, alongside an increase in performance distance and a reduction in the gradient of the cycling terrain, the somatotypes of cyclists typically lean towards an ectomorphic profile and longer limbs (Foley et al., 1989; Rauter et al., 2017; Tanner, 1964). However, there are exceptions. For example, it is advantageous for time trial and mountain bike cyclists to be ectomorphic for climbing and endurance features of a course, and mesomorphic for flat sprint features (Passfield et al., 2012). Thus, it is possible that time trial and mountain bike cyclists demonstrate both sprint and endurance anthropometric characteristics. In addition, it was previously assumed cyclists would present symmetrical anthropometry due to the symmetrical nature of cycling (Wozniak Timmer, 1991). However, literature has demonstrated asymmetries in cycling performance are prevalent (Carpes et al., 2010) and that such asymmetries are reflected within cyclists' anthropometry (Rauter et al., 2017).

Whilst previous studies have incorporated the use of complex anthropometrics into their assessment of cyclist (Daanen et al., 2016; Kordi et al., 2018; Rønnestad et al., 2010), very little is known about their usefulness in in comparison to simple anthropometrics. The aim of this study was to compare the ability of complex and simple anthropometrics to distinguish between cyclists from different disciplines, and in doing so expanding the understand of the anthropometric profiles of cyclists.

Material and Methods

Study design

This was a cross sectional observational study in which the anthropometrics of cyclists from different disciplines and non-cyclists were collected, collated and compared.

Participants

Participants were required to be aged 18 to 45 years, free from injury, able to stand unaided and to have never experienced major lower limb trauma, disease or illness that may have influenced physical development. All cyclists were required to have been competing at regional cycling events for a minimum of 2 years and score 1+ on the Swann et al., categorization model (Swann et al., 2014); as anthropometric profiles for a sporting population are most easily identified by assessing elite athletes from developed sports (Norton et al., 1996). 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 due to physical inactivity. As the degree to which ex-athletes retain elite traits following the cessation of elite performance remains unclear (Smith & McManus, 2009), non-cyclists were excluded if they competed or trained in any sport at an elite level in the last ten years.

Through convenience sampling 80 male volunteers we recruited: 23 non-cyclists and 57 cyclists. All participants provided informed consent, and completed a screening, cycling and physical activity questionnaire. All procedures were approved by Sheffield Hallam University Research Ethics Committee.

Protocol

All participants attended one 20-minute anthropometric data collection session. Although the upper and lower body contribute to cycling performance, it is predominantly the lower body that is responsible for force production and thus likely to hold the strongest relationship with anthropometrics (Knapp, 1963). Therefore, only anthropometrics of the lower body was explored. Data were collected from both the dominant and non-dominant sides, as to allow for exploration of symmetry. Data collection for each cycling discipline group occurred during peak season for the discipline to minimise variability due to seasonal variations. For non-cyclists, data collection occurred throughout the study. During each data collection session, participants were required to wear non-compressive form fitting shorts (that extended no further than the mid-thigh) and no socks. Each data collection session consisted of manual measurement of standing stature and body mass by a level one ISAK anthropometrist - using a stadiometer (Leicester, Seca Vogel, Germany) and digital scales (Weight Watchers Limited, UK) respectively - in adherence to ISAK guidelines (Stewart et al., 2011)).

Landmarking

The lower legs were defined as the region bounded by the epicondyles of the knee and malleoli, for the proximal and distal borders respectively. The upper leg was defined as the region between the middle of the gluteal fold and epicondyles of the knee, for the proximal and distal borders respectively.

To ensure anthropometrics were extracted from the correct locations, ten anatomical landmarks, five per leg, were manually palpated by a level one ISAK anthropometrist and marked using self-adhesive circular markers (0.8 cm x 0.8 cm):

- 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 middle of the gluteal fold; the horizontal crease formed by the inferior aspect of the buttocks and the posterior aspect of the thigh.

Measurement systems

A 3dMDbody5 (3dMD Limited, USA) stereo photogrammetry surface imaging system was used to capture 3D images of the participants' lower body. This system was selected due to its small magnitude of variability when anthropometrics were extracted through bespoke software (KinAnthroScan); 0.67 cm for girths, 0.48 cm2 for cross sectional areas, 67.85 ml in volumes and 0.99 cm2 in surface areas of typical leg segments (Bullas et al., 2022).

The configuration and calibration procedure of the 3dMDbody5 system followed the manufacturer’s guidelines. However, the exact methods of alignment, filtering and refinement used in the proprietary software are unknown. To avoid occlusion by the contralateral limb and ensure placement of the participants’ body segments within the centre of the calibrated volume, participants were asked to adopt three positions on a raised platform; participants stood on their right leg with the left leg raised on a higher platform to scan their right upper leg, on their left leg with the right leg raised on a higher platform to scan their left upper leg and stood on both legs shoulder distance apart to capture both lower legs. Participants were requested to remain relaxed in accordance with ISAK guidelines (Stewart et al., 2011) and visually focus on a single wall mounted circular markers (1.6 cm x 1.6 cm) at eye level, to minimise postural sway. Due to the high repeatability of the 3dMDbody5 system (Bullas et al., 2022), only one 3D image of each position was collected, resulting in three 3D images per participant.

Post processing of 3D images

KinAnthroScan software (Centre for Sports Engineering Research, Sheffield Hallam University, UK) was used to process all 3D images, in a manner identical to that described in Bullas et al., (2016). Briefly, the markers within each 3D image were manually digitised by one researcher (Total TEM of 0.044% (0.09 mm) when digitising the lower leg in KinAnthroScan). Once completed, KinAnthroScan returned a set of 3D coordinates for the marked anatomical landmarks. These digitised points identified the boundaries of the body segments. Following this, 32 size anthropometrics (Table 1) - 16 per side (7 simple, 9 complex), were extracted as outlined in previous studies (Bullas et al., 2016; Clarkson et al., 2015). Although the majority of size anthropometrics adhered to ISAK guidelines (Stewart et al., 2011), as the greater trochanter of many participants fell outside of the capture volume, measurement of the mid-thigh girth based upon ISAK guidelines was not suitable. Instead, the mid-thigh girth (the midpoint of the epicondyles of the knee and gluteal fold) was taken as the middle of the upper leg.

Sixteen symmetry anthropometrics (Table 1) were subsequently calculated using a normalised measure of absolute (ABS) symmetry (Equation 1) (Zifchock et al., 2008), using measurements of both the dominant (mD) and non-dominant sides (mND), to allow comparison between groups and eliminate the effect of body size.

Equation 1

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

Similar to previous studies (Schranz et al., 2010), anthropometrics that fell ± 2 standard deviations away from the mean were re-measured. A full list of the anthropometrics and their definitions is presented within Table 1.

Table 1. Definitions of each anthropometric

	Site	Measure	Type (unit)	Definition
Simple	Ankle	Girth	Size (cm)	The smallest girth of the lower leg (Stewart et al., 2011, p. 88), perpendicular to the long axis.
			Symmetry (%)	The percentage difference between the dominant and non-dominant ankle girth.
	Calf	Girth	Size (cm)	The maximal girth of the lower leg (Stewart et al., 2011, p. 87), perpendicular to the long axis.
			Symmetry (%)	The percentage difference between the dominant and non-dominant calf girth.
	Knee	Girth	Size (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.
			Symmetry (%)	The percentage difference between the dominant and non-dominant knee girth.
	Mid thigh	Girth	Size (cm)	Girth at the midpoint of the upper leg length, perpendicular to the long axis.
			Symmetry (%)	The percentage difference between the dominant and non-dominant mid-thigh girth.
	Thigh	Girth	Size (cm)	Girth of the thigh 1cm distal to the gluteal fold, perpendicular to the long axis (Stewart et al., 2011, p. 85).
			Symmetry (%)	The percentage difference between the dominant and non-dominant thigh girth.

	Lower leg	Length	Size (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).
			Symmetry (%)	The percentage difference between the dominant and non-dominant lower leg length.
	Upper leg	Length	Size (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.
			Symmetry (%)	The percentage difference between the dominant and non-dominant upper leg length.
Complex	Ankle	CSA	Size (cm^2)	CSA at the smallest girth of the lower leg (Stewart et al., 2011, p. 88), perpendicular to the long axis.
			Symmetry (%)	The percentage difference between the dominant and non-dominant ankle CSA.
	Calf	CSA	Size (cm^2)	The CSA at the maximal girth of the lower leg (Stewart et al., 2011, p. 87), perpendicular to the long axis.
			Symmetry (%)	The percentage difference between the dominant and non-dominant calf CSA.
	Knee	CSA	Size (cm^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.
			Symmetry (%)	The percentage difference between the dominant and non-dominant knee CSA.
	Mid-thigh	CSA	Size (cm^2)	CSA at the midpoint of the upper leg length, perpendicular to the long axis.
			Symmetry (%)	The percentage difference between the dominant and non-dominant mid-thigh CSA.
	Thigh	CSA	Size (cm^2)	CSA of the thigh 1cm distal to the gluteal fold, perpendicular to the long axis (Stewart et al., 2011, p. 85).
			Symmetry (%)	The percentage difference between the dominant and non-dominant thigh CSA.
	Lower leg	SA	Size (cm^2)	SA 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).
			Symmetry (%)	The percentage difference between the dominant and non-dominant lower leg SA.
	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).
		Symmetry (%)	The percentage difference between the dominant and non-dominant lower leg volume.
Upper leg	SA	Size (cm^2)	The SA 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 .
		Symmetry (%)	The percentage difference between the dominant and non-dominant upper leg SA.
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 .
		Symmetry (%)	The percentage difference between the dominant and non-dominant upper leg volume.

Data Analysis

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) was explored using their skewness, kurtosis and Kolmogorov-Smirnov values within SPSS (IBM SPSS Statistics 24.0). A one-way ANOVA with Games-Howell *post hoc* correction was then executed within SPSS, due to its suitability for use within unequal and small sample sizes (Field, 2009), to explore the differences in group descriptives (age, stature, body mass and, physical activity and cycling experience). Due to the high degree of multicollinearity between anthropometrics and the small differences between groups, statistical analysis of the anthropometrics such as multinomial logistic regression and statistical parametric mapping were deemed unsuitable.

To determine the magnitude of difference between each group, effect sizes for each anthropometric were calculated using the Hedges's *g* procedure (Hedges & Olkin, 2014) due to its correction for unequal and small sample sizes (Lakens, 2013). Effect sizes ≥ 0.8 and ≤ -0.8 are reported as meaningful differences ensure any differences detected were attributable to true change - not attributable to the measurement system's variability. 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 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 that the cyclists group were meaningfully more symmetrical than the non-cyclists group.

To determine the degree of variability for each anthropometric between groups the coefficient of variation ratio was calculated. Following 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.

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 2. There were no significant differences between groups in age and stature (p = 0.20, η_p^2 = 0.08 and p = 0.78, η_p^2 = 0.02 respectivly). Statistically significant differences (p = 0.03, η_p^2 = 0.13) were demonstrated in body mass; between endurance cyclists and the sprint cycling group (p = 0.93, 95% CI = -25.72, 1.52), the mountain bike group (p = 0.02, 95% CI = -20.47, -1.45) and non-cyclist group (p = 0.38, 95% CI = -0.89, -0.48).

Table 2. Group descriptive

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
Swann Classification		-	4.1 ± 1.0	5.0 ± 1.3	3.9 ± 1.9	2.0 ± 1.1
		-	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
	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.

Comparisons to the non-cycling group

Sprint group

When compared to the non-cyclist group, the sprint group were predominantly larger in size and demonstrated an increased degree of asymmetry, mostly a bias towards the dominant leg. Approximately 25% (12/48; 19% of simple anthropometrics, 30% of complex anthropometrics) of anthropometrics demonstrated a meaningful effect size (Figure 1a) and 79% (38/48; 67% of simple anthropometrics, 89% of complex anthropometrics) demonstrated a meaningful coefficient of variation ratio (Figure 1b). Approximately 21% (10/48; 14% of simple anthropometrics and 26% of complex anthropometrics) exhibited a meaningful effect size and coefficient of variation ratio were: non-dominant ankle girth, dominant ankle girth, dominant ankle CSA, lower leg surface, area symmetry, lower leg, volume symmetry, upper leg length symmetry, dominant upper leg volume, dominant and non-dominant upper leg surface area and knee CSA symmetry. Overall, when comparing to the non-cyclist and sprint cycling groups, complex anthropometrics identified differences to a greater extent than simple anthropometrics.

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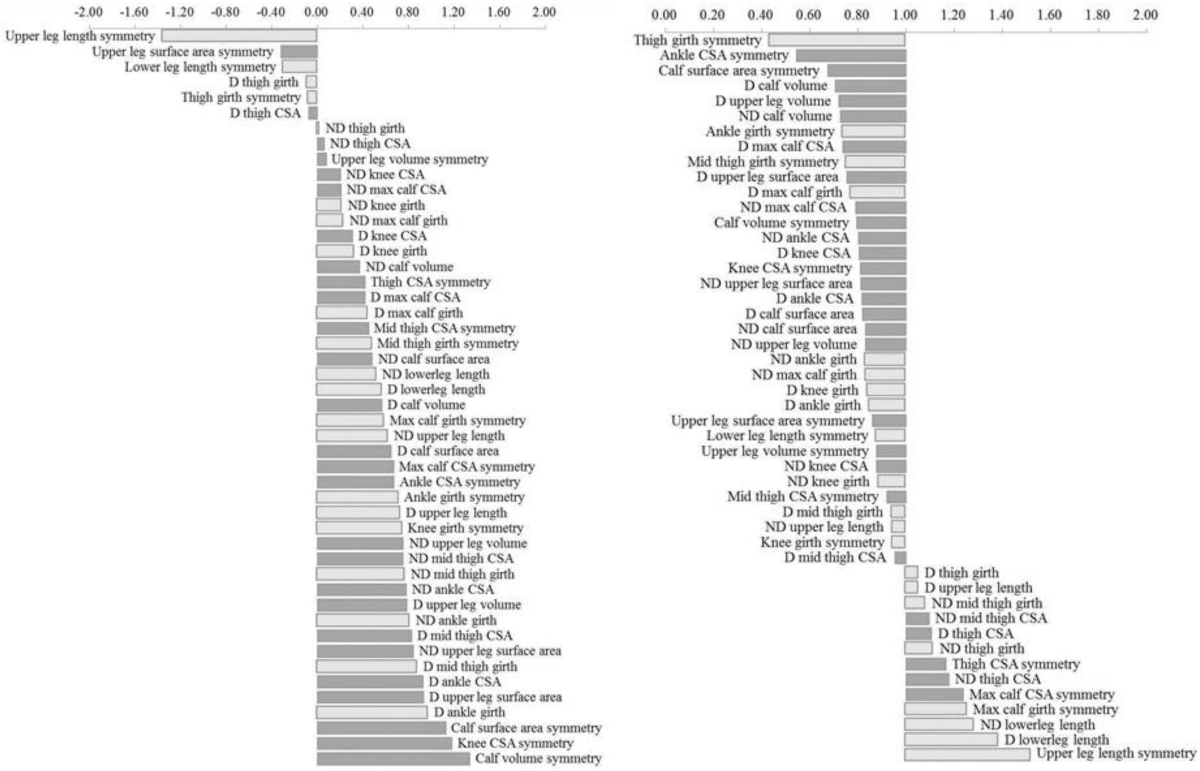

Figure 1: a) Effect sizes of the anthropometrics and b) coefficient of variation of the anthropometrics of the sprint group in comparison to the non-cyclists group.

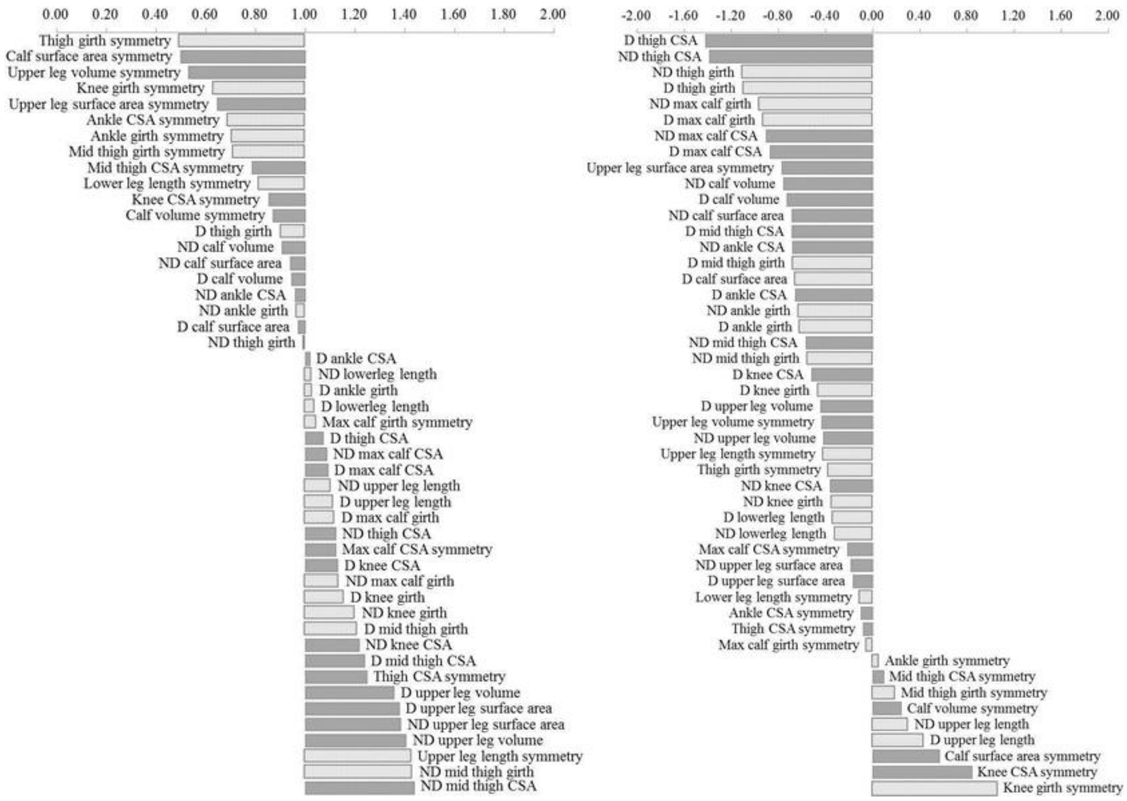

Figure 2: a) Effect sizes of the anthropometrics and b) coefficient of variation of the anthropometrics of the endurance group in comparison to the non-cyclists group.

Time Trial Group

The time trial group demonstrated little difference in size and symmetry to the non-cyclist group. Approximately 35% (17/48; 33% of simple anthropometrics, 37% of complex anthropometrics) of anthropometrics demonstrated a meaningful effect size (Figure 3a), and 46% (22/48, 43 % of simple anthropometrics, 48% of complex anthropometrics) exhibited a meaningful coefficient of variation ratio, compared to the non-cyclists group (Figure 3b). The only anthropometrics to exhibit a meaningful effect size and coefficient of variation ratio were dominant and non-dominant thigh CSA. When comparing the non-cyclist and time trial cycling groups, although simple and complex anthropometrics predominantly identified differences to a comparable degree, complex anthropometrics were able to identify differences unidentifiable by simple anthropometrics alone.

Mountain bike group

The mountain bike group demonstrated little difference in size or symmetry to non-cyclists. No anthropometric demonstrated a meaningful effect size (Figure 4a) and 56% (27/48, 15% of simple anthropometrics, 22% of complex anthropometrics) exhibited meaningful coefficient of variation ratio in comparison to the non-cyclists group (Figure 4b). No anthropometric demonstrated both a meaningful effect size and coefficient of variation ratio. Overall, when comparing the non-cyclist and mountain bike cycling groups, although simple and complex anthropometrics predominantly identified differences to a comparable degree.

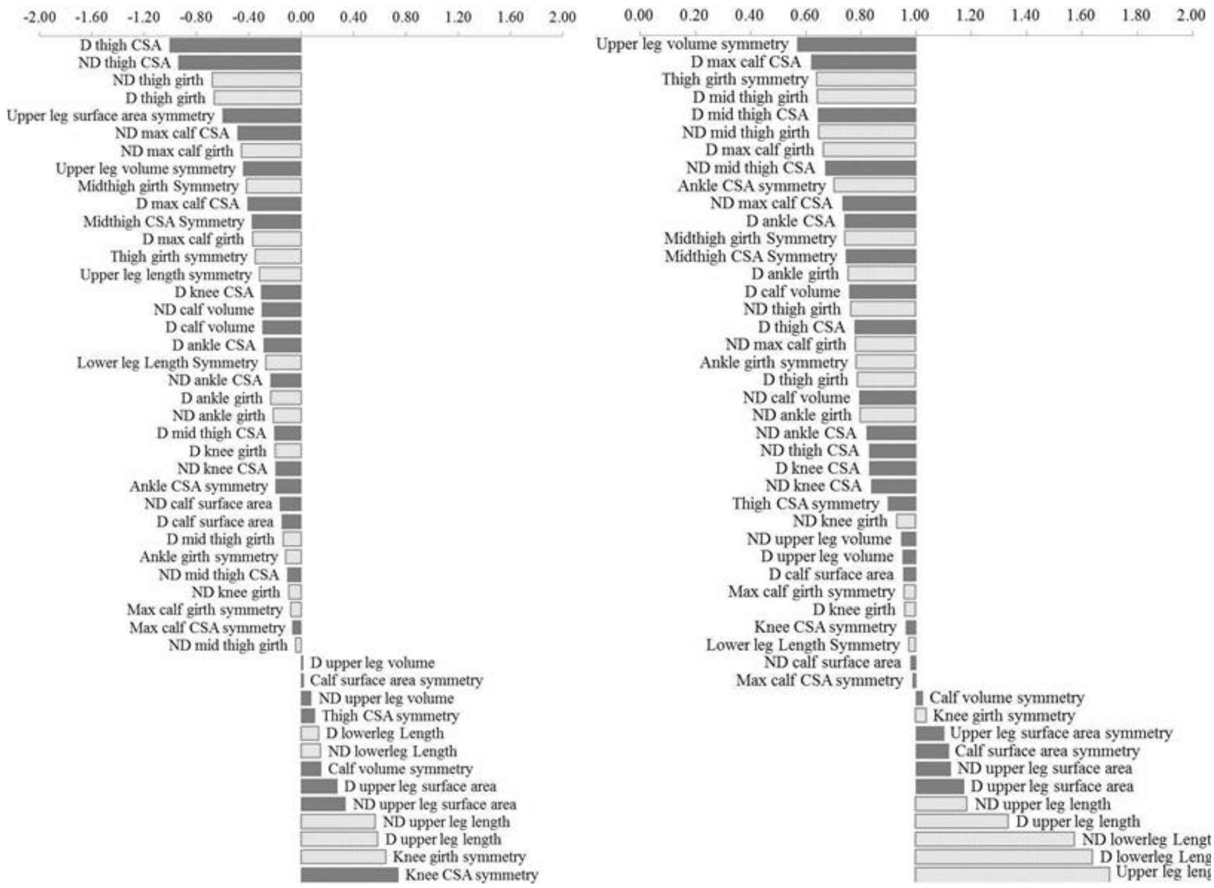

Figure 3: a) Effect sizes of the anthropometrics and b) coefficient of variation of the anthropometrics of the time trail group in comparison to the non-cyclists group.

Comparison between Cycling Disciplines

Several anthropometrics differed between cycling disciplines, listed within Table 3. Overall, complex anthropometrics distinguished between groups as effectively as simple anthropometrics, and in some cases highlighted differences that are unidentifiable through simple anthropometrics alone.

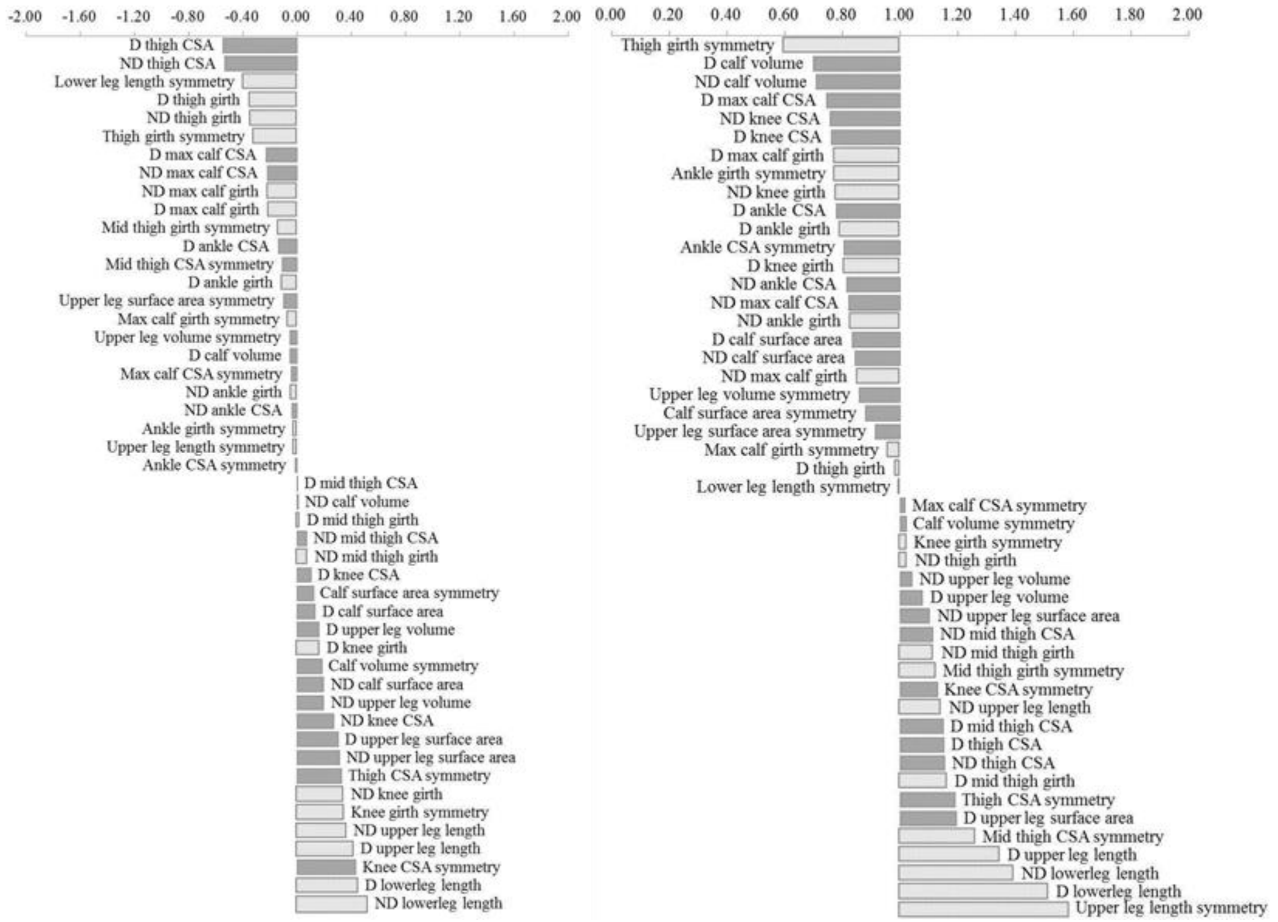

Figure 4: a) Effect sizes of the anthropometrics and b) coefficient of variation of the anthropometrics of the mountain bike group in comparison to the non-cyclists group.

Discussion

Size anthropometrics

Typically, cyclists in power based disciplines present mesomorphic somatotypes (Hopker et al., 2012), and those within endurance based disciplines present ectomorphic profiles (Tanner, 1964). In line with this, the results of this study demonstrated the sprint group to be the largest, followed by mountain bike, then time trial and then endurance groups. The time trial and mountain bike groups were most similar to the non-cyclists and each other. Previous investigations suggest that it is advantageous for time trial and mountain bike cyclists to be ectomorphic for climbing and endurance features of a course, and mesomorphic for flat sprint features (Passfield et al., 2012).

Thus, it is possible that time trial and mountain bike cyclists demonstrate both sprint and endurance anthropometric characteristics which present an amorphous anthropometric profile similar to non-cyclists. However, further research is necessary to confirm this.

Previous literature suggested that time trial cyclists have longer, and sprint cyclists shorter, legs (Foley et al., 1989) - due to the relationship between limb length and cadence (Astrand & Rodahl, 1977), however little difference was demonstrated between cycling disciplines in the present study. It is possible the differences between this and previous studies, are attributable to slight differences in cyclists' expertise; as expertise and asymmetry are believed to be linked, although the direction of this relationship in cycling remains unclear (Rauter et al., 2017). In addition, the differences could be the result of disparities in the landmarking of the upper leg; with the gluteal fold used to mark the proximal end of the thigh, as opposed to the greater trochanter in previous investigations and ISAK standards (Stewart et al., 2011).

The results of this study suggest that complex size anthropometrics distinguish between groups as effectively as simple size anthropometrics, and in some cases, can distinguish differences that are unidentifiable through simple anthropometrics alone.

Table 3. Simple and complex anthropometrics that demonstrated large effect sizes (≤ -0.8 and ≥ 0.8) and meaningful coefficient of variations ratios (≤ 0.9 and ≥ 1.1) when comparing between cycling disciplines.
(D=dominant, ND=non-dominant, SYM=symmetry, CSA=cross sectional area, SA=surface area).

	Measurement	Non-cyclists & sprint	Non-cyclists & endurance	Non-cyclists & time trial	Non-cyclists & mountain bike	Sprint & Endurance	Sprint & Time trial	Sprint & Mountain bike	Endurance & Time trial	Endurance & Mountain bike	Time trial & mountain bike
Simple	Ankle girth	*D *ND				*D *ND	*D				
	Calf girth		*D *ND			*D *ND	*D			*D *ND	
	Knee girth		*SYM								
	Mid-thigh girth					*D *ND	*D *ND				
	Thigh girth		*D			*D					
	Lower leg length										
	Upper leg length	*SYM				*SYM					
Complex	Ankle CSA	*				*D *ND	*D *SYM				
	Calf CSA	*SYM				*D *ND	*D			*D *ND	
	Knee CSA	*SYM	*SYM			*D					
	Mid-thigh CSA					*D *ND	*D *ND				
	Thigh CSA		*ND	*D *ND			*D *ND				
	Lower leg SA	*SYM				*D *ND	*D *SYM	*SYM		*D *ND	
	Lower leg volume	*SYM				*D *ND	*SYM	*SYM		*D *ND	
	Upper leg SA	*ND				*D *ND					
	Upper leg volume	*D				*D *ND	*D				

It is possible this is because complex anthropometrics consider the whole segment, presenting a better representation of difference, as opposed to a single point. These findings 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 value in single point anthropometrics – instead, collection of both would be preferable.

Symmetry Anthropometrics

Several previous investigations have suggested bilateral differences are prevalent within cycling (Rauter et al., 2017), and vary depending on pedalling cadence, exercise intensity and exercise duration (Carpes et al., 2010) - despite its perception as a symmetrical sport. Anthropometrics consider the whole segment, presenting a better representation of difference, as opposed to a single point. These findings 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 value in single point anthropometrics – instead, collection of both would be preferable.

Symmetry Anthropometrics

Several previous investigations have suggested bilateral differences are prevalent within cycling (Rauter et al., 2017), and vary depending on pedalling cadence, exercise intensity and exercise duration (Carpes et al., 2010) - despite its perception as a symmetrical sport. Within this study, all cyclist groups demonstrated little difference or a small meaningful increase in asymmetry when compared to the non-cyclists group. However, symmetry anthropometrics did identify differences between the sprint group and the other cycling groups; the sprint group predominantly demonstrated more asymmetry - specifically a bias towards the dominant leg. This is possibly attributable to the higher mean external power outputs generated in sprint cycling, as it is proposed pedalling asymmetries are exacerbated at higher mean external power outputs (≥ 200 watts) (Bini, 2011). Bini et al., (Bini, 2011) suggested that the increased degree of asymmetry causes the dominant leg to receive greater neural drive and provide a greater contribution to power output - reinforcing the asymmetry in anthropometry. However, more evidence is required to confirm this.

Typically, it is accepted that differences in symmetry anthropometrics will be small (Moller, 1993). The symmetry anthropometrics that demonstrated a meaningful difference between groups demonstrated differences greater than the 3dMDbody5 system variability. However, the absolute differences 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 was associated with a 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.

Overall, 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. For example, when comparing the sprint and mountain bike cycling groups, calf volume and SA symmetry highlighted differences between the groups that were not demonstrated by any simple symmetry anthropometric.

Limitations

This study has limitations that require consideration. First, because of the small and unequal sample sizes, substantial statistical difference testing was unsuitable, thus the degree to which these results are representative of wider populations is unclear. Second, the absence of body composition measurements means we cannot detect if differences in size are attributable to differences in muscle or fat mass. Third, the importance and role of each anthropometric during performance and how they change over time remains unknown, thus future research on complex anthropometrics in applied and longitudinal contexts, with larger sample sizes and accompanying body composition measurement is recommended

Conclusion

Complex anthropometrics distinguish between groups as effectively as simple anthropometrics, and in some cases, can distinguish differences that are unidentifiable through simple anthropometrics alone. In addition, this study expanded upon previous research examining the anthropometry of cyclists by demonstrating the lower body anthropometric profiles cyclists from different cycling disciplines and none cyclists differ. Therefore, researchers, anthropometrists and practitioners should consider the inclusion of complex anthropometrics in future anthropometric assessment to improve understanding of anthropometric changes and differences, such as monitoring and prevention of injury, examine the impact of training on growth and maturation, and in the early identification of athletic potential, and separate cyclists from different disciplines in future research.

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