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Original article

Evaluation of an Automatic Ultrasonic Device for Measuring Body Height

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Abstract

Body height explains the longitudinal dimensionality of humans. It has been is an important feature in research in humans from the perspective of anthropology, epidemiology, health, and physical performance. While methods for bod height measurement are well established, technological development provides nuanced, valid and reliable devices that could reduce the sources of measurement error. The aim of this study was to investigate the validity and reliability of an automatic ultrasonic device for measuring body height in comparison with the standard Martin anthropometric method. The study included 50 participants of both sexes who voluntarily took part in the testing. The testing protocol consisted of a standardized procedure for measuring body height using the Martin anthropometer (ANT_BH) and an automatic ultrasonic (IC) device (IC_BH). The results of this study demonstrated an exceptionally high level of reliability and precision of the automatic IC device for body height measurement, with a low coefficient of variation (ANT_BH = 4.35%, IC_BH = 4.19%), an excellent intraclass correlation coefficient (ICC = 0.998), and a small standard error of measurement (SEM_{aps} = 0.33 cm). Factor analysis, Bland–Altman analysis, and linear regression confirmed a high level of agreement with the standard anthropometric method, a small and statistically non-significant bias (0.26 cm), and a strong predictive relationship (R^2 = 0.946). The results suggest that the automatic IC device represents a highly reliable, precise, and valid alternative to the standard anthropometric method of measuring body height, without the presence of systematic or proportional error.

Keywords: reliability, validity, anthropometric assessment, measurement

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Introduction

Height is a fundamental anthropometric measure of body longitudinality and is essential for monitoring patterns of growth and development (Falch-Joergensen et al. 2023; Milasinovic et al. 2019). The measurement of body height is a process by which the vertical distance between the vertex of the head and the feet of an individual is determined (Ratthi et al. 2024). Accurate height measurement is of great importance in several fields, such as healthcare, exercise science, and ergonomics (Zaric et al. 2020). In addition, body height is required for the calculation of parameters such as body mass index (BMI), a primary indicator of nutritional status, for the estimation of basal metabolic rate, and for the proper planning of other diagnostic procedures. Anthropometric characteristics play a key role in athlete selection. In basketball, players of different heights typically occupy different positions within a team (Zaric et al. 2020), with shorter players most often responsible for organizing the ball transition into the offensive half, while taller players use their height to score more easily (Zhang et al. 2018). In addition, an athlete's anthropometric profile represents an important predictor of his or her ability to compete at the highest level in a given sport (Baker et al. 2018).

In this context, the reliability of measurement procedures is crucial for obtaining consistent and precise results in sports and clinical research, as confirmed by studies by Kostovski et al. (2011) and Lockie et al. (2024) who report high intraclass correlation coefficients (ICC) and low coefficients of variation (CoV) for tests and devices used to assess motor abilities. Various techniques and methods are used to measure body height. The basic approach is measurement with an anthropometer, while contemporary approaches include camera-based methods (Bieler et al. 2019; Liu et al. 2018), sensor-based methods (Ly et al. 2018; Riaz et al. 2015), as well as methods that estimate height based on body segments (Duyar & Pelin, 2003; Pelin et al. 2010). All of these methods have their advantages and limitations; however, the gold standard for height measurement remains the standard manual method using the Martin anthropometer (GPM, Switzerland).
Despite the high accuracy of the standard method, its reliability largely depends on the experience of the measurer, proper use of the instrument, and correct positioning of the participant, especially in situations involving mass testing or when measurements are conducted by multiple individuals (Mikula et al. 2016). Consequently, inconsistencies in results and reduced objectivity may occur. This has led to growing interest in automated devices for measuring body height, which eliminates subjective errors, provide greater standardization, and simplify the measurement process under various conditions. One of the emerging technologies is the ultrasonic (IC) device for automatic body height measurement (Ultrasonic Height Rod, Charder Electronic Co., Ltd., Taichung, Taiwan). This device measures body height with an accuracy of 0.1 cm, providing higher precision compared to the anthropometer, where the standard procedure achieves measurements with a 0.5 cm precision. The system is based on ultrasonic technology, specifically on the time-of-flight principle. The device emits ultrasonic waves and determines body height based on the time interval between signal emission and its reflection from the subject's head.

Therefore, the aim of this study is to evaluate and confirm the validity of the automated method using the IC device in comparison with the gold standard—body height measurement with the Martin anthropometer. It is expected that the new automated method will demonstrate a high level of reliability in assessing body height, which will be confirmed by the stability and reproducibility of the obtained results. If the study results confirm the validity and reliability of the IC device, its application could significantly accelerate the process of measuring body height in situations requiring mass testing, such as school health examinations, sports clubs, the military, or large population studies. Additionally, its use is valuable in clinical practice, where measurement accuracy and repeatability are crucial for monitoring growth, nutritional status, or therapy effects.

Methods

This study was designed as a cross-sectional study, employing a laboratory testing method aimed at collecting data at a single time point under controlled measurement conditions.

Participants

This non-experimental study included a total sample of 50 participants, of whom 19 were female (age = 24.8 ± 7.6 years, body mass = 64.2 ± 8.9 kg, BMI = 22.6 ± 2.4 kg/m^2) and 31 were male (age = 30.5 ± 11.9 years, body mass = 81.4 ± 8.6 kg, BMI = 24.9 ± 2.3 kg/m^2). All participants were students of the Faculty of Sport and Physical Education, University of Belgrade (FSFV UB) and voluntarily took part in the study. The study was conducted in accordance with the ethical principles of the Declaration of Helsinki and with prior approval from the Ethics Committee of FSFV UB (484-2).

Measurements and Procedures

The participants' body height was measured using the Martin anthropometer (GPM, Switzerland) following a standardized protocol and pre-defined procedure (Dopsaj et al. 2020), as well as with the automatic IC device. The automatic IC device was factory calibrated, so no additional calibration was required prior to use. The order of measurements was randomized to reduce potential measurement error. For some participants, measurement started with the IC device, while for others the anthropometer was used first. Participants assumed a standardized posture with heels together and feet slightly apart, arms extended alongside the body, and the head in a neutral position. Measurement began after the measurer instructed the participant to stand as tall as possible. All participants stood barefoot on a hard, flat surface to ensure maximum measurement accuracy. Each participant's height was measured four times using the IC device, with the device removed from the head after each individual measurement before recording the reading. Additionally, height was measured once using the anthropometer. The obtained values were subsequently used for statistical analysis. All measurements were conducted in the FSFV UB research laboratory during morning hours by the same person.

Figure 1. IC device measurement procedure.

Figure 2. Ultrasonic IC Height Rod automatic device

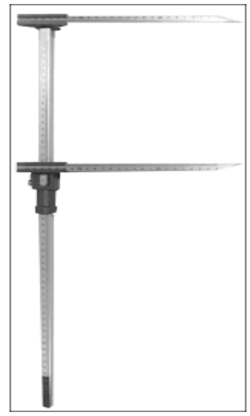

Figure 3.) Martin anthropometer (GPM, Switzerland

Variables

For the purposes of this study, the primary variable was body height, measured to validate the new height measurement device. Body height values were obtained immediately after measurement using the tested IC device (IC_BH) and then compared with the gold standard (Martin Anthropometer) to assess accuracy and reliability (ANT_BH). The measurement precision for both instruments was 0.1 cm. The data obtained from body height measurements were used as a key parameter in the analysis, and device validation included the assessment of systematic deviations, repeatability, reliability, and measurement consistency.

Statistical analyses

For the variables under investigation, the following descriptive statistics were calculated: mean (M), standard deviation (SD), coefficient of variation (CoV), minimum (Min), maximum (Max), as well as absolute and relative standard error of measurement (SEM_{abs} and SEM_{rel}). Additionally, the 95% confidence interval of the mean (95% CI Lower and 95% CI Upper) was calculated. The reliability of the new device was assessed using the ICC, with interpretation thresholds defined as follows: ICC < 0.50 = small reliability, ICC = 0.50–0.75 = moderate reliability, ICC = 0.76–0.90 = high reliability, and ICC > 0.90 = excellent reliability (Koo & Li, 2016). The agreement between results from different height measurement methods was evaluated using the Bland–Altman method, including calculation of bias and limits of agreement (LoA) (Bland & Altman, 1986). To determine whether both methods measured the same construct and to define a representative body height value obtained by the IC device, factor analysis was applied. Linear regression analysis was conducted to assess the predictive ability of one measurement device relative to the other and to quantify the prediction error between measurement methods. Sample size was determined using G*Power software (version 3.1.9.7). Analysis parameters included a significance level of α = 0.05 and statistical power of 0.95. Based on these parameters and the statistical procedure, a minimum sample of 45 participants was estimated to achieve adequate statistical power and ensure reliable results. All statistical analyses were performed using IBM SPSS 25 (IBM Corp. 2017) and Microsoft Excel (Microsoft Corp. 2018).

Results

The results in Table 1 indicate nearly identical mean values of body height between the two measurement devices with a very similar coefficient of variation. Additionally, an exceptionally high level of reliability was observed for IC_BH accompanied by minimal standard error of, confirming a high degree of consistency and precision of the obtained results.

Table 1. Reliability and descriptive statistics of body height measured using two devices.

Variables	*N*	*M*	*SD*	*CoV*	*Lower 95% CI*	*Upper 95% CI*	*Min*	*Max*	*SEM_{abs}*	*SEM_{rel} (%)*	*ICC*
ANT_BH	50	176.4	7.76	4.35	174.09	178.57	158.4	189.7			
IC_BH	50	176.2	7.38	4.19	173.85	178.15	158.3	189.3	0.33	0.19	0.998

Note: BH (Body Height) (cm); SEM_{abs} = SD * $\sqrt{1 - ICC}$ (cm); $SEM_{rel} = (SEM \div Mean) \times 100$ (%)

The results of the Kaiser–Meyer–Olkin test (KMO = 0.886) and Bartlett's test of sphericity ($p < 0.001$) (Table 2) confirmed the adequacy of the data for factor analysis.

Table 2. Results of the KMO and Bartlett's Test .

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.886
Bartlett's Test of Sphericity	Approx. Chi-Square	586.268
	df	6
	Sig.	.000

The results of the factor analysis (Table 3) indicate that both measurement instruments assess the same latent dimension, namely body height. In addition, one dominant component was extracted, explaining 99.2% of the total variance, which indicates high homogeneity and a unidimensional structure of all measurements.

Table 3. Factor analysis with extracted and explained factor.

Variables	Component
IC_BH1	.998
IC_BH2	.997
IC_BH4	.996
IC_BH3	.996
ANT_BH	.986

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	3.967	99.169	99.169	3.967	99.169	99.169

The results in Table 4 indicate that all trials were of very homogeneous quality, consistent, and measured the same dimension. The factor structure showed that the results of the third measurement with the IC device were the most representative, and therefore were used in the evaluation analysis (Bland–Altman plot and regressions).

Table 4. Factor structure of body height measurements.

	Component
	1
IC_BH3	.997
IC_BH4	.997
IC_BH2	.997
IC_BH1	.992

Figure 1 showed that the automatic IC device provides a stable level of precision across all height categories. There is no increase in error at low, medium, or high body height values; rather, the error is consistent across the entire measurement range. Furthermore, Table 5 shows a small and statistically non-significant bias between the automatic IC device and the anthropometer (mean difference = 0.26 cm). The limits of agreement ranged from –2.29 to 2.82 cm, with the corresponding 95% confidence interval (Table 5).

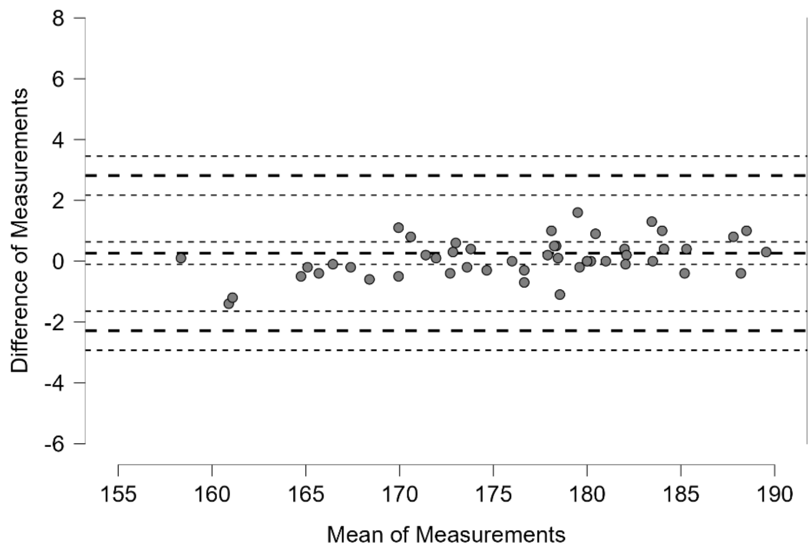

Figure 1. Bland–Altman Plot – agreement between different methods of measuring body height.

Table 5. Bland Altman table.

Bias & Limits	*Point Value*	*Lower 95% CI*	*Upper 95% CI*
Mean difference + 1.96 SD	2.816	2.175	3.457
Mean difference	0.264	-0.106	0.634
Mean difference - 1.96 SD	-2.288	-2.929	-1.647

Linear regression analysis (Figure 2) showed a very strong linear relationship between body height measurements obtained with the anthropometer and the IC device (R^2 = 0.946). The results indicate that

94.6% of the variance in the IC device measurements can be explained by the reference anthropometer measurements, confirming the high external validity of the tested IC instrument.

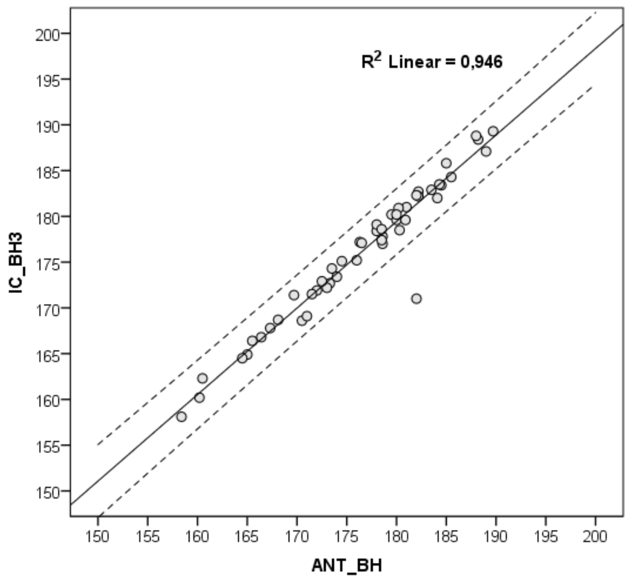

Figure 2. Regression analysis of body height measurements between the Martin anthropometer and the IC device.

Discussion

The results of this study indicate a high level of measurement reliability, homogeneity of results, minimal repeated measurement error, and the absence of statistically significant variations in the body height values obtained with the tested automated IC device. The coefficient of variation was low and almost identical for both measurement instruments (ANT_BH = 4.35%, IC_BH = 4.19%), indicating good sample homogeneity. The SEM_{aps} was 0.33 cm for the automatic IC device, confirming high measurement precision, i.e., a very small expected error range in repeated measurements. Furthermore, the automatic IC device demonstrated excellent reliability (ICC = 0.998). These findings suggest that the automatic device can represent a reliable alternative to the standard anthropometric method of measuring height, with the practical advantages of a faster and easier measurement procedure.

The results of the factor analysis indicate the presence of a clearly extracted dominant component that explains 99.2% of the total variance. This finding confirms the unidimensional structure of body height measurements and indicates a high degree of agreement between repeated measurements, as well as between different measurement protocols. From a methodological perspective, these results suggest that repeated measurements are highly reliable. Therefore, it can be concluded that under practical conditions using the IC device, performing three measurement attempts and using the third value as the most representative measurement item is sufficient, achieving an optimal balance between measurement accuracy and efficiency of the measurement procedure (Table 4). This approach is particularly important in field settings, where time rationalization and reducing participant burden are crucial.

The results of the Bland–Altman analysis indicate a high level of agreement between the automatic IC device and the Martin anthropometer in measuring body height. A small bias was also observed (0.26 cm, or 0.15%), which was not statistically significant (95% CI = -0.11 to 0.63), suggesting that there is no systematic overestimation or underestimation of height compared to the reference anthropometric method. Such values are considered highly acceptable deviations for sports and research applications in body height measurement, especially given that most differences on average were less than 0.26 cm and no proportional error depending on participant height was observed (Ly et al. 2018). Duyar and Pelin reported differences between estimated and actual height of 8.2 mm, 4.2 mm, and 6.3 mm in short, medium, and tall participants, respectively (Duyar & Pelin, 2003), while in our study the average difference was 0.26 mm, indicating a much smaller measurement error and potentially higher precision of the applied method. Several studies have reported small average differences between automatic and classical anthropometric methods, most commonly in the range of 0 to 0.5 cm, with limits of agreement of approximately ±2 to ±3 cm, which is very similar to the results obtained in this study (Duyar & Pelin, 2003; Liu et al. 2018).

An important finding of this study is the absence of proportional error, meaning that the difference between methods does not depend on the participant's height. This indicates that the automatic devices do not show a tendency for greater deviations in shorter or taller individuals, but rather provide relatively consistent measurements across the entire range of body height. Such measurement stability has significant practical implications, as it demonstrates the reliability of the device across different populations and anthropometric profiles. The results of the linear regression analysis indicate a very strong predictive relationship between body height measurements obtained with the anthropometer and the IC device (R^2 = 0.946), with 94.6% of the variance in one measurement being explained by the other. The distribution of data around the regression line shows a high degree of agreement and a small estimation error.

From an application perspective, the results of this study support the use of automatic devices in sports science, clinical practice, and epidemiological research, especially in situations where rapid, standardized, and objective measurement of a large number of participants is required. Future research should include different age groups, populations with extreme body height values, as well as longitudinal measurements to assess the stability of agreement over time. Additionally, comparisons with other types of automatic devices could contribute to a better understanding of technical factors affecting measurement precision. Overall, the findings confirm the high reliability of the applied measurement procedures and indicate that variations between individual measurements primarily represent random error rather than a systematic difference between devices or trials.

Conclusion

The results of this study indicate an exceptionally high level of reliability and precision in measuring body height using the automatic IC device. The coefficient of variation was low and nearly identical for both measurement systems (ANT_BH = 4.35% and IC_BH = 4.19%), confirming good sample homogeneity and measurement stability. The automatic IC device demonstrated excellent reliability (ICC = 0.998), with a very small repeated measurement error (SEM_{aps} = 0.33 cm). Factor analysis identified one dominant component explaining 99.2% of the total variance, while Bland–Altman analyses showed high agreement between the automatic IC device and the reference anthropometric method, with a small and statistically non-significant bias of 0.26 cm (95% CI = −0.11 to 0.63). Additionally, linear regression results confirmed a very strong relationship between the methods (R^2 = 0.946), with 94.6% of the variance in measurements explained by the alternative procedure. Based on these findings, it can be concluded that the automatic IC device represents a highly reliable, precise, and valid alternative to the standard anthropometric method of measuring body height, without the presence of systematic or proportional error.

***Conflict of interests*:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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