Validity of a Structure Sensor-based Anthropometric Measurement: Performing a Pilot Study

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Abstract: Development of new technologies is offering possibilities to overcome "traditional" limitations of anthropometric measures and enable the production of a new generation of simple, high-speed, inexpensive, highly defined and precise scanners for superficial body imaging. This study is an attempt to determine the metric characteristic of the instrument (BodyRecog PRO) which technology is based on the method of deep infrared 3D-scanning (Structure sensor). Reliability of the digitally obtained anthropometric measures was tested in the process of relating them with the measures obtained via the traditional anthropometric quantification.

1 INTRODUCTION

A contemporary level of technological development makes it possible to construct instruments that are portable and mobile enough to meet requirements of versatile scientific branches in the field of data acquisition.

In this paper, the focus is on the need to acquire anthropometric measures. The intense development of technology in a couple of the last decades has gradually upgraded a "traditional" model of anthropometric measures (length, width, skinfolds' thickness, circumferences) with more complex measures such as volumes and surface sizes of the measured objects, by which changes in body size and shape can, relatively inexpensively, be detected in real time quite precisely, the goal hardly achievable by the traditional measuring instruments (Rønnestad, Hansen & Raastad, 2010; Schranz et al., 2010, 2012). The application of the already well-known and generally accepted techniques of digital body measuring, founded upon the three dimensional (3D) systems for superficial imaging, is limited due to their high purchase costs, complex implementation and constrained accessibility. However, the development of new technologies (sensors and cameras of high definition, data processing using machine learning and artificial intelligence…) is offering posibilities to overcome the mentioned limitations; it has enabled the production of a new generation of simple, high-speed, inexpensive, highly defined and precise scanners for superficial body imaging (Simmons & Istook, 2003; Zhang et al., 2014; Ryder & Ball, 2012; Bragança et al.).

Different types of body scan sensing based technologies can be found at the market. They differ regarding ease of use, and quality of 3D models reconstructed.

Applicable value of such technologically saturated instruments depends on various factors that have a direct influence on reliability and validity of the process of measurement.

This paper investigates the utility of specific 3D body scan technology in relation to classical anthropometric approach.

2 METHODS

Besides the classical antropometric instruments, a newly constructed measuring instrument assessing girths of body segments – BodyRecog PRO has been used in the research. The objective was to test metric characteristics of the instrument founded upon the method of a infrared depth-sensing 3D-scanning technology. Therefore, reliability of the digitally obtaine anthropometric measures was tested in the process of relating them with the measures obtained via the traditional anthropometric quantification, thus also testing validity of the new instrument.

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2.1 Digital Mesurement Technology

The digital measurement was conducted by an iPad Air 2 tablet with the iOS (ver. 10) operational system and a 3D-scanner Structure Sensor - model: ST01 (Occipital, 2019) and with support of BodyRecog PRO software (ver. 0.9.19).

Structure Sensor's technical specification includes the following technical elements important for the study: Maximum recommended range (3.5m+), minimum recommended range (40cm), precision (0.5mm at 40cm, 30mm at 3m), field of view (Horizontal: 58 degrees, Vertical: 45 degrees), Resolution (VGA 640x480, QVGA 320x240).

Each of the above mentioned has a direct impact on the result obtained.

2.2 Subjects

A convenience sample consisted of 71 participants of both genders (men: n=52, age in years: mean±21,7; SD±0,7; women: n=19; age in years: mean±20,9; SD±0,4), students of the Faculty of Knesiology in Zagreb. Participants were first manually measured – by a set of standard anthropometric measurements of circumferences, and then a digital measurement was conducted using a newly constructed measuring instrument BodyRecog PRO.

2.3 Variables

Entities were described by the sample of 34 variables[1], out of which 18 were variables obtained by the classical measurement of anthropometric dimensions, whereas 16 variables were obtained by the digital measurement of anthropometric dimensions; the latter variables were defined by the body sites and points that were either equivalent to the ones of the traditional anthropometric measurement (three measurement trials), or were repositioned in an acceptable way.

A group of the traditional anthropometric measures consisted of the following variables: body height (BH), body mass (BM), waist circumference, abdominal circumference, hip circumference, neck circumference, breast circumference, chest cavity circumference, left upperarm circumference, right upperarm circumference, left forearm circumference, right forearm circumference, left wrist circumference, right wrist circumference, left thigh circumference, right thigh circumference, left lowerleg (calf) circumference, right lowerleg (calf) circumference.

A group of the digital anthropometric measures consisted of the following variables[2]: D-BodyHeight, D-NeckGirth, D-WaistGirth, D-AbdominalGirth, D-HipsGirth, D-ChestGirth, D-BreastGirth, D-RightUpperArmGirth, D-LeftUpperArmGirth, D-RightForearmGirth, D-LeftForearmGirth, D-RightWristGirth, D-LeftWristGirth, D-RightWristDiameter, D-LeftWristDiameter, D-RightUpperLegGirth, D-LeftUpperLegGirth, D-RightLowerLegGirth, D-LeftLowerLegGirth.

2.4 Measurement Protocols

The traditional anthropometric measurement used the standard procedure, conducted according the International Biological Programme (IBP) and using the standard measurement instruments but for a slight modification – the examinee's position was adjusted to the position assumed in the digital scanning (the feet hip-width apart and the extended arms raised laterally at the shoulder height). Extremity circumference measurements were executed on both sides.

The digital anthropometric measurement followed the traditional one. For the standardisation purposes, the digital anthropometric measurement protocol was designed. Here is a shortened version:

The space within which measurement scanning is conducted must be at least 3 x 3 m with the central marker for the participant. The examinee stands quietly with the feet hip-width apart facing the measurer. The arms are in side raise, paralell with the floor, with the palms facing the floor. The participant's gaze is directed straight forward throughout the measurement procedure. The measurer, facing the participant 2-2.5 m apart (distance in calibration phase) and holding the iPad with the scanner perpendicular to the floor and at the height corresponding to the participant's abdomen, positions the reference framework of the software (guided by the software). Upon the software signal saying that the action has been executed properly, the measurer circles around the examinee 1 m apart (distance in digital scaning phase); iPad must be perpendicular to the floor all the time and at the half of the participant's height. The measurer stops circling for a while after every circle quarter in order to enhance body contours' imaging. The measurement

[1] Measurement units (classical and digital measurement): BodyMass (kg), BodyHeight (cm), Girths (cm), Diameters (cm).

[2] Prefix "D" denotes a digital measurement.

is over after three successfully registered/recorded repetitions.

2.5 Statistical Analysis

Data were processed using the statistical package StatisticaDell Inc. (Dell, 2017). The used procedures included the computation of descriptive parameters (mean, standard deviation, total range, variability coefficient, distribution form parameters: skewness and kurtosis). Reliability, based on the traditional anthropometric measurement model, was assessed using the method of internal consistency to establish the following reliability coefficients: Cronbach and Spearman-Brown's (standardised) alpha. Pearson's correlation coefficient was applied to determine a diagnostic validity of the newly constructed measuring instrument (BodyRecog PRO).

3 RESULTS AND DISCUSSION

Descriptive parameters of both the traditionally and digitally measured circumference variables were computed for each of the convenience subsamples of female and male students.

Basic descriptive parameters (central – arithmetic mean, dispersive – range and standard deviation) of the traditionally measured variables are presented in Tables 1 and 2.

Table 1: Descriptive parameters (clasical measuremet) – male students.

Variable name	Mean	Range	Std.Dev.
BodyMass	80,346	41,900	8,537
BodyHeight	183,138	34,200	7,455
NeckGirth	39,048	6,300	1,442
WaistGirth	79,950	17,600	4,081
AbdominalGirth	82,627	20,300	4,897
HipsGirth	100,921	20,400	4,471
ChestGirth	98,950	24,000	4,607
BreastGirth	95,867	23,400	4,308
RightUpperArmGirth	31,548	9,200	2,331
LeftUpperArmGirth	31,244	10,600	2,431
RightForearmGirth	28,469	8,000	1,440
LeftForearmGirth	28,062	7,300	1,479
RightWristGirth	17,677	3,800	0,765
LeftWristGirth	17,510	3,400	0,708
RightWristDiameter	5,946	1,400	0,298
LeftWristDiameter	5,871	1,100	0,255
RightUpperLegGirth	57,085	15,200	3,152
LeftUpperLegGirth	56,692	16,100	3,189
RightLowerLegGirth	38,554	7,200	1,734
LeftLowerLegGirth	38,285	8,000	1,802

Values of the traditionally measured variables and their parameters were in line with the values obtained in the many same or similar previous measurements conducted with the population of female and male students of the Faculty of Kinesiology in Zagreb.

Table 2: Descriptive parameters (clasical measurement) – female students.

Variable name	Mean	Range	Std.Dev.
BodyMass	62,000	28,300	6,929
BodyHeight	168,668	20,500	5,783
NeckGirth	32,837	5,900	1,408
WaistGirth	69,921	15,700	4,126
AbdominalGirth	77,363	15,700	5,032
HipsGirth	97,979	15,500	4,160
ChestGirth	86,174	16,200	3,583
BreastGirth	88,247	17,800	4,456
RightUpperArmGirth	27,132	7,000	1,778
LeftUpperArmGirth	26,595	6,600	1,713
RightForearmGirth	24,068	4,000	0,949
LeftForearmGirth	23,711	3,800	1,056
RightWristGirth	15,632	2,900	0,791
LeftWristGirth	15,532	3,000	0,799
RightWristDiameter	5,253	1,000	0,284
LeftWristDiameter	5,121	1,200	0,288
RightUpperLegGirth	54,226	12,400	3,269
LeftUpperLegGirth	53,847	12,200	3,363
RightLowerLegGirth	35,668	7,200	1,991
LeftLowerLegGirth	35,595	7,300	1,902

Tables 3 and 4 show basic descriptive parameters (central – arithmetic mean, dispersive – range and standard deviation) of the variables mesured digitally by the BodyRecog PRO instrument.

Table 3: Descriptive parameters (digital measurement) – male students.

	Mean	Range	Std.Dev.
D-BodyMass	80,177	41,900	8,613
D-BodyHeight	184,570	36,107	7,646
D-AbdominalGirth	84,736	21,993	5,255
D-HipsGirth	101,436	22,833	4,766
D-ChestGirth	104,205	27,230	4,920
D-BreastGirth	97,753	23,763	4,577
D-RightUpperArmG	33,221	10,673	2,536
D-LeftUpperArmG	32,673	10,397	2,617
D-RightForearmG	30,525	15,037	2,737
D-LeftForearmG	31,118	33,343	6,276
D-RightWristGirth	19,789	11,057	2,207
D-LeftWristGirth	20,977	15,980	3,939
D-RightUpperLegG	54,709	31,893	5,496
D-LeftUpperLegG	54,817	35,467	6,058
D-RightLowerLegG	37,770	19,913	2,982
D-LeftLowerLegG	37,226	20,037	3,043

We should emphasise here that the descriptive parameters of the marked variables of the subsamples of men and women (Tables 3 and 4) were computed from the data saturated with the perceived and recorded measurement errors. Unsuccessful scans were reported primarily due to body movement - examinee was not able to stand upright absolutely still, low iPad battery or other types of software issues.

The proportional contribution of the so contaminated data to particular variables (no gender differentiation) was the following: D-RightForearmGirth (9.38%), D-LeftForearmGirth (11.73%), D-RightWristGirth (13.14%), D-LeftWristGirth (18.77%), D-RightUpperLegGirth (3.28%), D-LeftUpperLegGirth (3.28%), D-RightLowerLegGirth (10.79%), D-LeftLowerLegGirth (10.79%). Although the research was a pilot-project, the analysis results should be observed with additional caution.

Table 4: Descriptive parameters (digital measurement) – female students.

	Mean	Range	Std.D.
D-BodyMass	61,953	28,300	7,267
D-BodyHeight	169,753	20,810	6,031
D-AbdominalGirth	81,307	18,793	4,951
D-HipsGirth	99,353	16,743	4,956
D-ChestGirth	90,936	19,363	4,660
D-BreastGirth	90,528	18,883	4,969
D-RightUpperArmG	30,266	8,520	1,905
D-LeftUpperArmG	30,229	8,353	2,016
D-RightForearmG	26,233	10,493	2,576
D-LeftForearmGirth	26,148	7,310	1,757
D-RightWristGirth	17,490	7,800	2,257
D-LeftWristGirth	18,262	8,373	2,280
D-RightUpperLegG	51,769	26,203	5,687
D-LeftUpperLegG	50,674	12,933	4,148
D-RightLowerLegG	39,829	16,203	4,359
D-LeftLowerLegGirth	40,250	13,093	3,747

Deviation magnitudes[3] of the corresponding variables (the ones with the matching measuring points) in the group of the traditional and the digital measurement are significantly different (Table 5).

The biggest deviation (in the form of average increase in the results) was observed in the variable delta-ChestGirth, followed by the variables of the upper segments of the arms.

Only the circumferences of both the left and the right thigh demonstrated a tendency of a significant decrease in the results when compared with the reference, traditional, measurement.

It is interesting to notice that the first six variables, whose measurement points are within the centrally positioned reference framework of the instrument (including the height of the instrument relative to the measurement object), delta-BodyHeight, delta-AbdominalGirth, delta-HipsGirth, delta-ChestGirth, delta-BreastGirth, delta-RightUpperArmGirth, delta-LeftUpperArmGirth, follow most proportinally average deviations (with the increase in the results) and adequate dispersion. A higher dispersion of the results was emphasised in every variable of the digital circumference measurement positioned distally from the body trunk and upper segments of the upper extremities. The mentioned can also be followed via the standard deviation magnitudes (Table 5).

Table 5: Deviation magnitudes.

Variable name	Mean	Range	Std.D.
delta_BodyMass	-0,137	10,700	1,076
delta_BodyHeight	1,339	8,090	1,225
delta_AbdominalGirth	2,600	18,543	2,826
delta_HipsGirth	0,745	9,663	1,996
delta_ChestGirth	5,123	16,817	2,406
delta_BreastGirth	1,991	10,990	1,760
delta_RightUpperArmG.	2,064	4,910	1,142
delta_LeftUpperArmG.	2,019	7,120	1,479
delta_RightForearmG.	2,085	12,517	2,132
delta_LeftForearmGirth	2,891	28,920	4,892
delta_RightWristGirth	2,044	9,607	2,097
delta_LeftWristGirth	3,270	14,837	3,332
delta_RightUpperLegG.	-2,397	30,030	4,568
delta_LeftUpperLegG.	-2,223	28,523	4,372
delta_RightLowerLegG.	0,540	19,173	3,649
delta_LeftLowerLegG.	0,471	18,530	3,699

Table 6: Reliability measures.

Variable name	Crombach alpha	Standardized alpha
D-Body Height	0,989	0,990
D-AbdominalGirth	0,952	0,952
D-HipsGirth	0,897	0,898
D-ChestGirth	0,968	0,969
D-BreastGirth	0,987	0,988
D-RightUpperArmG.	0,969	0,970
D-LeftUpperArmGirth	0,897	0,908
D-RightForearmGirth	0,739	0,748
D-LeftForearmGirth	0,828	0,869
D-RightWristGirth	0,575	0,579
D-LeftWristGirth	0,672	0,696
D-RightUpperLegGirth	0,604	0,717
D-LeftUpperLegGirth	0,621	0,721
D-RightLowerLegG.	0,454	0,523
D-LeftLowerLegGirth	0,539	0,574

[3] Prefix “delta” denotes a deviation magnitude.

Reliability of the anthropometric measurement using the digital instrument was expressed by the method of internal consistency among the measurement items; Cronbach's and standardised alpha were computed.

Reliability measures (Table 6) indicated an acceptable reliability of the following digital girth measures (variables): Body Height, AbdominalGirth, HipsGirth, ChestGirth, BreastGirth, RightUpperArmGirth, LeftUpperArmGirth. As regards the other digital measures, a considerable further work is needed.

The magnitudes of average correlation among the items of digital measurement (which could also be recognised as a homogeinity measure) expectedly follow reliability decrements in case of the distal measurement points.

Correlation coefficient magnitudes (Table 7) indicate the correlation power of the corresponding variables.

Table 7: Correlation magnitudes.

Classic	r	Digital
BodyMass	0,996*	D-BodyMass
BodyHeight	0,992*	D-BodyHeight
AbdominalGirth	0,863*	D-AbdominalGirth
HipsGirth	0,912*	D-HipsGirth
ChestGirth	0,949*	D-ChestGirth
BreastGirth	0,951*	D-BreastGirth
RightUpperArmG	0,922*	D-RightUpperArmGirt
LeftUpperArmG.	0,875*	D-LeftUpperArmGirth
RightForearmG.	0,763*	D-RightForearmGirth
LeftForearmG.	0,578*	D-LeftForearmGirth
RightWristGirth	0,506*	D-RightWristGirth
LeftWristGirth	0,502*	D-LeftWristGirth
RightUpperLegG	0,591*	D-RightUpperLegGirth
LeftUpperLegG.	0,674*	D-LeftUpperLegGirth
RightLowerLegG	0,244*	D-RightLowerLegGirth
LeftLowerLegG.	0,212	D-LeftLowerLegGirth

The Pearson's correlation coefficient was used as a measure of validity. Marked correlations (*) are significant at $p<0,05$. An gradation of correlation coefficients magnitudes (both in size and colour – from cool colours to warm ones) clearly illustrates association between the traditional measures and the corresponding digital measures corroborating poorer validity of distal measures in the comparison to the central ones.

4 CONCLUSIONS

The analysed measurement instrument has not yet met the targeted reliability level at all the measured points (apart from, relatively, D-BodyHeight, D-AbdominalGirt, D-ChestGirth, D-BreastGirth, D-Hips Girth, D-RightUpperArmGirth and D-LeftUpperArmGirth).

The obvious decrements in reliability of the measures taken digitally distally from the body trunk measures and upper segments of the upper extremities indicate possible association with the technical characteristics of the measuring instrument as well as with the camera position management in relation to the measurement object (the measures gathered at the level of the central body trunk girth measures, with no camera angle correction in relation to the measures collected using the scanning angles corrections towards the distal body segments while relatively preserving the scanning height).

A needed additional partial analysis of varying influences of measurement conditions and techniques, as well as the analysis of their combined influence on the measured results together with additional software improvements will contribute to the targeted measuring instrument's utility.

The observed analytical limitations of the study are closely related to the type of study conducted (pilot study), therefore additional differences analysis and standardized comparison methods will be made after satisfactory hardware and software modifications of the measuring instrument.

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