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Reliability of the Styku 3D Whole-Body Scanner for the Assessment of Body Size in Athletes

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ABSTRACT

Anthropometry is important for predicting sports performance. While 3-dimensional (3D) body scanners increase the feasibility of anthropometric assessment, reliability data on athletes are lacking. The aim of this study was to determine the test–retest reliability of a portable, single-camera 3D body scanning system (Styku S100) to assess circumferences, and whole-body and segmental surface areas and volumes of athletes. Forty-nine (19 males) athletes were scanned 6 times (two sessions of three scans). The Styku scanner demonstrated nearly perfect reliability. Systematic errors were negligible (mean standardized bias [95%CI]: scan 1 vs. 4, 0.04 [0.02, 0.06]), random errors were negligible (mean standardized typical error [95%CI]: scan 1 vs. 4, 0.14 [0.10, 0.17]), and test–retest correlations were nearly perfect (mean intra-class correlation coefficient [95% CI]: scan 1 vs. 4, 0.98 [0.97, 0.99]). Single-camera 3D body scanning systems may provide practitioners and researchers with a feasible tool to evaluate body size and shape.

KEYWORDS
3D anthropometry; whole-body measurement; kinanthropometry; repeatability; sport

Introduction

Researchers and practitioners, interested in sports performance and health, have used anthropometry – the surface measurement of skinfolds, lengths, breadths, and circumferences of the human body – for decades (Kerr et al., 1995). Direct manual anthropometric assessment (e.g., through the use of skinfold calipers, circumference tapes, bone calipers) has traditionally been used due to the low cost, availability, and maintenance of equipment. However, this approach is invasive, has a high participant burden, requires a high level of tester expertise, and is unable to directly measure whole and segmental body surface areas and volumes (Kuehnapfel et al., 2017). Advancements in anthropometry, such as 3-dimensional (3D) body scanning, have sped up and simplified anthropometric assessment (Bragança et al., 2016), considerably reducing the participant burden and tester training requirements. Additionally, 3D scanning is less invasive as there is no need for physical contact and participants can be scanned without being viewed by testers.

Anthropometric measures can be used to predict sports performance (Brocherie et al., 2014), track changes in body size and shape over an athlete's competitive season, and inform important decisions related to rehabilitation (Kordi et al., 2019). 3D scanners provide practitioners with the ability to measure large samples quickly and less-invasively compared to traditional methods, making in-competition measurements more feasible (Schranz et al., 2010, 2012). Interestingly, 2-dimensional (e.g., cross-sectional areas) and 3D (e.g., volumes and surface areas) measures are generally better predictors of sporting success than are 1-dimensional measures (e.g., lengths, girths, breadths) (Schranz et al., 2010, 2012). Furthermore, 3D scanning was required to capture many of the largest anthropometric differences (i.e., volumes and surface areas) between elite athletes and the general population in Schranz et al. (2010), comparisons which are commonly used to establish the importance of an anthropometric trait for sporting success (e.g., greater importance is indicated by larger differences in magnitude and/or reduced variability).

In recent years, the cost of 3D scanners has significantly decreased, with commercially available, single-camera systems (e.g., the Styku S100 scanner) demonstrating high reliability and comparing favorably with dual-energy x-ray absorptiometry (DXA) for circumference and segmental volume measurements in clinical settings (Bourgeois et al., 2017). The Styku S100 scanner, which uses a single camera

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to emit harmless infrared light, is a portable 3D scanner, making it an appealing field measure for sport. However, previous reliability studies evaluating single-camera systems have not recruited athletes (Bourgeois et al., 2017; Ng et al., 2016; Silver & Wilson, 2020), who tend to represent the extreme in muscularity, and the anthropometric dimensions reported have varied. Athletes' greater muscle mass may increase measurement error associated with the automatic landmark identification software (e.g., thighs touching, or upper arm, and torso contact, during standard scanning pose). Furthermore, while a recent study has reported improvements in reliability when averaging multiple scans of younger adults (Silver & Wilson, 2020), it is not known whether improvements in reliability gained from averaging scans are practically meaningful in athletes. Adoption of 3D anthropometry may become more applicable to coaches, practitioners, and researchers if less expensive, portable scanners demonstrate high reliability in athletes.

The aim of this study was to determine the test–retest reliability of the Styku S100 scanner to assess circumferences, and whole-body and segmental surface areas and volumes of collegiate and recreational athletes.

Materials and methods

Participants

Forty-nine collegiate and recreational athletes (mean ±SD: age 22.7 ± 3.3 yrs, height 174 ± 8 cm, mass 75 ± 14 kg, BMI 24.4 ± 3.4 kg/m^2; 30 females, 19 males; 17 Division I collegiate athletes, 17 CrossFit athletes, 15 kinesiology students) were recruited from the University of North Dakota and retained in the analysis. Two athletes were excluded for missing data. Participants were excluded if they were injured, had casts or braces appended to their body, or were unable to stand unsupported on a raised rotating platform. The University of North Dakota Institutional Review Board approved all testing procedures. Informed written consent was obtained from all participants before the start of the study.

Procedures

During a single visit to the University of North Dakota's Human Performance Laboratory, participants were scanned 6 times (two sessions of three scans) with a 5-minute break between the two sessions so as to create two separate testing sessions. Upon arriving at the laboratory, participants changed into form-fitting underwear (briefs for men and briefs plus sports bra for women) and had their height measured with a stadiometer (Seca, Chino, CA) to the nearest 0.1 cm and their mass measured with a digital scale (Detecto, Webb City, MO) to the nearest 0.1 kg. Participants were ushered to the scanning area where they were scanned using a Styku 3D S100 whole-body scanner, which was configured using manufacturer specifications. This 3D scanner comprised a turntable, a Microsoft Kinect V2 camera (Microsoft Corporation, Redmond, WA) enclosed in a lightweight aluminum stand, and the MyBodee measurement extraction software (Styku, Los Angeles, CA). Participants were asked to step onto the turntable and assume a standard scanning pose, where they stood still, with their feet on the marked footprints, arms abducted ~45°, hands closed into a fist, head in a horizontal plane, while they breathed normally and the turntable rotated 360° for a duration of ~35 seconds. During this time, the scanning stand comprising the Kinect camera system projected a structured light pattern onto the participant, with the reflections captured as Cartesian coordinates. The MyBodee software uses recognition technology to automatically locate surface landmarks, which were used to extract circumferences, and whole-body and segmental surface areas and volumes.

Three scans were made of each participant with minimal time in-between scans. The turntable was returned to the proper starting position and the standard scanning pose was reset before each scan. Participants then stepped off the turntable and rested in a standing/seated position for 5 minutes before they were scanned another 3 times. A scan was repeated if excessive movement during the scan was observed or indicated (image distortion) during a quick inspection after each bout of scans. Scans were also inspected for image and circumference placement irregularities during data extraction. All measurement data for a single scan were excluded from the analysis if irregularities were detected by one researcher (J.D.). Athletes were excluded from the analysis if they had missing data for scans 1 or 4, or had irregularities in two or more scans (n = 2). The mean of two scans, instead of three scans, was used in the second reliability analysis for athletes with irregularities detected on one scan (n = 6).

Statistical analyses

Between-session reliability was examined by comparing scans 1 and 4 and by comparing the means of scans 1–3 and 4–6. Data were inspected and two volume measurements for separate scans were identified as extreme errors (>5 times the mean plus standard deviation of the between-session difference scores) and removed due to undue influence on reliability statistics. Descriptive statistics were presented as means and standard deviations. Systematic (bias) error, random (within-subject) error, and test–retest correlation were used to quantify measurement reliability. Systematic error was quantified as the absolute and standardized difference in means; random error as the percent and standardized typical error; and test–retest correlation as the intra-class correlation coefficient (ICC). All calculations were performed using a publically available reliability calculator (Hopkins, 2015). To interpret the magnitude of bias and typical error, standardized effect sizes (ES) of 0.2, 0.5, and 0.8 were used as thresholds for small, moderate, and large, respectively, with ES<0.2 considered to be negligible (Cohen, 1988). Percent typical error data were compared to international error standards recommended by the International Society for the Advancement of Kinanthropometry (i.e., technical error of measurement ≤1.5%) as the criterion-referenced threshold (Stewart et al., 2011). This threshold is appropriate when examining the typical error when systematic bias is negligible. To interpret the magnitude of correlation, ES of 0.1, 0.3, 0.5, 0.7, and 0.9 were used as thresholds for low, moderate, high, very high, and nearly perfect, respectively, with ES<0.1 considered to be negligible (Cohen, 1988). Ninety-five percent confidence intervals (95%CI) were calculated for all variables. A threshold for (error-free) real change for a given measurement was calculated by multiplying the percent typical error by 1.645 (90% confidence) as per Hopkins (2000) to determine the percent change needed to confidently detect real changes. Next, the resultant product was multiplied by the mean of session 1.

Results

Between-session reliability using a single scan

The Styku S100 scanner demonstrated nearly perfect between-session reliability when comparing scans 1 and 4. Systematic errors were negligible (mean standardized bias [95%CI]: 0.04 [0.02, 0.06]), random errors were negligible (mean typical error [95%CI]: percent, 1.5 [1.0, 2.0]; standardized, 0.14 [0.10, 0.17]) with more than half of the measures (68%) demonstrating acceptable random error compared to international standards (Table 1). Test–retest correlations were nearly perfect (mean ICC [95%CI]: 0.98 [0.97, 0.99]). Differences in mean systematic errors, random errors, and test–retest correlations between body dimension types (circumferences, surface areas, and volumes) were negligible.

Between-session reliability using the mean of three scans

The Styku S100 scanner demonstrated nearly perfect between-session reliability when comparing the means of scans 1–3 and scans 4–6. Systematic errors were negligible (mean standardized bias [95%CI]: 0.02 [0.01, 0.03]), random errors were negligible (mean typical error [95%CI]: percent, 0.9 [0.6, 1.2]; standardized, 0.08 [0.06, 0.10]) with most measures (82%) demonstrating acceptable random error compared to international standards (Table 2). Test–retest correlations were nearly perfect (mean ICC [95%CI]: 0.99 [0.99, 1.00]). Differences in mean systematic errors, random errors, and test–retest correlations between body dimension types were negligible. The differences between using a single scan and the mean of three scans for typical errors were negligible.

Discussion

The aim of this study was to determine the test–retest reliability of a commercially available, portable 3D body scanning system (Styku S100) in athletes. We observed negligible between-session systematic and random errors, and nearly perfect test–retest correlations, with most random errors, considered “acceptable” relative to international error standards (i.e., technical error of measurement ≤1.5%) when using a single scan and when taking the mean of three scans. These findings indicate that a single scan is all that is required to reliably collect most circumferences, surface areas, and volumes for research and professional applications. However, a comparison of between-session random errors shows some measurements (e.g., arm circumferences, surface area, and volume) have higher typical errors and appear to benefit from averaging multiple scans. Thus, taking an average of three scans may be indicated when evaluating these measurements. Between-session standardized random errors indicate that the Styku S100 scanner can detect negligible differences between individuals when using a single scan and when taking the mean of three scans.

The random errors reported in our study compare favorably to those reported for Kinect-based multi-camera systems to extract circumference measurements of cylinders (Clarkson et al., 2016) and thigh volume in humans (Bullas et al., 2016; Clarkson et al., 2016), and single-camera systems evaluating multiple anthropometric measures in the general population (Bourgeois

Table 1. Between-session Reliability Data Comparing Scan 1 (Session 1) and Scan 4 (Session 2)

	Session 1	Session 2						
Measurement	Mean (SD)	Mean (SD)	Bias (95%CI)	Standardized Bias (95%CI)	Percent TE (95%CI)	Standardized TE (95% CI)	ICC (95%CI)	Threshold for Real Change
Neck Circumference (cm)	34.2 (4.0)	34.3 (4.0)	0.09 (−0.08, 0.27)	0.02 (−0.02, 0.07)	1.3 (1.1, 1.6)	0.11 (0.09, 0.14)	0.99 (0.98, 0.99)	0.7
Chest Circumference (cm)	93.2 (10.0)	93.0 (10.1)	−0.25 (−0.65, 0.16)	−0.03 (−0.07, 0.02)	1.1 (0.9, 1.4)	0.11 (0.09, 0.13)	0.99 (0.98, 0.99)	1.7
Waist Circumference (umbilicus) (cm)	78.9 (9.9)	78.8 (9.8)	−0.03 (−0.5, 0.44)	0.00 (−0.05, 0.05)	1.4 (1.1, 1.7)	0.12 (0.10, 0.15)	0.99 (0.98, 0.99)	1.8
Waist Circumference (Low) (cm)	86.1 (7.5)	86.1 (7.6)	−0.03 (−0.28, 0.23)	0.00 (−0.04, 0.03)	0.7 (0.6, 0.9)	0.09 (0.08, 0.12)	0.99 (0.99, 1.00)	1.0
Waist Circumference (Narrowest) (cm)	74.2 (9.0)	74.2 (9.3)	0.05 (−0.14, 0.24)	0.00 (−0.02, 0.02)	0.6 (0.5, 0.7)	0.05 (0.04, 0.06)	1.00 (1.00, 1.00)	0.7
High Hip Circumference (cm)	94.0 (6.0)	94.1 (6.0)	0.13 (−0.03, 0.29)	0.02 (0.00, 0.05)	0.4 (0.3, 0.5)	0.07 (0.06, 0.09)	1.00 (0.99, 1.00)	0.6
Hip Circumference (cm)	100 (5.7)	100 (5.8)	0.14 (−0.04, 0.32)	0.02 (−0.01, 0.06)	0.4 (0.4, 0.5)	0.08 (0.07, 0.10)	0.99 (0.99, 1.00)	0.7
Upper Bicep Circumference (cm)	28.7 (3.8)	28.8 (3.5)	0.04 (−0.21, 0.30)	0.02 (−0.05, 0.09)	2.2 (1.8, 2.8)	0.18 (0.15, 0.22)	0.97 (0.95, 0.98)	1.0
Lower Bicep Circumference (cm)	26.2 (3.1)	26.2 (2.8)	0.05 (−0.26, 0.36)	0.03 (−0.08, 0.14)	2.9 (2.4, 3.6)	0.26 (0.22, 0.33)	0.94 (0.89, 0.96)	1.2
Forearm Circumference (cm)	25.8 (2.8)	26 (2.8)	0.14 (−0.13, 0.40)	0.05 (−0.05, 0.15)	2.7 (2.3, 3.4)	0.25 (0.21, 0.32)	0.94 (0.90, 0.97)	1.1
Upper Thigh Circumference (cm)	60.2 (5.1)	60.2 (4.8)	0.01 (−0.20, 0.22)	0.01 (−0.04, 0.05)	0.8 (0.7, 1.0)	0.10 (0.09, 0.13)	0.99 (0.98, 0.99)	0.8
Mid-Thigh Circumference (cm)	56.3 (4.1)	56.6 (4.2)	0.24 (0.07, 0.41)	0.06 (0.02, 0.10)	0.8 (0.6, 0.9)	0.11 (0.09, 0.13)	0.99 (0.98, 0.99)	0.7
Lower Thigh Circumference (cm)	42.9 (3.0)	43.3 (3.0)	0.44 (0.23, 0.64)	0.15 (0.08, 0.23)	1.2 (1.0, 1.5)	0.18 (0.15, 0.22)	0.97 (0.95, 0.98)	0.8
Calf Circumference (cm)	35.2 (2.3)	35.6 (2.1)	0.40 (0.14, 0.66)	0.20 (0.07, 0.32)	1.8 (1.5, 2.3)	0.31 (0.26, 0.38)	0.92 (0.86, 0.95)	1.1
Torso Surface Area (cm^2)	6308 (753)	6321 (745)	13.0 (−13.4, 39.5)	0.02 (−0.02, 0.06)	1.0 (0.8, 1.3)	0.09 (0.07, 0.11)	0.99 (0.99, 1.00)	104
Arm Surface Area (cm^2)	1250 (205)	1256 (192)	5.9 (−12.1, 24.0)	0.04 (−0.05, 0.14)	3.7 (3.1, 4.7)	0.24 (0.20, 0.30)	0.95 (0.91, 0.97)	76
Leg Surface Area (cm^2)	2245 (206)	2265 (201)	20.9 (7.57, 34.2)	0.11 (0.04, 0.18)	1.5 (1.2, 1.8)	0.17 (0.14, 0.21)	0.97 (0.95, 0.99)	55
Whole Body Surface Area (cm^2)	16340 (1637)	16402 (1625)	62.5 (20.8, 104)	0.04 (0.01, 0.07)	0.6 (0.5, 0.8)	0.07 (0.05, 0.08)	1.00 (0.99, 1.00)	161
Torso Volume (cm^3) *	38981 (8960)	39039 (8925)	58 (−74, 189)	0.01 (−0.02, 0.5)	0.8 (0.6, 1.0)	0.04 (0.03, 0.05)	1.00 (1.00, 1.00)	513
Arm Volume (cm^3)	2264 (647)	2270 (635)	6.3 (−35.7, 48.4)	0.01 (−0.05, 0.08)	4.8 (4.0, 6.1)	0.17 (0.14, 0.21)	0.97 (0.95, 0.98)	179
Leg Volume (cm^3)	6195 (926)	6274 (930)	79.0 (27.5, 131)	0.09 (0.03, 0.15)	2.0 (1.7, 2.5)	0.14 (0.12, 0.18)	0.98 (0.97, 0.99)	204
Whole Body Volume (cm^3)	63682 (12155)	63930 (12149)	248 (59.1, 437)	0.02 (0.00, 0.04)	0.8 (0.6, 1.0)	0.04 (0.04, 0.05)	1.00 (1.00, 1.00)	838

Notes: Sample size was 49 except when noted by *, n = 48. TE = Typical error; ICC = intra-class correlation coefficient; The right limb was assessed for all limb measurements. The threshold for real change was calculated to provide 90% confidence that meaningful change occurred if this value is exceeded.

et al., 2017; Ng et al., 2016). Notably, the reliability of the Styku S100 scanner in our athlete sample was similar to Bourgeois et al. (Bourgeois et al., 2017), who reported comparable random errors across four circumferences (coefficient of variation [CV] range: 0.3–0.8%) and six volumes (CV range: 0.3–2.4%) using the same technology on apparently healthy adults from a clinical center. In addition, Ng et al. (2016) evaluated the reliability of the Fit3D Proscanner and reported random errors across six circumferences (CV range: 0.8–2.2%), four volumes (CV range: 0.7–4.5%), and four surface areas (CV range: 0.8–3.5%) consistent with the random errors in this study, especially those calculated from single scans. Together these findings suggest that the Styku

Table 2. Between-session Reliability Data Comparing the Means of Scans 1–3 (Session 1) and Scans 4–6 (Session 2)

	Session 1	Session 2						
Measurement	Mean (SD)	Mean (SD)	Bias (95%CI)	Standardized Bias (95%CI)	Percent TE (95%CI)	Standardized TE (95% CI)	ICC (95%CI)	Threshold for Real Change
Neck Circumference (cm)	34.3 (4.0)	34.3 (4.0)	0.02 (−0.12, 0.16)	0.01 (−0.03, 0.04)	1.1 (0.9, 1.3)	0.09 (0.08, 0.12)	0.99 (0.99, 1.00)	0.6
Chest Circumference (cm)	93.0 (10.1)	92.7 (10.1)	−0.27 (−0.53, −0.01)	−0.03 (−0.06, 0.00)	0.7 (0.6, 0.9)	0.07 (0.06, 0.08)	1.00 (0.99, 1.00)	1.1
Waist Circumference (umbilicus) (cm)	78.8 (9.7)	78.8 (9.8)	−0.01 (−0.23, 0.21)	0.00 (−0.03, 0.02)	0.7 (0.6, 0.8)	0.06 (0.05, 0.07)	1.00 (0.99, 1.00)	0.9
Waist Circumference (Low) (cm)	86.0 (7.5)	86.0 (7.6)	0.00 (−0.13, 0.13)	0.00 (−0.02, 0.02)	0.4 (0.3, 0.5)	0.05 (0.04, 0.06)	1.00 (1.00, 1.00)	0.6
Waist Circumference (Narrowest) (cm)	74.2 (9.1)	74.2 (9.2)	−0.02 (−0.15, 0.11)	0.00 (−0.02, 0.01)	0.4 (0.4, 0.5)	0.04 (0.03, 0.05)	1.00 (1.00, 1.00)	0.5
High Hip Circumference (cm)	94.0 (6.0)	94.0 (6.0)	0.03 (−0.05, 0.12)	0.01 (−0.01, 0.02)	0.2 (0.2, 0.3)	0.04 (0.03, 0.05)	1.00 (1.00, 1.00)	0.3
Hip Circumference (cm)	99.7 (5.7)	99.8 (5.7)	0.09 (−0.02, 0.20)	0.02 (0.00, 0.04)	0.3 (0.2 0.4)	0.05 (0.04, 0.06)	1.00 (1.00, 1.00)	0.5
Upper Bicep Circumference (cm)	28.9 (3.7)	28.7 (3.6)	−0.18 (−0.38, 0.02)	−0.05 (−0.11, 0.01)	1.8 (1.5, 2.3)	0.15 (0.12, 0.18)	0.98 (0.96, 0.99)	0.9
Lower Bicep Circumference (cm)	26.3 (3.0)	26.3 (2.8)	−0.04 (−0.21, 0.14)	−0.01 (−0.07, 0.05)	1.6 (1.3, 2.0)	0.15 (0.12, 0.18)	0.98 (0.96, 0.99)	0.7
Forearm Circumference (cm)	26.0 (2.8)	26.0 (2.8)	0.02 (−0.11, 0.15)	0.01 (−0.04, 0.06)	1.3 (1.1, 1.6)	0.12 (0.10, 0.15)	0.99 (0.98, 0.99)	0.6
Upper Thigh Circumference (cm)	60.2 (4.9)	60.2 (4.9)	0.01 (−0.12, 0.14)	0.00 (−0.02, 0.03)	0.5 (0.4, 0.7)	0.07 (0.06, 0.08)	1.00 (0.99, 1.00)	0.5
Mid-Thigh Circumference (cm)	56.4 (4.2)	56.6 (4.2)	0.16 (0.05, 0.28)	0.04 (0.01, 0.07)	0.5 (0.4, 0.6)	0.07 (0.06, 0.9)	0.99 (0.99, 1.00)	0.5
Lower Thigh Circumference (cm)	43.1 (3.0)	43.3 (3.0)	0.21 (0.09, 0.32)	0.07 (0.03, 0.11)	0.6 (0.5, 0.8)	0.09 (0.08, 0.12)	0.99 (0.99, 1.00)	0.4
Calf Circumference (cm)	35.4 (2.2)	35.7 (2.1)	0.29 (0.13, 0.45)	0.14 (0.07, 0.22)	1.1 (0.9, 1.4)	0.19 (0.16, 0.24)	0.97 (0.94, 0.98)	0.6
Torso Surface Area (cm^2)	6319 (752)	6311 (743)	−8 (−25, 9)	−0.01 (−0.03, 0.01)	0.7 (0.6, 0.9)	0.06 (0.05, 0.08)	1.00 (0.99, 1.00)	73
Arm Surface Area (cm^2)	1258 (202)	1259 (200)	1.8 (−8.5, 12.1)	0.01 (−0.05, 0.07)	2.2 (1.9, 2.8)	0.14 (0.12, 0.18)	0.98 (0.97, 0.99)	46
Leg Surface Area (cm^2)	2251 (201)	2262 (199)	11 (3, 20)	0.06 (0.01, 0.10)	0.9 (0.8, 1.2)	0.11 (0.09, 0.13)	0.99 (0.98, 0.99)	33
Whole Body Surface Area (cm^2)	16378 (1618)	16409 (1614)	31 (6, 57)	0.02 (0.00, 0.04)	0.4 (0.3, 0.5)	0.04 (0.03, 0.05)	1.00 (1.00, 1.00)	108
Torso Volume (cm^3)	38984 (8850)	38984 (8831)	−0.65 (−70, 206)	0.00 (−0.01, 0.01)	0.5 (0.4, 0.6)	0.02 (0.02, 0.03)	1.00 (1.00, 1.00)	321
Arm Volume (cm^3)	2280 (642)	2283 (641)	2.92 (−21, 26)	0.00 (−0.04, 0.04)	2.8 (2.4, 3.6)	0.10 (0.08, 0.13)	0.99 (0.98, 0.99)	105
Leg Volume (cm^3)	6225 (923)	6271 (930)	46 (16, 76)	0.05 (0.02, 0.08)	1.2 (1.0, 1.4)	0.08 (0.07, 0.10)	0.99 (0.99, 1.00)	123
Whole Body Volume (cm^3)	63798 (12095)	63983 (12114)	185 (70, 301)	0.02 (0.01, 0.03)	0.4 (0.4, 0.5)	0.02 (0.02, 0.03)	1.00 (1.00, 1.00)	420

Notes: Sample size was 49. TE = Typical error; ICC = intra-class correlation coefficient; The right limb was assessed for all limb measurements. The threshold for real change was calculated to provide 90% confidence that meaningful change occurred if this value is exceeded.

S100 scanner, which is designed for portability and cost savings, is capable of capturing reliable 3D measurements in general and athlete populations.

Our reliability data can be used to determine the threshold for real or meaningful change when monitoring individual athletes. To determine the threshold for a given measurement, coaches and practitioners can multiply the percent typical error for a measurement by 1.5–2.0 (roughly 84–95% confidence) as per Hopkins (2000) to determine the percent change needed to confidently detect real changes for an individual athlete. We have provided the 90% confidence threshold for real change in absolute values associated with taking a single scan (Table 1) and using the mean of three scans (Table 2) for our group of athletes. Our thresholds for real change were similar to those reported in Silver and Wilson (2020) for 21 circumferences when using the Styku S100 scanner to evaluate between-day reliability in younger adults. Also consistent with Silver and Wilson (2020) was the reduction in the threshold for real change when the mean of multiple scans was taken to calculate between-session reliability: the thresholds for most measures were reduced by 30–50% when averaging multiple scans compared to taking a single scan. Coaches, practitioners, and researchers should consider the anthropometric variables of interest, the expected change due to intervention, and the time burden associated with scanning and data processing when determining if measurements should be derived from a single scan or averaged across multiple scans. It should also be appreciated that taking multiple scans during a session may help protect against missing data for an athlete due to scanning irregularities (e.g., movement artifacts), which may not be detected by the tester during the session.

3D scanners provide an efficient and noninvasive means of obtaining anthropometric measurements (Schranz et al., 2010), suitable for mass surveillance (e.g., team sports, research, etc.), which have meaningful relationships with sports performance. Thigh circumferences and cross-sectional areas (calculated using circumference data) have exhibited strong associations with sprinting speed (Hermassi et al., 2018) and countermovement jump performance in elite athletes (Brocherie et al., 2014). Whole-body and segmental body volumes appear to predict elite rowing performance (Schranz et al., 2010, 2012). In addition, limb circumferences, or preferably direct volumes, can be used to estimate lean mass volume (predictor of maximal-intensity exercise performance) (Kordi et al., 2019) and asymmetry (Rauter et al., 2017). Moreover, 3D scanning could be used to obtain whole body and regional body composition estimates using prediction equations after calibration with DXA (Ng et al., 2016). Tracking changes in whole body and lower-extremity lean mass using 3D scanning would be an inexpensive and safer alternative to DXA and magnetic resonance imaging, and could be used to evaluate anthropometric responses to training and detraining, with potential applications to performance enhancement and rehabilitation (Kordi et al., 2019).

This study is not without limitations. Participants were competitive and recreational athletes with a mean BMI indicative of normal weight status. Therefore, the results of this study may not be generalizable to athletes competing in certain sports with a high prevalence of obesity (e.g., American football). Extremes in standing height were not represented in this study, which may limit generalizability to athletes competing in sports where standing height is advantageous (e.g., basketball). We did not examine the reliability of sessions on separate days. Thus, our reliability statistics may underestimate day-to-day typical errors. Future investigations should examine the reliability of single-camera systems across greater time periods (e.g., 8 hours, 24 hours) to investigate within-day (circadian) and between-day variability, and recruit athletes with greater weight status and standing height. Participants' arms are not supported during the Styku S100 scanning procedure, which may augment error associated with movement during and between scans. However, the Styku S100 exhibited lower CVs for most circumference and volume measurements when compared to the Fit3D Proscanner, which provides handholds for the participant (Bourgeois et al., 2017). Future research should assess the effect of participant instructions designed to minimize postural deviations between scans. Our study did not assess the accuracy of scanned measurements, though previous studies evaluating single-camera systems found good agreement among 3D scanners and DXA derived whole-body and segmental volumes (R^2 = 0.69–0.99), tape measure circumferences (R^2 = 0.71–0.96), and the Du Bois model of whole-body surface area (R^2 = 0.97) (Bourgeois et al., 2017; Ng et al., 2016).

In conclusion, the commercially available, single-camera Styku S100 scanner is highly repeatable, capable of identifying negligible changes between individuals, and exceeds international standards for precision for most measurements. Coaches, practitioners, and scientists could utilize this portable technology to quickly measure large groups (e.g., sporting teams) without the invasiveness or technical proficiency required for manual measurements (Schranz et al., 2010). A multitude of measurements can be extracted or calculated from the scans, which can be used for talent identification (Schranz et al., 2010, 2012) and tracking changes associated with exercise training (Kordi et al., 2019), with the aim of optimizing exercise prescription for performance and health.

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