Comparison of Manual Anthropometry and a Mobile Digital Anthropometric System

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Keywords: Morphology, Anthropometry, Portable, Protocol.

Abstract: With the progress of technology, new digital shape-analysis tools are being developed for use in several different fields. Innovation and market demand has pushed developers to create a portable 3D scanner. The aim of this research was to perform a comparison of a new portable measuring system for digital measurement of anthropometric dimensions of the body, with the system of manual anthropometry. The results show that the Coefficient of determination (R2) was in 7 measurements over 90%, in 6 measurements over 80%, and in 2 measurements above 74.9%. Cronbach Alpha results of compared variables were all over 90%, which show very strong expected correlations. No significant bias between measurement techniques was shown as Bland-Altman plots showed a good agreement between measurement techniques with a small number of outliers. Results provide high validity and accuracy of the new portable scanner when correctly used. However, methods of 3D body scanning and classical anthropometry should not be regarded as interchangeable as there are differences in initial body positions due to the implementation of measurement protocols. Further work is recommended to make the two methods more interchangeable, with the possible usage of corrective coefficients.

1 INTRODUCTION

With the progress of technology, new digital shape-analysis tools are not limited to the traditional one-dimensional measurements, but instead, they enable measurement of complex geometrical features (i.e., curvatures and partial volumes) (Bragança et al., 2014). With the advancement of the anthropometrical field and application of 3D body scanners, methods for obtaining anthropometric body data have become more practical, contactless, fast and, above all, accurate (Simmons & Istook, 2003; Zhang et al., 2014; Ryder & Ball, 2012; Bragança et al., 2014). These methods range from laser scanners to mobile applications (Katović et al., 2016; Gruić et al., 2019). The 3D scanning methods are frequently used in a variety of fields as the textile industry (Apeagyei, 2010; Troynikov & Ashayeri, 2011), sport (Schranz et al., 2010; Rauter, Vodičar & Šimenko, 2017; Šimenko et al., 2017; Kambič et al., 2017), healthcare (Treleaven & Wells, 2007; Sims et al., 2012), national surveys of the general population (Wells et al., 2015), motor performance (Lim et al., 2015; Sevick et al., 2016; Taha et. al., 2016), posture/balance training (Dutta et al., 2014; Mentiplay et al., 2013; Oh et al., 2014; Saenz-deUrturi & Garcia-Zapirain Soto, 2016) and rehabilitation (Galna et al., 2014; Mobini et al., 2015; De Rosario et al., 2014; Shapi'i et al., 2015). Advantages of 3D scanning represent a rapid raw data collection, a wide variety of digital shape outputs that can extend to 2D or 3D format, an electronic achieving of scans, which could be utilized in future analysis with improved software, a construction, and comparison of composite shape models, etc. (Wells et al., 2015; Šimenko & Čuk, 2016). The 3D body scanning systems are in general stationery, but the market demand for a portable 3D scanner has pushed the developers to create new products. The validity of instruments in clinical and sport application differ, therefore the goal of this research was to initially

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Bušić, A., Bušić, J., Coleman, J. and Šimenko, J.
Comparison of Manual Anthropometry and a Mobile Digital Anthropometric System.
DOI: 10.5220/0010178201090115
In *Proceedings of the 8th International Conference on Sport Sciences Research and Technology Support (icSPORTS 2020)*, pages 109-115
ISBN: 978-989-758-481-7

perform a comparison of the results acquired by a new portable measuring system for digital measurement of anthropometric dimensions of the body, with the results of manual anthropometry.

2 METHODS

2.1 Subjects

This study included 51 subjects consisting of 12 females and 39 males. All of them participated voluntarily and gave written consent.

2.2 Variables

Measurements were performed in the Physiological Laboratory of the University of Ljubljana, Faculty of Sport, Ljubljana, Slovenia. Anthropometrical measurements in a classic setting were performed by an expert with extensive measurement experience. 3D measurement was conducted by an expert from the Technology Department of LIVE GOOD d.o.o., Zagreb, Croatia.

2.2.1 Manual Anthropometry

Body height was measured with the GPM anthropometer (Switzerland). Chest girth, breast girth, hips girth, waist girth, Left (L) – Right (R) upper arm girth, L - R elbow girth, L - R forearm girth, L - R wrist girth, L - R upper leg girth, and L - R lower leg girth were measured using a flexible and inextensible tape with a 1 mm accuracy, as according to guidelines by the International Biological Program (IBP) (Lohman et al., 1988). Thus, IBP's basic rules and principles relating to the choice of parameters, standard conditions, and measurement techniques were followed.

2.2.2 Scanning Protocol

Subjects were scanned in a standing position with legs 30 cm apart on a designated line. Arms were elevated to a 90° angle, parallel to the ground, with straight elbows. Subjects were standing in form-fitting underwear. Scans of each subject were taken twice.

Scanning was performed by going once around the subject, with the iPad-Structure Sensor held perpendicular to the ground, at approximately half of the subject's height. Space around the subject was sufficient to take a full-body scan, optimally a 3 m radius, although a 2 m radius is still sufficient. Room was sufficiently illumined, with low levels of infrared light. Time per scan was usually around 30 seconds.

2.2.3 Technical Specifications

Scanning hardware consisted of the Structure Sensor, (Occipital, Inc., San Francisco, CA, USA) mounted on an iPad Air 2 (Apple, Inc., Cupertino, CA, USA). The minimum and maximum recommendations by the manufacturer for a Structure Sensor is to scan from 40 cm to 3.5 m, with the precision of 0.5 mm at 40 cm (0.15%) and 30 mm at 3 m (1%). Resolution of the acquired frames is VGA (640 x 480) or QVGA (320 x 240). The frame rate of scanning was 30 / 60 frames per second. Illumination consisted of an infrared structured light projector with uniform infrared LEDs. Scanner field of View horizontally spans 58°, and vertically 45°.

The scanning software was part of a digital health platform BodyRecog PRO that performed health risk assessments for certain cardiovascular diseases, type 2 diabetes, and certain cancers based on 3D scan-obtained body measurements (BodyRecog Metrics, Inc., Boston, MA, USA). The software allowed for manual adjustments of each girth position taken if required. Saved 3D scan measurements were automatically transferred to the cloud-based web app for further analyses, i.e. health risk assessments.

2.3 Statistical Analysis

Analyses were conducted using SPSS for Windows (Version 21.0; SPSS, Inc., Chicago, IL, USA). Data were presented according to the descriptive statistics (Means ± SD). Furthermore, we performed the following tests: Kolmogorov-Smirnov test, coefficient of variation (CV), standard error of measurement (SEM), paired-sample T-test, Pearson correlation, coefficient of determination (R^2), Cronbach's Alpha, Bland-Altman (Bland & Altman, 1986) and average relative error. Relative error was calculated as the absolute difference between the 3D scanning method and classical anthropometry result and divided with classical anthropometry result, and at the end, the average relative error was calculated. Bland-Altman method of assessing agreement (Bland & Altman, 1986) was performed using the MedCalc software (Version 14.8.1; MedCalc®, Belgium). For calculating Bland-Altman figures, we subtracted classical anthropometry values from the values obtained by the 3D body scanning. All statistical significances for t-test, Pearson correlation and Cronbach's alpha were set to $p<0.05$.

3 RESULTS AND DISCUSSION

Table 1 presents the acquired results reflecting strong Pearson correlation coefficient values. Larger differences were detected in the breast and chest girth, but this reliability issue can be explained by the fact that the chest is always in slight movement due to breathing. The same issue also occurs in breast and chest girth measurements in manual anthropometry. Also, the difference in the data acquisition line exists in those measurements. The manual anthropometry (measurement tape) in those measurements do not all the time firmly touch the skin due to the anatomical structure of bones (angle of the scapula, sternum and backbone) and certain width of the tape. However, the mobile 3D body scanner acquires data from the contours of the body-skin regardless of angles and does not measure a straight line, but the entire length of the contours in acquired 2D cross-sections. This is evident in the fact that 3D-acquired values in those two measurements are larger than the manual anthropometry values, which confirms and explains the differences. SEM between the two techniques is pretty much the same, which means both techniques were performing with a fairly similar error.

Coefficient of determination (R^2) shows that in 7 measurements it amounts to over 90%, in 6 measurements to over 80%, and in 2 measurements

Table 1: Descriptive statistics, Standard error (SE), Coefficient of variation (CV), Standard error of measurement (SEM), Pearson correlation, Coefficient of determination (R^2), Mean difference, T-test significance, Cronbach's Alpha and Average relative error.

		Mean	SD	SE	CV	SEM	Pearson corr.	R^2	Mean Diff.	Sig. T-test	Cronb. Alpha	Aver. Rel. err.
Pair 1	Body Height A	179.16	9.12	1.665	5.090	0.499	0.995	0.990	0.961	0.007	0.997	0.004
	Body Height 3D	178.65	9.41	1.717	5.265	0.515						
Pair 2	Waist Girth A	76.66	5.41	0.988	7.057	0.593	0.976	0.953	1.216	0.000	0.988	0.023
	Waist Girth 3D	78.35	5.60	1.022	7.145	0.613						
Pair 3	Hips Girth A	97.67	4.20	0.766	4.295	0.849	0.922	0.849	1.664	0.000	0.959	0.015
	Hips Girth 3D	99.04	4.20	0.767	4.243	0.851						
Pair 4	Chest Girth A	95.64	8.27	1.510	8.647	1.547	0.937	0.878	2.898	0.000	0.965	0.044
	Chest Girth 3D	99.57	7.49	1.367	7.520	1.401						
Pair 5	Breast Girth A	94.08	7.17	1.310	7.624	0.907	0.969	0.939	1.805	0.052	0.984	0.017
	Breast Girth 3D	94.75	7.29	1.330	7.689	0.922						
Pair 6	Right Upper Arm Girth A	27.98	2.85	0.520	10.178	0.493	0.942	0.887	0.977	0.000	0.970	0.048
	Right Upper Arm Girth 3D	29.26	2.87	0.523	9.797	0.496						
Pair 7	Left Upper Arm Girth A	27.21	2.70	0.492	9.911	0.409	0.959	0.919	0.851	0.000	0.977	0.053
	Left Upper Arm Girth 3D	28.66	2.95	0.539	10.291	0.447						
Pair 8	Right Forearm Girth A	27.00	2.44	0.446	9.050	0.328	0.965	0.931	0.673	0.000	0.982	0.024
	Right Forearm Girth 3D	26.51	2.55	0.465	9.611	0.342						
Pair 9	Left Forearm Girth A	26.40	2.52	0.461	9.559	0.299	0.972	0.945	0.592	0.001	0.986	0.021
	Left Forearm Girth 3D	26.00	2.43	0.443	9.337	0.287						
Pair 10	Right Wrist Girth A	17.02	1.33	0.242	7.789	0.293	0.910	0.829	0.599	0.767	0.951	0.026
	Right Wrist Girth 3D	17.05	1.45	0.264	8.479	0.320						
Pair 11	Left Wrist Girth A	16.86	1.28	0.234	7.589	0.311	0.889	0.789	0.611	0.468	0.941	0.026
	Left Wrist Girth 3D	16.78	1.30	0.238	7.769	0.317						
Pair 12	Right Upper Leg Girth A	54.46	3.61	0.658	6.620	0.614	0.948	0.898	1.163	0.034	0.971	0.018
	Right Upper Leg Girth 3D	53.99	3.27	0.596	6.050	0.556						
Pair 13	Left Upper Leg Girth A	53.65	3.50	0.638	6.514	0.399	0.977	0.954	0.820	0.073	0.987	0.012
	Left Upper Leg Girth 3D	53.38	3.75	0.685	7.032	0.428						
Pair 14	Right Lower Leg Girth A	37.17	2.37	0.432	6.366	0.639	0.865	0.749	1.196	0.073	0.927	0.024
	Right Lower Leg Girth 3D	36.86	2.19	0.401	5.954	0.593						
Pair 15	Left Lower Leg Girth A	37.20	2.38	0.434	6.389	0.537	0.912	0.833	1.134	0.939	0.949	0.022
	Left Lower Leg Girth 3D	37.22	2.75	0.502	7.390	0.621						

3D - measurements obtained with the portable 3D scanner, A - measurements obtained with classical anthropometry above 74.9%. These results are acceptable. Results of Cronbach Alpha are over 90%, which indicates very strong expected correlations.

The biggest differences in average relative error were in chest measurements 4.4% (which is understandable due to reasons explained before in SEM) and upper arm girth (5.3% for the left and 4.8% for the right arm). Differences in the upper arm girths can be explained by the possibility of arms being fully extended in the elbow joint. The difference can occur when the subject fully elicits the elbow (in some more flexible subjects even hyperextension can occur), and thus triggers the triceps (consequently the triceps is larger and biceps is more extended), and when the subject relaxes its arms smoothly and does not activate the triceps fully (consequently the triceps is smaller). Also, the position with arms elevated to the 90° angle can cause minor fluctuation of arm positions, which can lead to larger differences. All other measurements' error is below 2.8%, which presents a good and excitable result.

Figure 1, Figure 2 and Figure 3 present Bland-Altman plots, for all critical parameters showing a good agreement between measurement techniques.

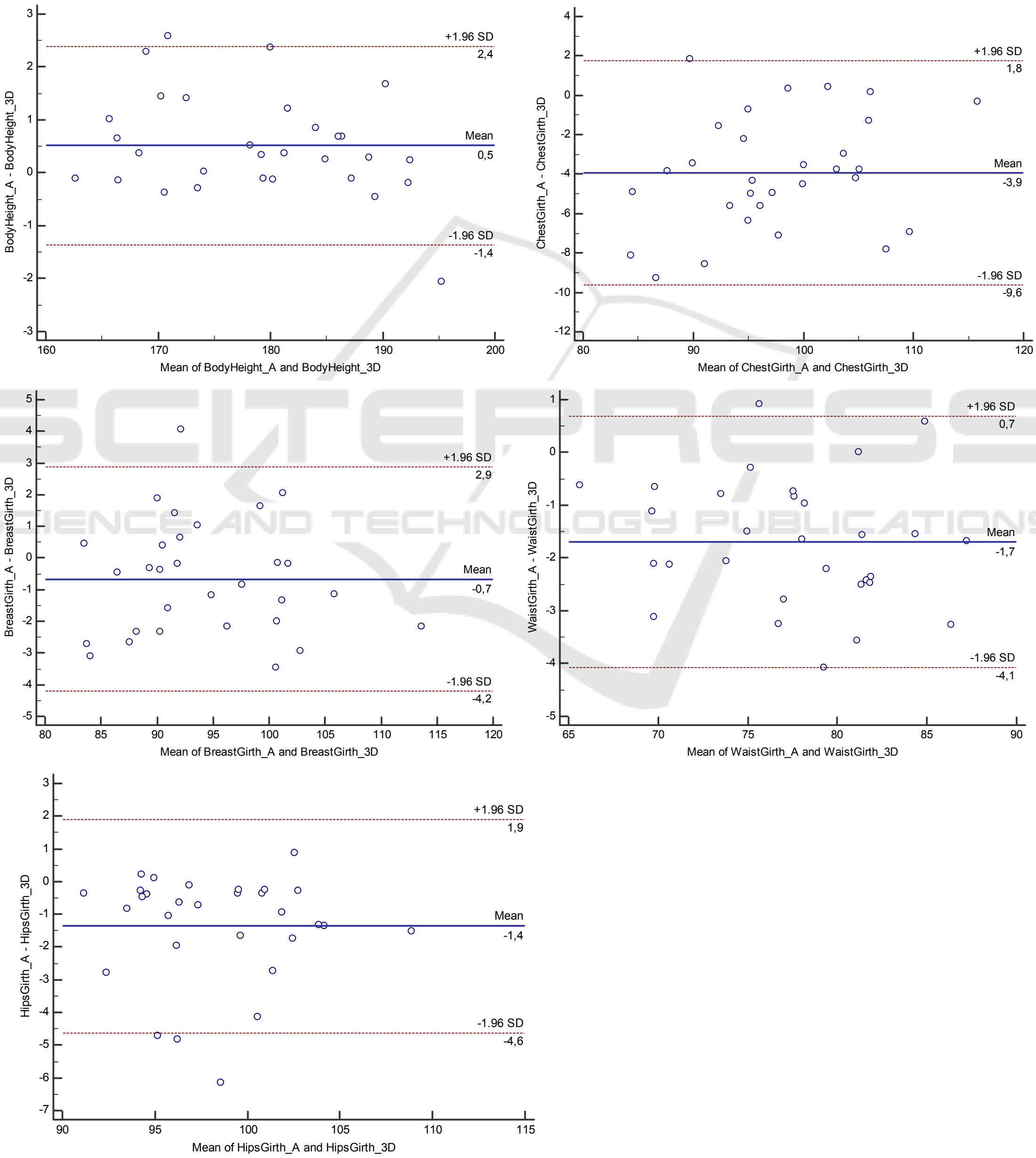

Figure 1: Bland-Altman plots for the body height, chest girth, breast girth, waist girth and hips girth.

No significant bias between measurement techniques was shown as Bland-Altman plots showed a good agreement between measurement techniques with a small number of outliers.

4 CONCLUSIONS

Altogether, the BodyRecog® mobile 3D scanner has a great potential for anthropometric measurements that may be used in a wide variety of fields from elite sport, recreation, fitness to healthcare. The comparison between the 3D scanning technology and manual anthropometry shows a high agreement between methods. It provides high validity and

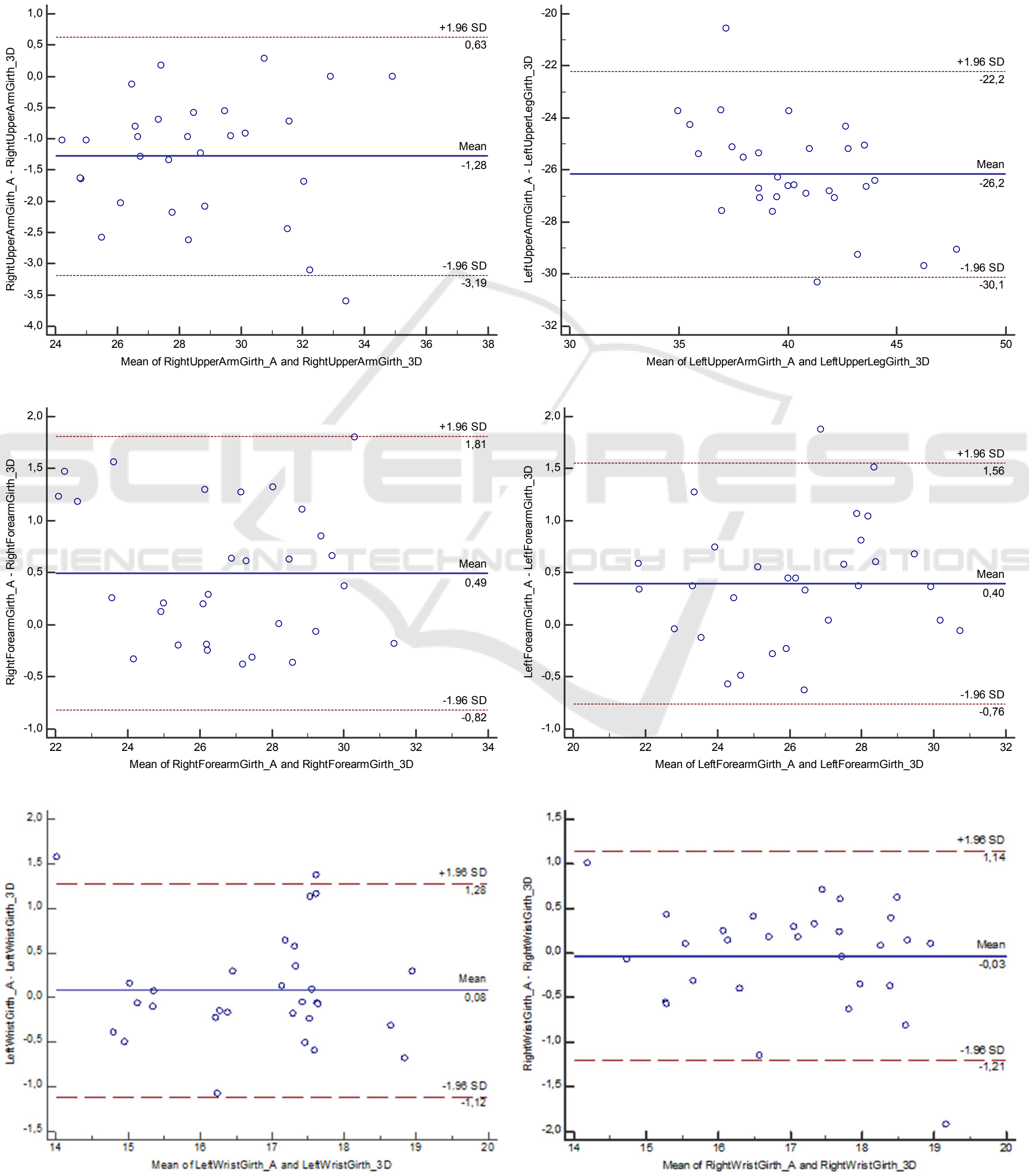

Figure 2: Bland-Altman plots for the L and R upper arm girth, L and R forearm girth and for the L and R wrist girth.

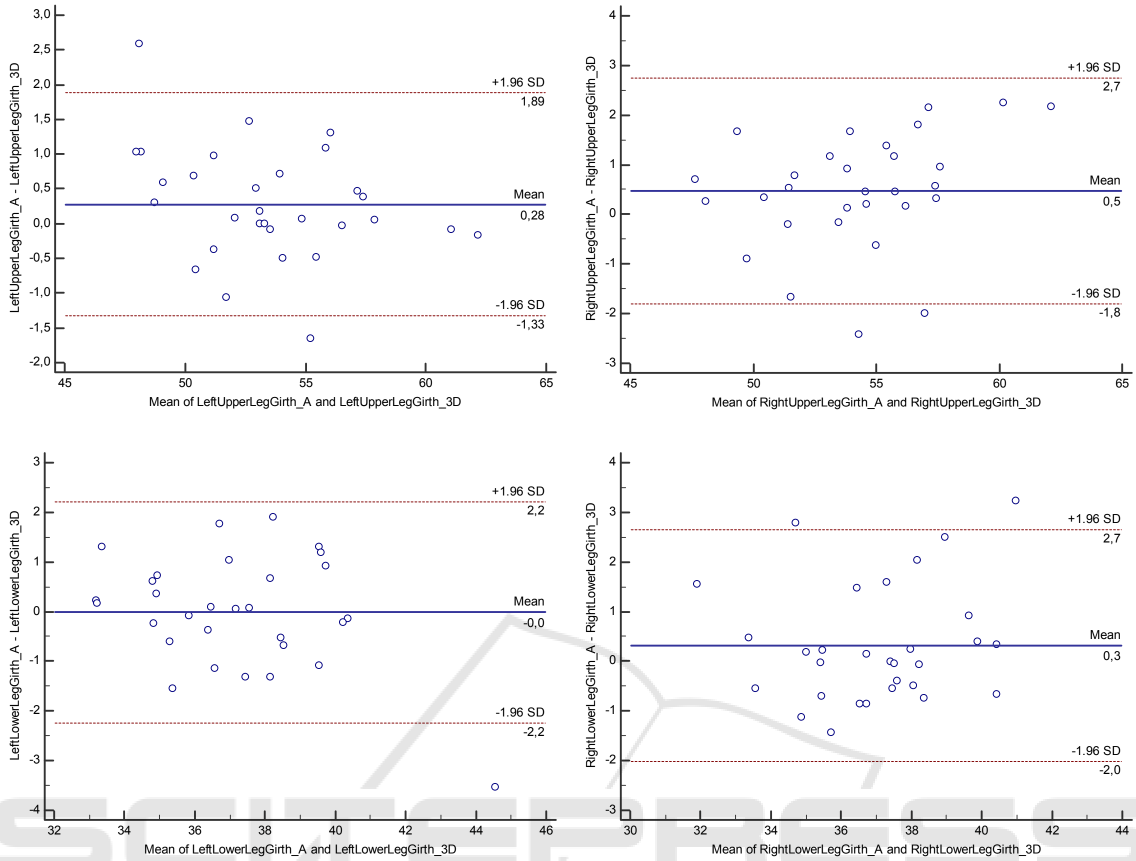

Figure 3: Bland-Altman plots for the L and R upper leg girth and for the L and R lower leg girth.

accuracy when correctly used. However, methods of the 3D body scanning and classical anthropometry should not be regarded as interchangeable as there are differences in initial body positions due to the implementation of measurement protocols (Wells et al., 2015). Further work is recommended to make the two methods more interchangeable, with the possible usage of corrective coefficients.

ACKNOWLEDGEMENTS

The LIVE GOOD team would like to acknowledge the great contribution of Prof.Dr.Sc. Marjeta Mišigoj-Duraković in creating and testing various versions of the BodyRecog PRO digital health platform. Without her expert advice, we would not have achieved as much as we did. Her team of the Laboratory of Kinanthropometry at the Faculty of Kinesiology, University of Zagreb, Croatia, has been exceptionally cooperative and kind to us, and it has been a great honour to work with them all.

We would also like to extend our gratitude to Prof.Dr.Sc. Vladimir Medved who allowed us to use his Laboratory of Biomechanics, Faculty of Kinesiology, University of Zagreb, Croatia, as a testing lab. His insight into technical matters has been invaluable. Much gratitude goes to the Laboratory of Biomechanics team, with a special mention of Dr.Sc. Igor Gruić who has been an avid supporter of our joint work, and Dr.Sc. Darko Katović whose statistical abilities and knowledge of scientific validation protocol has proven a truly great asset.

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