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Concurrent Validity of the Inertial Measurement Unit *Vmaxpro* in Vertical Jump Estimation

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Abstract: The aim of this study was to evaluate if the inertial measurement unit (IMU) *Vmaxpro* is a valid device to estimate vertical jump height (VJH) when compared to a motion capture system (MoCAP). Thirteen highly trained female volleyball players participated in this study which consisted of three sessions. After a familiarization session, two sessions comprised a warm-up followed by ten countermovement jumps, resting two min between each attempt. Jump height was measured simultaneously by *Vmaxpro* using take-off velocity and MoCAP using center-of-mass vertical excursion. Results show significant differences in jump height between devices (10.52 cm; $p < 0.001$; ES = 0.9), a very strong Spearman's correlation ($r_s = 0.84$: $p < 0.001$), and a weak concordance correlation coefficient (CCC = 0.22; $\rho = 0.861$; $C_b = 0.26$). Regression analysis reveals very high correlations, high systematic error (8.46 cm), and a nonproportional random error (SEE = 1.67 cm). Bland–Altman plots show systematic error (10.6 cm) with 97.3 % of the data being within the LoA. In conclusion, *Vmaxpro* can be considered a valid device for the estimation of VJH, being a cheaper, portable, and manageable alternative to MoCAP. However, the magnitude of systematic error discourages its use where indistinguishable data from *Vmaxpro* and MoCAP are used unless the corresponding specific fitting equation is applied.

Keywords: validation; error; countermovement jump; MoCAP; portable devices; IMU; sensitivity; accelerometer

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1. Introduction

Vertical jump height (VJH) is a common measure of athletic ability in various disciplines widely used for monitoring the performance of subjects [1]. The test consists of measuring the height that an individual is able to jump vertically from a stationary position. Different devices, such as jump mats [2,3], photoelectric cells [4], linear position transducers [5], video recordings from smartphones [6–8], or accelerometers [7,9–11], can be used to assess VJH. However, despite the availability of these instruments, 3D motion capture (MoCAP) is still considered the gold standard instrument for determining VJH. MoCAP tracks a marker placed at the center of mass [1,2,7], but it requires postprocessing of the data [12], and it is immune to errors arising from the rigid body model [13]. Nonetheless, MoCAP remains the most accurate method for determining VJH because it allows for a more direct determination than other systems [1,14].

Likewise, force platforms (FP) are considered reference systems in the estimation of VJs. These instruments can use the double integration of vertical ground reaction forces or flight time to estimate VJH [15]. Despite the availability of more manageable, portable, and inexpensive FPs, their use is still restricted to laboratory conditions because they remain very expensive. Furthermore, they are not error-free, and a small failure in data capture can be multiplied drastically due to the double integration process [16]. Despite these limitations, FPs have been considered the main reference tools in the determination of VJH [1,14,17].

On the other hand, the growing demand for more affordable and user-friendly monitoring tools for physical activity specialists has led to an increase in the number of various devices on the market. Accelerometers, together with global position systems, are one of these new systems. Accelerometers are often accompanied by a gyroscope and a gravimeter, forming an inertial measurement unit (IMU), which has the advantage of being easy to use, portable, and the ability to operate on any type of surface and condition [9,18,19].

The *Vmaxpro*, an IMU that was initially designed for measuring barbell speed in resistance exercises, is a valid and reliable instrument for speed monitoring, is at an economical price, and is easy to handle, especially in strength exercises involving displacements in a single plane, such as the squat, hip thrust [20] deadlift, barbell row [21], hang clean, or weighted jumps [22]. At the same time, the manufacturer has conducted validation studies for squat, bench press, clean, and deadlift exercises and found this tool to be valid and reliable when measuring maximum speed, average speed, and distance (Vmaxpro V2, Blaumann and Meyer-Sports Technology UG, Magdeburg, Germany).

Some studies have assessed VJH using accelerometers. Although less common than those focusing on execution velocity on strength exercises, validation studies of IMUs related to jumping tend to show acceptable validity values. For example, *Push* 2.0 (PUSH Inc., Toronto, ON, Canada) was examined by Montalvo et al. [7] who found a proportional systematic error in VJH. Similarly, C. M. Watkins et al. [9] observed that *Push* was a valid device for estimating VJH but with systematic errors of 4.4 cm for the CMJ jump. In both studies, the device was placed on the hip and an FP was used as the criterion instrument. On the other hand, when IMUs are compared against MoCAP systems, it is also appreciated that those devices are valid, showing Pearson correlation values ranging from $r = 0.77$ to 0.82 for *Catapult GPS Minimax X S4* (Catapult Innovations, Docklands, Australia) [18,19] to $r = 0.94$ obtained by *MMS* (Motus Design Group, Victoria, BC, Canada) [10]. Once again, the presence of significant differences between the IMU and the criterion can be seen, indicating the presence of systematic error and highlighting the need for approach validation studies from different perspectives, not just the possible existence of correlation.

It is worth noting that the validity of the *Vmaxpro* has only been examined in studies that have assessed velocity in barbell-weighted jumps, and therefore the IMU is located in the barbell, further from the center of mass. In this sense, Olovsson Stahl and Öhrner [23] carried out a validation of *Vmaxpro* against a linear position transducer using loads of 25, 50, and 75% of 1RM (one-repetition maximum) in the squat to perform a loaded jump with a countermovement. They found strong correlations between the two devices (r = 0.92–0.96) when studying the peak velocity from which the vertical height can be estimated. At the same time, all the data obtained were between the LoA in the Bland–Altman plots. However, a systematic error was shown in the plots (−0.12 m/s), and significant differences were observed when performing a paired samples t-test ($p < 0.001$). In a similar study performing countermovement jumps with a 50% 1RM squat load, Fritschi et al. [22] once again found strong correlation coefficients (r = 0.92–0.99) and SEE values of 0.11 m/s when compared to MoCAP.

Despite the manufacturer's claims that the *Vmaxpro* can be used to estimate jump height [24], no validation studies have been identified that assess the accuracy of this device when used to measure countermovement jump (CMJ) or any other type of VJH using an accelerometer placed at the hip, as is common in sports science research. Additionally, no studies have examined the device's accuracy in measuring jumps performed without additional load, which is how most jumps related to technical actions in sports or daily life are performed. The lack of load in these jumps allows for a higher take-off velocity, making it suitable to validate the instrument within that speed range.

Therefore, this study aimed to quantify the concurrent validity of the *Vmaxpro* IMU compared to a 3D motion capture instrument considered a gold standard when estimating the VJH in CMJ execution.

2. Materials and Methods

2.1. Participants

Thirteen highly trained [25] female volleyball players from the Spanish Superliga 2 league participated voluntarily in this validation study (Table 1). Before implementation of the intervention, the participants read and signed an informed consent document in which they were informed of the characteristics of the study and the strictly scientific use of the data obtained as specified in the Declaration of Helsinki of the World Medical Association (WMA); Ethical Principles for Medical Research Involving Human Subjects of 1975 (revised in Fortaleza, Brazil in 2013). This study has also been approved by the ethics committee of the University of Alicante (UA-2018-11-17).

Table 1. Descriptive statistics of study participants.

	Mean	SD
Age (years)	22.23	3.26
Height (m)	1.72	0.06
Body mass (kg)	64.12	7.33
Fat mass percentage (%)	16.49	2.50
BMI (kg/m^2)	21.64	2.14
Experience (years)	8.77	2.01

SD = standard deviation; BMI = body mass index; Experience = years practicing volleyball.

The following criteria were applied to select participants:

- Inclusion criteria: being female, over 18 years of age, with at least 3 years of experience in the practice of high-level volleyball, and being familiar with the countermovement jump.
- Exclusion criteria: presenting a current or previous pathology that entailed a medical contraindication for physical activity, presenting a previous musculoskeletal injury or one acquired during the development of the experimental phase, not participating in all the interventions included in the study, and ingesting alcohol or drugs in the 48 h before the performance of the tests.

2.2. Study Design

This was an observational study designed to determine concurrent validity for which jump tests were scheduled using a design of repeated measures design of intrasession VJH. The data were collected from two different devices simultaneously to compare the results of the estimation of the jump obtained by the IMU (*Vmaxpro*) with the values of the criterion instrument based on direct estimation (MoCAP)). For a statistical power of 80%, a minimum of 250 jumps (α = 0.1, two-tailed) was determined using *G*Power* (v3.1.9.7, Heinrich-Heine-Universität Düsseldorf, Düsseldorf, Germany). To accomplish this number of jumps without inducing fatigue, the 13 participants performed 10 CMJ resting 2 min between attempts in two sessions separated by 7 days [9,26], resulting in 260 valid jumps.

2.3. Instruments

2.3.1. Motion Capture System Optitrack

The direct determination of the VJH was performed using a MoCAP system (Optitrack motive, Corvallis, OR, USA) which consists of 6 *Optitrack Flex 3* cameras (Optitrack motive, OR, USA). This device allows the 3D tracking of a marker, consisting of a reflective sphere capable of reflecting infrared light in the same direction in which it is received. The marker is placed between the L4 and L5 vertebrae, in the same place as the IMU, near the center of mass [27,28]. The infrared light is emitted by the 26 LEDs surrounding the camera lens (IR 850 nm) in a ring configuration synchronized with the capture shutter. Furthermore, the 6 cameras operate at 100 Hz with a shutter speed of 20 μs, achieving an overall resolution of 0.001 m. The height of the VJH was determined from the data obtained, calculating the difference in the position on the vertical axis of the marker before the execution of the jump, during the rest phase, and at the highest point recorded in the flight phase.

The signal was transmitted via a USB cable connection to a laptop where it was stored and analyzed using the *Motive Tracker 2* software (Optitrack motive, OR, USA). In addition, this software synchronizes and calibrates the image collection systems as well as exporting the data obtained in text format separated by commas (CSV) for subsequent analysis in a spreadsheet and thus determining the VJH through the difference in positions.

2.3.2. Inertial Measurement Unit Vmaxpro

The IMU *Vmaxpro* (Blaumann and Meyer-Sports Technology UG, Magdeburg, Germany) consists of a triaxial accelerometer, a gyroscope, and a magnetometer (16 g, 4.5 × 2.7 × 1.2 cm). It has a sampling rate of 1000 Hz [20] and can be attached to metal surfaces with magnets or placed elsewhere with an elastic strap. This IMU can record acceleration data in all three axes and is primarily designed for velocity-based resistance training. From the integration of the accelerations, the device can estimate other related variables such as peak velocity, average velocity, peak eccentric velocity, average eccentric velocity, percentage of force development, percentage of eccentric force development, average propulsive velocity, distance, and duration. Therefore, if the vertical peak velocity data is known, the VJH can be assessed as this corresponds to the take-off velocity [29]. The integration of the acceleration signal is performed internally by the *Vmaxpro* device and sent instantly via Bluetooth wireless connection (65 Hz) to a smartphone or tablet device with the *Vmaxpro app* previously installed (Blaumann and Meyer-Sports Technology UG, Magdeburg, Germany). This application allows the user to view the data instantly and export it to a spreadsheet in CSV format. Before each measurement, the device must be calibrated on all its axes by placing it on a completely flat surface on each of the six faces of the octahedron for enough time for the software to recognize them and set the local three-dimensional coordinates of the IMU. Once calibrated, the instrument was placed on an elastic band to be as close as possible to the center of mass, at the subject's hip, according to the manufacturer's specifications [24]. The maximum velocity data obtained were transformed into VJH data according to the equation $\text{VJH} = v_o^2/(2g)$ [29], where v_o is considered as the take-off velocity registered as the maximum velocity recorded by *Vmaxpro,* and g is the gravitational constant (9.8 m/s^2).

2.4. Experimental Procedure

The procedure was carried out in three sessions separated by seven days each in the sports science laboratory of the University of Alicante, as shown in Figure 1. All participants performed the tests at the same time of day to avoid possible effects associated with circadian rhythms. In the first session, participants were familiarized with the experimental protocols and anthropometric measurements were carried out (Table 1). In the second and third sessions, participants performed a standardized warm-up consisting of five minutes of continuous running followed by three minutes of dynamic range-of-motion exercises. Next, they executed two minutes of familiarization jumps in which the subjects were instructed in the initial and final positions of VJH. The warm-up was followed by four minutes of rest during which the inertial device was placed, and the jumping protocols were reviewed. Finally, subjects performed 10 CMJ jumps with two minutes between each attempt to avoid the effects of fatigue [30].

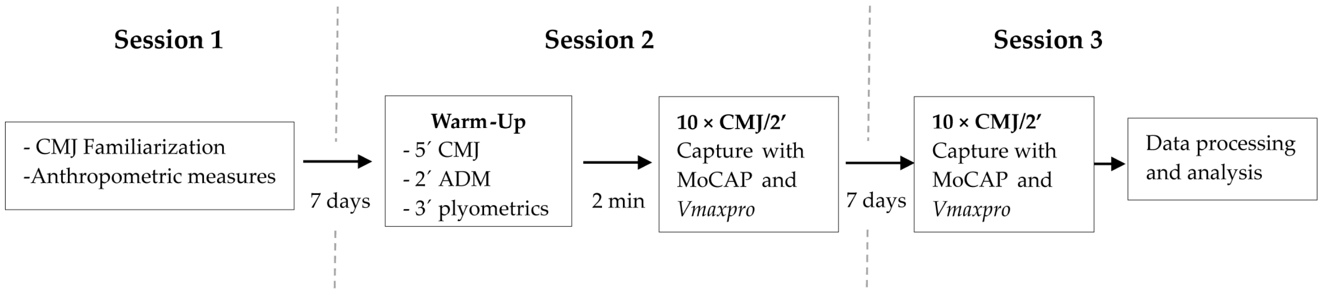

Figure 1. Experimental design: CMJ = countermovement jumping; ADM, the amplitude of movement exercises; MoCAP = 3D motion capture system; Vmaxpro = inertial measurement unit.

To avoid displacements in the transverse and frontal plane, jumps were performed on a 29.2 cm × 42 cm bounded surface so that both the take-off and landing phases were executed completely within the boundaries. CMJs were performed with a rapid descent from a self-selected depth by each participant [31,32] followed by a quick ascent to achieve take-off. All tests were performed with the hands placed on the iliac crests in the Akimbo position [33] to avoid the variability generated by the action of the arms.

The participants were instructed to jump as high as possible on each attempt and to land on the tips of their toes, imitating the position adopted by the ankle joint in the take-off phase to minimize the error produced by variations in the angle of ankle flexion in the landing phase [13]. Jumps were always supervised by an instructor to avoid any errors in execution. Attempts were considered invalid if the subjects did not land within the established limits, did not land on their toes, or separated their hands from the iliac crests in any phase of the jump. All records were collected simultaneously by both measuring instruments, IMU *Vmaxpro* and MOCAP *Optitrack system*.

2.5. Statistical Analysis

Descriptive data are shown as mean and standard deviation. The normality of the data was verified using the Kolmogorov–Smirnov test, resulting in a non-normal sample for MoCAP ($p = 0.011$). To assess the degree of agreement and the presence of systematic error between the two instruments, Lin's concordance coefficient (CCC) was calculated. This statistic is expressed as $\rho_c = \rho \times C_b$, providing information on how close the pairing data in both devices are (ρ, precision) for VJ and how close to ideality this line is (C_b, accuracy), where ideal fit is represented by a straight-line $x = y$ [34]. The results obtained are classified as <0.9 (poor), 0.90–0.95 (moderate), 0.95–0.99 (substantial), and ≥0.99 (near perfect) [35]. In addition, a correlational analysis was performed by determining Spearman's bivariate correlation coefficient (r_s) since the size and non-normal nature of the sample [36] discourage the use of Pearson's coefficient. For interpretation, the following criteria were used: ≤0.1 (trivial), 0.1–0.3 (low), 0.3–0.5 (moderate), 0.5–0.7 (high), 0.7–0.9 (very high), and ≥0.9 (almost perfect) [37,38].

The Passing and Bablok regression [39] for nonparametric samples was used for the regression analysis to determine the existence of a linear relationship between the paired data from both instruments. The relationship between two variables can be described using the equation $y = ax + b$, which allows for the prediction of the values of the dependent variable y based on the values of the independent variable x. The parameter a represents the slope, which ideally should be 1, and provides information on the proportional differences between the two methods. On the other hand, b is the cut-off point with the x-axis (intercept) which, in its ideal value, would be 0 and represents the systematic differences between the two devices in a quantitative approach. The standard error of the estimated (SEE) was also calculated; the lower the SEE values, the closer the points are to the regression line and therefore the lower the error in the estimation. To check the applicability of

Passing and Bablok regression, the Cusum test resulting in a p-value less than 0.05 indicates no linear relationship between the Mocap and *Vmaxpro*.

To analyze the existence of systematic error, significant differences in the values of the *Vmaxpro* and the criterion instrument were calculated using a Wilcoxon test for paired samples, and the effect size (ES) was determined as bias corrected Hedges ES [40]. The differences expressed as g were interpreted according to W. G. Hopkins et al. [40] as trivial (<0.2), small (0.2–0.6), moderate (0.6–1.2), and large (>1.2). In the same way, the existence of significant differences between sessions 1 and 2 was studied using the Wilcoxon test (intradevice and between sessions), interpreting that the nonexistence of these differences ($p > 0.05$) indicates that both sessions are equivalent, and therefore, the data can be used in a summative way in the determination of the validity of the *Vmaxpro*.

The level of agreement between the VJH data of the two matched devices was assessed using Bland–Altman plots, which allows for the determination of the systematic error and its limits of agreement for 95% (LoA = 1.96SD). The maximum allowable differences between devices were calculated from the coefficients of variation (CV) of each method according to the expression $(CV^2_{Vmaxpro} + CV^2_{\mathrm{MoCAP}})^{1/2}$ [41]. If the 95% confidence limits of the upper LoA are below the maximum allowable difference and the lower LoA is above the maximum allowable difference, the methods do not disagree [42]. At the same time, the presence of proportional error was identified if the Pearson product–moment correlation coefficient (r^2) of the differences was greater than 0.1 [43,44].

Statistical analysis was carried out using *MedCalc Statistical Software* version 20.100 (MedCalc Software Ltd., Ostend, Belgium).

3. Results

Validation of Vmaxpro

No statistically significant differences were found between sessions two and three in either instrument ($p = 0.684$ for *Vmaxpro* and $p = 0.549$ for MoCAP). Therefore, both sessions can be considered equivalent in terms of the total number of recorded jumps.

Table 2 shows the values of Spearman's correlation coefficient, Lin's concordance correlation coefficient, and Wilcoxon's test results for paired samples between the *Vmaxpro* and the MoCAP criterion instrument, showing a strong correlation value for Spearman´s correlation and CCC values, indicating weak concordance correlation. There are also statistically significant differences between the paired data for the heights of the two instruments ($p < 0.001$), with a mean difference between the two of 10.58 cm and an ES of large ($g = 2.4$) [45].

Table 2. Mean, mean difference, significant differences between means and Spearman correlations and Vmaxpro and MoCAP concordance.

	$H_{Vmaxpro}$ (cm)	H_{MoCAP} (cm)	Diff. (cm)	ES (g)	r_s	CCC
Mean	28.37	38.95	−10.58 *	2.39	0.844 *	0.219
95% CI	(27.78–28.63)	(38.39–39.49)	(−10.87–−10.30)	(2.17–2.62)	(0.810–0.878)	(0.186–0.252)

H = mean height; r_s = Spearman's correlation coefficient; CCC = Lin's concordance correlation coefficient; CI = confidence intervals; p = significant at 95%. * Statistically significant differences ($p < 0.001$), ES = Effect size bias corrected (Hedges).

The Passing and Bablok regression analysis (Figure 2) shows a fit equation expressed as $H_{\mathrm{MoCAP}} = 8.463 + 1.067\ H_{Vmaxpro}$ (cm). This equation describes the association between the two devices, showing the existence of a linear relationship between MoCAP and *Vmaxpro* that is very good since the slope is almost no different from unity. Therefore, both instruments behave similarly when they measure the same sample; in other words, the precision of *Vmaxpro* is similar to that of the reference system. However, the intercept is very large, which shows a systematic error, indicating that *Vmaxpro* underestimates VJH when compared to MoCAP. Spearman's correlation coefficient was calculated $r_s = 0.847$ ($p < 0.001$), implying a very strong correlation. Likewise, a SEE of 1.67 cm was obtained, indicating that the regression model can fit the data. Furthermore, the analysis of the residual plot reveals no appreciable trends and shows no significant difference with the linearity condition in the Cusum test ($p = 0.17$) [39].

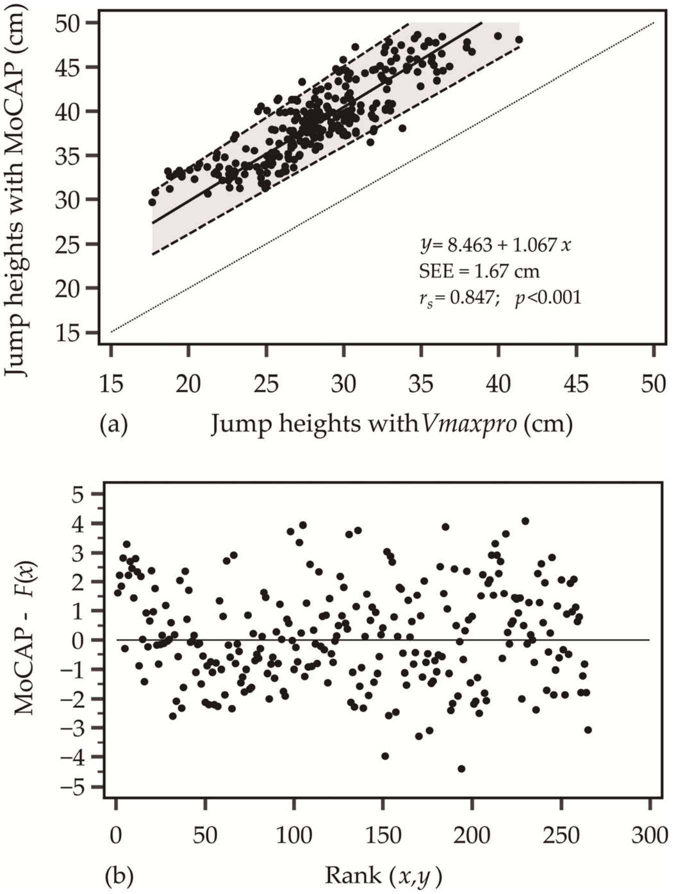

Figure 2. Correlation analysis between MoCAP system and *Vmaxpro* IMU through Passing and Bablok regression (**a**): the continuous line represents the regression line; the shaded area represents the confidence intervals for 95% of the regression line; the grey line is the $x = y$ line; r_s represents Spearman's correlation coefficient; SEE standard error of the estimate. (**b**) Residuals plot: No trend is shown, so linearity is assumed.

The Bland–Altman plots (Figure 3) show systematic error values of 10.6 cm (95% CI 10.29–10.86 cm), meaning that the *Vmaxpro* IMU provides estimations 10.6 cm less than the MoCAP reference system. Furthermore, the LoAs are 15.2 cm (95% CI 14.73–15.71 cm) for the upper limit and 5.96 cm (95% CI 5.47–6.45 cm) for the lower limit with 97.3% of the points falling within the LoA, so the agreement between devices is high given that the dispersion of differences is low. The fit line, *Difference* = 8.849 + 0.0518·*Mean*, refers to the existence of proportional bias in which a steep slope indicates the absence of heteroscedasticity of the error. In this case, a slightly increasing slope (0.0518) is found, but according to the bivariate Pearson product–moment correlation of $r^2 = 0.009$, the *Vmaxpro* does not add proportional error to the measure ($r^2 = <0.2$). The maximum allowable differences were determined as ±19.1 cm with both LoAs falling within this range, i.e., all the data included in the LoA are within the predefined limit of clinical agreement.

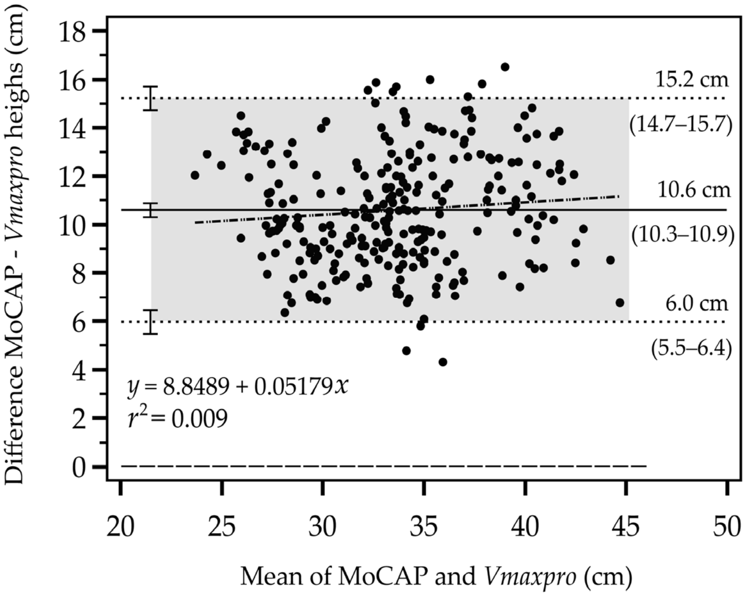

Figure 3. The solid black line indicates the mean of the differences (systematic error); dotted lines indicate the upper and lower LoA; dashed line represents the line of perfect agreement (null difference). The dotted and dashed line represents the regression line of the differences; shaded areas = area of the LoAs; CI of 95% indicated between parentheses.

4. Discussion

This study aimed to analyze the concurrent validity of the IMU Vmaxpro when compared to a criterion instrument based on a motion capture system for the estimation of VJH in the CMJ in high-level female volleyball athletes.

The main results show a positive linear dependence between both instruments, with correlations that can be interpreted as very high ($r_s = 0.847$), similar to those obtained in other studies. In this research, the accelerometer was placed between L4 and L5, in the same position as the reflective marker used by the MoCAP system to detect position, in order to be as close as possible to the hypothetical center of mass. Comparing our results with studies that used an equivalent arrangement on the body (IMU on the hip), Forza and Edmundson [11] obtained similar results for the correlation between IMU and MoCAP with very high Pearson correlation coefficients ($r = 0.89$). These values are slightly lower than those obtained by Grainger et al. [10], which found almost perfect correlations ($r > 0.90$). On the other hand, placing the accelerometer on the torso does not show very different correlations when compared to our study, with values of r ranging from 0.72 to 0.95 [18,19,46].

In the same way, very high correlations are obtained when comparing IMUs against FP. In general, the results obtained are closer to perfect correlation ($r = 1$) than those obtained against MoCAP, with values ranging from $r = 0.70$ to $r = 0.95$ [38,46–48]. Therefore, the correlation values are in line with other studies and can be considered acceptable in terms of validation. However, Pearson´s correlations or their nonparametric equivalent (Spearman), although often used in validation studies, are not the most appropriate tool to assess the dependence between two devices since they do not provide information about the nature of the correlation and do not distinguish between data pairings. In contrast, Lin's CCC does make this distinction, and for the relationship between *Vmaxpro* and MoCAP, values of $\rho_C = 0.22$ are obtained, indicating a low correlation. The precision value is $\rho = 0.861$ (very high), while the accuracy value is $C_b = 0.2611$ (low). Consequently, the factor inherent to precision is the most important factor in the low final value observed for CCC, indicating that the pairs are far from the perfect $x = y$ line, which raises suspicions of systematic error even though the precision seems high.

The Passing–Bablok regression plot (Figure 3) can help to better interpret this correlation. The intercept has a value of 8.463 cm, thus indicating that the systematic error is high, which confirms what was observed for CCC. However, the slope does not differ much from the value of 1 (1.067), indicating that the correlation is high, as discussed in the previous paragraph ($r_s = 0.847$). Furthermore, the results of the regression analysis led to an equation $H_{MoCAP} = 8.463 + 1.067\ H_{Vmaxpro}$, which allows for predicting the mean height values of MoCAP (considered as a gold standard) from the mean height values of *Vmaxpro*. Therefore, the observed high systematic error can be corrected, allowing for valid data by simply applying the fitting equation [2]. On the other hand, the random error can be quantified by the values of the standard error of the estimated (SEE), which, in this study, shows a value of 1.67 cm. The random error is quantified as moderate (standardized SEE of 0.36) [49], in agreement with the study by Brooks et al. [47] who compared the results of the *Vert* accelerometer when estimating the VJH in CMJ jumps with arm mobilization (Abalakov) and found standardized SEE values of 0.32 (moderate). On the other hand, if the IMU is placed on the forefoot, larger random errors are observed (2.70 cm) than those observed in our study [50]. Similarly, Montoro-Bombú et al. [51] found values with larger errors placing the IMU in the forefoot (SEE = 4.5 cm). Accordingly, the SEE values are also in agreement with those observed in other studies.

At the same time, in addition to the intercept and C_b, the existence of a high systematic bias can be confirmed through the study of the difference in the means and the analysis of the Bland–Altman plots. The simple observation of the mean of the differences is already an indicator of this error, which is further consolidated by the existence of statistically significant differences between the two methods of 10.54 cm and a moderate ES in the Wilcoxon paired sample test.

The systematic error detected in the Bland–Altman analysis (10.58 cm) shows similar numbers to those obtained in the mean difference and regression results (8.46 cm), implying that the *Vmaxpro* device performs measurements that underestimate the results by approximately 10 cm when compared to a MoCAP-based gold standard. This difference is three times greater than those found by Spangler et al. [18] in their analysis of the differences between a MoCAP system and the accelerometer *Catapult system* in real conditions, where they found differences for maximum jumps of −3.70 cm. Surprisingly, better results were obtained in this study in terms of validity even though the jumps were less controlled, as they were part of a fitness circuit, which suggests greater variability than in our study. In addition, the accelerometer was placed on the upper back, which indicates that the error would be greater. However, since this study was not carried out in a laboratory, this increase in variability should mainly affect the magnitude of the random error and, to a lesser extent, the systematic error. In any case, the difference between *Catapult* and MoCAP results is still significant in the same way as in our study.

Similar results were found by Grainger et al. [10] who observed systematically lower measurements (−8.89 cm) when studying the IMU *MMS* (Motus Design Group) and comparing it to a 3D MoCAP system. These authors placed the accelerometer between L4 and L5, close to the center of mass, which is similar to the experimental procedure used in our study where the IMU was placed above the hip and showed lower measurements in absolute terms. In contrast, Toft Nielsen et al. [52] found differences of 5.7 cm for the *MicroStrain* IMU (Inertia-Link–3DM-GX2) placed at the hip in the CMJ. In this case, unlike our study, the IMU tends to overestimate the measurement. Similarly, J. Lake et al. [37] found slight differences due to the overestimation of the *Push band 2.0* IMU when analyzing peak velocities. These results translate into an overestimation of the jump (0.32 cm) and, in addition, a proportional error. Such heteroscedasticity is not present in the case of *Vmaxpro*, as reflected in the scatter plot (Figure 2b), showing no clustering trend in the data. The latter is reinforced by the Cusum test for which no significant differences are seen with the linearity condition. On the other hand, the IMU position represents the position concerning a reference system and not the body center of mass position which depends on the postures adopted by the body [10,52], which may lead to measurement errors.

When comparing the systematic error found in this work with other studies that use force platforms as a criterion instrument, it is observed that the differences are smaller than those found for MoCAP systems and are even below one cm [47,48,50,53]. However, when analyzing the validity of *Push Band 2.0*, which represents an IMU with very similar characteristics to *Vmaxpro*, C. M. Watkins, Maunder, and Tillaar et al. [9] found systematic overestimation errors of 4.4 cm in the CMJ. These values, although lower in absolute value than those found for Vmaxpro, are closer to the latter but opposite in sign, as was the case when compared to a motion capture system. Similarly, Wee et al. [54] found even higher overestimation values for *Push Band 2.0* (14.4 cm). These data coincide with those obtained with other accelerometers where overestimation error is observed when compared to a force platform. These results agree with other studies that use *Push Band* [55,56] or other accelerometers [57]. For example, Rantalainen et al. [19], which places the IMU *Catapult System* on the torso, found differences of 9.4 cm using take-off velocity as a variable for height estimation. This error is larger than others found, although the authors indicated that the location of the IMU on the torso is a factor that can increase the systematic error. However, in this same study, the bias is reduced by half, 4.3 cm, when they used flight time as the calculation variable. Similarly, MacDonald et al. [58] found differences of 4.1 cm when comparing a MoCAP system versus the IMU *Vert* for maximum jumps in competition. Therefore, the reference instrument used may affect the magnitude of the systematic error found and affect the validity of its accuracy.

On the other hand, when analyzing the jump values obtained using flight time, double integration, and take-off speed versus MoCAP, it is appreciated that the greatest difference is found for the calculation of VJH from take-off velocity. Toft Nielsen et al. [52] found that while for double integration and flight time, the difference was around 1.3 cm, it was around 5.7 cm for the take-off velocity method, values closer to those obtained in this study. Consequently, the differences between the two instruments could be explained as a function of the calculation variables used to estimate the jump. In the case of *Vmaxpro*, VJH has been estimated from the take-off velocity, taken as the maximum speed recorded, which is not entirely true since the maximum speed was reached about 27 ms after take-off [37]. This delay implies a variation in take-off velocity detection of 0.162 m/s, which, translated to jumping, may imply increments of 1 cm to 4 cm [59,60]. Such increments may explain the overestimation of measurements when compared to force platforms but not in our case, as significantly lower values are obtained.

The sampling frequency may also influence the ability of the IMU to detect the precise instant of take-off [10] or, in the case of *Vmaxpro*, the exact moment at which the maximum velocity is reached. However, the 1000 Hz sampling rate advertised by the manufacturer seems sufficient to minimize the error, as it would imply a 0.2 cm error in the jump but fail to explain the nearly 10 cm error between the two instruments. Even so, the Bluetooth technology of the device transmits at a significantly lower frequency of 65 Hz, and depending on whether the data are transmitted continuously to the software or temporarily stored and then sent to the software in data packets, the error will be greater or lesser in magnitude. In addition, the ability of the device to detect the exact moment of take-off may also be affected by variability due to the way the device is positioned on the body segment. In this study, the IMU was attached above the hip using an elastic device supplied by the manufacturer, which in turn was anchored to a belt. This fixation system can generate vibrations in the instrument given its elastic characteristics and cause an error in the IMU measurement [11,61]. In this sense, fixing the accelerometer with adhesive tape on the same body segment (above the hip) showed lower absolute error values (4.0 cm), although the correlations were somewhat lower compared to a force platform (r = 0.74) [62].

Consequently, the criterion instrument against which the IMU is compared, the body segment on which the measuring instrument is placed, the resolution of the instrument, the attachment to the body segment, and the way height is estimated may affect the validity of the *Vmaxpro* IMU [18] when compared with a MoCAP system. As a result, these factors mainly affect the appearance of a systematic error that generates an underestimation of the measurement. However, the existence of a random error similar to that of other previously validated accelerometers and the existence of a correlation between both devices suggests that the IMU has acceptable levels of validity as long as the error due to underestimation of *Vmaxpro* is taken into account and comparisons are not made by exchanging data obtained by other systems.

The estimation error of an IMU used to measure jump height can impact the accuracy of athletic ability monitoring in a few ways. Firstly, if the error is too high, it can make it difficult to accurately evaluate absolute performance and compare it to benchmarks or standards. Secondly, even if the error is relatively low, it can still affect the accuracy of tracking trends and improvement over a long training period. This is because small errors can accumulate and potentially mask or exaggerate true trends in performance. Therefore, it is important to consider and minimize estimation errors in order to accurately monitor and analyze athletic abilities.

In any case, the characteristics of *Vmaxpro* make it possible to obtain data from large groups and a multitude of VJHs, such as Abalakov jumps, squat jumps, drop jumps, multiple jumps, loaded jumps, and a long variety of sports-specific jumps, with slight modifications in the configuration of the software used by *Vmaxpro*. This versatility contrasts with laboratory instruments, such as force platforms or systems based on photogrammetry, which require greater logistics and also imply a more laborious pre- and postintervention treatment or a high cost to perform analysis of equivalent magnitude.

Finally, to the authors' knowledge, this is the only study that addresses the validity of a sample composed only of high-level female athletes, and therefore the possible effect that the gender variable may have on biological variability has not been studied before as a possible source of error enhancement or attenuation that could affect the validity of the instrument. Therefore, more research is needed in the future comparing validity values for the same apparatus and protocol between sexes.

5. Conclusions

This study shows that the *Vmaxpro* IMU provides strong correlations and a random error rate comparable to other jump measurement devices already validated against a motion capture system. Therefore, the results suggest that *Vmaxpro* can be considered a valid device for the estimation of vertical jump in female volleyball players, being a cheaper alternative and of greater ecological value than motion capture.

Although the magnitude of the observed systematic error could lead to discouraging the use of *Vmaxpro* for the estimation of vertical jump, the main source of error is of a systematic nature. With the aim of the proposed adjustment, $H_{MoCAP} = 8.463 + 1.067\ H_{Vmaxpro}$, users can predict the jump height of the motion capture system from the *Vmaxpro* measures, and therefore, data from both devices can be used interchangeably.

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References

1. Eagles, A.N.; Sayers, M.G.L.; Bousson, M.; Lovell, D.I. Current Methodologies and Implications of Phase Identification of the Vertical Jump: A Systematic Review and Meta-Analysis. *Sport. Med.* **2015**, *45*, 1311–1323. https://doi.org/10.1007/S40279-015-0350-7/TABLES/3.
2. Pueo, B.; Lipinska, P.; Jiménez-Olmedo, J.M.; Zmijewski, P.; Hopkins, W.G. Accuracy of Jump-Mat Systems for Measuring Jump Height. *Int. J. Sports Physiol. Perform.* **2017**, *12*, 959–963. https://doi.org/10.1123/ijspp.2016-0511.
3. Soler-López, A.; García-de-Alcaraz, A.; Moreno-Villanueva, A.; Pino-Ortega, J. Concurrent Validity and Reliability of Devices to Measure Jump Height in Men’s Handball Players. *Sensors* **2022**, *22*, 9070. https://doi.org/10.3390/S22239070.
4. Condello, G.; Khemtong, C.; Lee, Y.-H.; Chen, C.-H.; Mandorino, M.; Santoro, E.; Liu, C.; Tessitore, A. Validity and Reliability of a Photoelectric Cells System for the Evaluation of Change of Direction and Lateral Jumping Abilities in Collegiate Basketball Athletes. *J. Funct. Morphol. Kinesiol.* **2020**, *5*, 55. https://doi.org/10.3390/jfmk5030055.
5. Ferro, A.; Floría, P.; Villacieros, J.; Muñoz-López, A. Maximum Velocity during Loaded Countermovement Jumps Obtained with an Accelerometer, Linear Encoder and Force Platform: A Comparison of Technologies. *J. Biomech.* **2019**, *95*, 109281. https://doi.org/10.1016/J.JBIOMECH.2019.07.025.
6. Balsalobre-Fernández, C.; Glaister, M.; Lockey, R.A. The Validity and Reliability of an IPhone App for Measuring Vertical Jump Performance. *J. Sports Sci.* **2015**, *33*, 1574–1579. https://doi.org/10.1080/02640414.2014.996184.
7. Montalvo, S.; Gonzalez, M.P.; Dietze-Hermosa, M.S.; Eggleston, J.D.; Dorgo, S. Common Vertical Jump and Reactive Strength Index Measuring Devices: A Validity and Reliability Analysis. *J. Strength Cond. Res.* **2021**, *35*, 1234–1243. https://doi.org/10.1519/JSC.0000000000003988.
8. Vieira, A.; Blazevich, A.J.; Souza, A.; Costa, D.A.; Tufano, J.J.; Bottaro, M. Validity and Test-Retest Reliability of the Jumpo App for Jump Performance Measurement. *Int. J. Exerc. Sci.* **2021**, *14*, 677.
9. Watkins, C.M.; Maunder, E.; Tillaar, R.V.D.; Oranchuk, D.J. Concurrent Validity and Reliability of Three Ultra-Portable Vertical Jump Assessment Technologies. *Sensors* **2020**, *20*, 7240. https://doi.org/10.3390/s20247240.
10. Grainger, M.; Weisberg, A.; Stergiou, P.; Katz, L. Comparison of Two Methods in the Estimation of Vertical Jump Height. *J. Hum. Sport Exerc.* **2019**, *15*, 623–632. https://doi.org/10.14198/jhse.2020.153.12.
11. Forza, J.; Edmundson, C.J. Comparison between Gyko Inertial Sensor and Chronojump Contact Mat for the Assessment of Squat Jump, Countermovement Jump and Abalakov Jump in Amateur Male Volleyball Players, Amateur Male Rugby Players and in High School Students. *J. Multidiscip. Eng. Sci. Technol.* **2019**, *6*, 9982–9988.
12. Mcmahon, J.J.; Lake, J.P.; Stratford, C.; Comfort, P. A Proposed Method for Evaluating Drop Jump Performance with One Force Platform. *Biomechanics* **2021**, *1*, 178–189. https://doi.org/10.3390/biomechanics1020015.
13. Wade, L.; Lichtwark, G.A.; Farris, D.J. Comparisons of Laboratory-Based Methods to Calculate Jump Height and Improvements to the Field-Based Flight-Time Method. *Scand. J. Med. Sci. Sports* **2020**, *30*, 31–37. https://doi.org/10.1111/sms.13556.
14. Pueo, B.; Jimenez-Olmedo, J.M.; Lipińska, P.; Buśko, K.; Penichet-Tomas, A. Concurrent Validity and Reliability of Proprietary and Open-Source Jump Mat Systems for the Assessment of Vertical Jumps in Sport Sciences. *Acta Bioeng. Biomech.* **2018**, *20*, 51–57. https://doi.org/10.5277/ABB-01132-2018-02.
15. Buckthorpe, M.; Morris, J.; Folland, J.P. Validity of Vertical Jump Measurement Devices. *J. Sports Sci.* **2012**, *30*, 63–69. https://doi.org/10.1080/02640414.2011.624539.
16. Vanrenterghem, J.; de Clercq, D.; van Cleven, P. Necessary Precautions in Measuring Correct Vertical Jumping Height by Means of Force Plate Measurements. *Ergonomics* **2001**, *44*, 814–818. https://doi.org/10.1080/00140130118100.
17. Hatze, H. Validity and Reliability of Methods for Testing Vertical Jumping Performance. *J. Appl. Biomech.* **1998**, *14*, 127–140. https://doi.org/10.1123/jab.14.2.127.
18. Spangler, R.; Rantalainen, T.; Gastin, P.B.; Wundersitz, D. Inertial Sensors Are a Valid Tool to Detect and Consistently Quantify Jumping. *Int. J. Sports Med.* **2018**, *39*, 802–808. https://doi.org/10.1055/S-0044-100793/ID/R6559-0025.
19. Rantalainen, T.; Gastin, P.B.; Spangler, R.; Wundersitz, D. Concurrent Validity and Reliability of Torso-Worn Inertial Measurement Unit for Jump Power and Height Estimation. *J. Sports Sci.* **2018**, *36*, 1937–1942. https://doi.org/10.1080/02640414.2018.1426974.
20. Held, S.; Rappelt, L.; Deutsch, J.-P.; Donath, L.; Jimenez-Olmedo, M. Valid and Reliable Barbell Velocity Estimation Using an Inertial Measurement Unit. *Int. J. Environ. Res. Public Health* **2021**, *18*, 9170. https://doi.org/10.3390/ijerph18179170.
21. Menrad, T.; Edelmann-Nusser, J. Validation of Velocity Measuring Devices in Velocity Based Strength Training. *Int. J. Comput. Sci. Sport* **2021**, *20*, 106–118. https://doi.org/10.2478ijcss-2021-0007.
22. Fritschi, R.; Seiler, J.; Gross, M. Validity and Effects of Placement of Velocity-Based Training Devices. *Sports* **2021**, *9*, 123. https://doi.org/10.3390/sports9090123.

23. Olovsson Stahl, E.; Öhrner, P. *Concurrent Validity of an Inertial Sensor for Measuring Muscle Mechanical Properties*; Umea Universitet: Umeå, Sweden, 2020.
24. Linnecke, T. How to Perform Jump Tests with Vmaxpro. Available online: https://vmaxpro.de/how-to-perform-jump-tests-with-vmaxpro/ (accessed on 19 September 2022).
25. McKay, A.K.A.; Stellingwerff, T.; Smith, E.S.; Martin, D.T.; Mujika, I.; Goosey-Tolfrey, V.L.; Sheppard, J.; Burke, L.M. Defining Training and Performance Caliber: A Participant Classification Framework. *Int. J. Sports Physiol. Perform.* **2022**, *17*, 317–331. https://doi.org/10.1123/IJSPP.2021-0451.
26. Gruber, M.; Peltonen, J.; Bartsch, J.; Barzyk, P. The Validity and Reliability of Counter Movement Jump Height Measured with the Polar Vantage V2 Sports Watch. *Front. Sports Act. Living* **2022**, *4*, 423. https://doi.org/10.3389/fspor.2022.1013360.
27. Hasan, S.S.; Robin, D.W.; Szurkus, D.C.; Ashmead, D.H.; Peterson, S.W.; Shiavi, R.G. Simultaneous Measurement of Body Center of Pressure and Center of Gravity during Upright Stance. Part I: Methods. *Gait Posture* **1996**, *4*, 1–10. https://doi.org/10.1016/0966-6362(95)01030-0.
28. García-Orea, G.P.; Juan, R.H.E.; Dalla-Vecchia, A.A.; Pérez-Caballero, C.; Campillos, J.A. Vertical Jump Performance Measurement Devices and Techniques: What Options Do We Have? *Int. J. Phys. Exerc. Health Sci.* **2017**, *1*.
29. Rantalainen, T.; Finni, T.; Walker, S. Jump Height from Inertial Recordings: A Tutorial for a Sports Scientist. *Scand. J. Med. Sci. Sports* **2020**, *30*, 38–45. https://doi.org/10.1111/sms.13546.
30. Read, M.M. *The Effects of Varied Rest Interval Lengths on Depth Jump Performance*; San Jose State University: San Jose, CA, USA, 1997; Volume 15.
31. Mandic, R.; Jakovljevic, S.; Jaric, S. Effects of Countermovement Depth on Kinematic and Kinetic Patterns of Maximum Vertical Jumps. *J. Electromyogr. Kinesiol.* **2015**, *25*, 265–272. https://doi.org/10.1016/J.JELEKIN.2014.11.001.
32. Pérez-Castilla, A.; Rojas, F.J.; Gómez-Martínez, F.; García-Ramos, A. Vertical Jump Performance Is Affected by the Velocity and Depth of the Countermovement. *Sports Biomech.* **2019**, *20*, 1015–1030. https://doi.org/10.1080/14763141.2019.1641545.
33. López, J.M.; López, J.L. Relevance of the Technique of Immobilizing Arms for the Kinetic Variables in the Countermovement Jump Test. *Cult. Cienc. Deporte* **2012**, *7*, 173–178. https://doi.org/10.12800/ccd.v7i21.82.
34. Lin, L.; Hedayat, A.S.; Sinha, B.; Yang, M. Statistical Methods in Assessing Agreement: Models, Issues, and Tools. *J. Am. Stat. Assoc.* **2002**, *97*, 257–270. https://doi.org/10.1198/016214502753479392.
35. McBride, G.B. A Proposal for Strength-of-Agreement Criteria for Lin's Concordance Correlation Coefficient. *NIWA Client Rep.* **2005**, *HAM2005*, 307–310.
36. Schober, P.; Boer, C.; Schwarte, L.A. Correlation Coefficients. *Anesth. Analg.* **2018**, *126*, 1763–1768. https://doi.org/10.1213/ANE.0000000000002864.
37. Lake, J.; Augustus, S.; Austin, K.; Mundy, P.; McMahon, J.; Comfort, P.; Haff, G. The Validity of the Push Band 2.0 during Vertical Jump Performance. *Sports* **2018**, *6*, 140. https://doi.org/10.3390/sports6040140.
38. Rago, V.; Brito, J.; Figueiredo, P.; Carvalho, T.; Fernandes, T.; Fonseca, P.; Rebelo, A. Countermovement Jump Analysis Using Different Portable Devices: Implications for Field Testing. *Sports* **2018**, *6*, 91. https://doi.org/10.3390/SPORTS6030091.
39. Passing, H.; Bablok, W. Comparison of Several Regression Procedures for Method Comparison Studies and Determination of Sample Sizes Application of Linear Regression Procedures for Method Comparison Studies in Clinical Chemistry, Part II. *J. Clin. Chem. Clin. Biochem.* **1984**, *22*, 431–445. https://doi.org/10.1515/CCLM.1984.22.6.431.
40. Hopkins, A.G.; Marshall, S.W.; Batterham, A.M.; Hanin, J. Progressive Statistics for Studies in Sports Medicine and Exercise Science. *Med. Sci. Sports Exerc.* **2009**, *41*, 3–12. https://doi.org/10.1249/MSS.0b013e31818cb278.
41. Petersen, P.H.; Fraser, C.G. Strategies to Set Global Analytical Quality Specifications in Laboratory Medicine: 10 Years on from the Stockholm Consensus Conference. *Accredit. Qual. Assur.* **2010**, *15*, 323–330. https://doi.org/10.1007/s00769-009-0630-8.
42. Stöckl, D.; Rodríguez Cabaleiro, D.; van Uytfanghe, K.; Thienpont, L.M. Interpreting Method Comparison Studies by Use of the Bland-Altman Plot: Reflecting the Importance of Sample Size by Incorporating Confidence Limits and Predefined Error Limits in the Graphic. *Clin. Chem.* **2004**, *50*, 2216–2218. https://doi.org/10.1373/CLINCHEM.2004.036095.
43. Atkinson, G.; Nevill, A.M. Statistical Methods for Assessing Measurement Error (Reliability) in Variables Relevant to Sports Medicine. *Sport. Med.* **1998**, *26*, 217–238. https://doi.org/10.2165/00007256-199826040-00002.
44. Bartlett, J.W.; Frost, C. Reliability, Repeatability and Reproducibility: Analysis of Measurement Errors in Continuous Variables. *Ultrasound Obstet. Gynecol.* **2008**, *31*, 466–475. https://doi.org/10.1002/uog.5256.
45. Rhea, M.R. Determining the Magnitude of Treatment Effects in Strength Training Research Through the Use of the Effect Size. *J. Strength Cond. Res.* **2004**, *18*, 918–920. https://doi.org/10.1519/00124278-200411000-00040.
46. Pino-Ortega, J.; García-Rubio, J.; Ibáñez, S.J. Validity and Reliability of the WIMU Inertial Device for the Assessment of the Vertical Jump. *PeerJ* **2018**, *6*, e4709. https://doi.org/10.7717/peerj.4709.
47. Brooks, E.R.; Benson, A.C.; Bruce, L.M. Novel Technologies Found to Be Valid and Reliable for the Measurement of Vertical Jump Height With Jump-and-Reach Testing. *J. Strength Cond. Res.* **2018**, *32*, 2838–2845. https://doi.org/10.1519/JSC.0000000000002790.
48. Schleitzer, S.; Wirtz, S.; Julian, R.; Eils, E. Development and Evaluation of an Inertial Measurement Unit (IMU) System for Jump Detection and Jump Height Estimation in Beach Volleyball. *Ger. J. Exerc. Sport Res.* **2022**, *52*, 228–236. https://doi.org/10.1007/s12662-022-00822-1.
49. Hopkins, W.G. Measures of Reliability in Sports Medicine and Science. *Sport. Med.* **2000**, *30*, 1–15. https://doi.org/10.2165/00007256-200030010-00001.

50. Garnacho-Castaño, M. v.; Faundez-Zanuy, M.; Serra-Payá, N.; Maté-Muñoz, J.L.; López-Xarbau, J.; Vila-Blanch, M. Reliability and Validity of the Polar V800 Sports Watch for Estimating Vertical Jump Height. *J. Sports Sci. Med* **2021**, *20*, 149–157. https://doi.org/10.52082/JSSM.2021.149.
51. Montoro-Bombú, R.; Field, A.; Santos, A.C.; Rama, L. Validity and Reliability of the Output Sport Device for Assessing Drop Jump Performance. *Front. Bioeng. Biotechnol.* **2022**, *10*, 1–9. https://doi.org/10.3389/fbioe.2022.1015526.
52. Toft Nielsen, E.; Jørgensen, P.B.; Mechlenburg, I.; Sørensen, H. Validation of an Inertial Measurement Unit to Determine Countermovement Jump Height. *Asia-Pac. J. Sport. Med. Arthrosc. Rehabil. Technol.* **2019**, *16*, 8–13. https://doi.org/10.1016/J.ASMART.2018.09.002.
53. Marković, S.; Dopsaj, M.; Tomažič, S.; Umek, A. Potential of IMU-Based Systems in Measuring Single Rapid Movement Variables in Females with Different Training Backgrounds and Specialization. *Appl. Bionics Biomech.* **2020**, *2020*, 7919514. https://doi.org/10.1155/2020/7919514.
54. Wee, J.F.; Lum, D.; Lee, M.; Roman, Q.; Ee, I.; Suppiah, H.T. Validity and Reliability of Portable Gym Devices and an IPhone App to Measure Vertical Jump Performance. *Sci. Perform. Sci. Rep.* **2018**, *1*, 1–5.
55. Orser, K.; Agar-Newman, D.J.; Tsai, M.-C.; Klimstra, M. The Validity of the Push Band 2.0 to Determine Speed and Power during Progressively Loaded Squat Jumps. *Sports Biomech.* **2020**, 1–9. https://doi.org/10.1080/14763141.2020.1829691.
56. Ripley, N.; Mcmahon, J.J. Validity and Reliability of the PUSH Wearable Device to Measure Velocity and Power During Loaded Countermovement Jumps. In Proceedings of the NSCA 2016 Congress, New Orleans, LA, USA, 22 June 2016; National Strength and Conditioning Association: Colorado Springs, CO, USA, 2016.
57. Clemente, F.; Badicu, G.; Hasan, U.C.; Akyildiz, Z.; Pino-Ortega, J.; Silva, R.; Rico-González, M. Validity and Reliability of Inertial Measurement Units for Jump Height Estimations: A Systematic Review. *Hum. Mov.* **2022**, *23*, 1–20. https://doi.org/10.5114/hm.2023.111548.
58. MacDonald, K.; Bahr, R.; Baltich, J.; Whittaker, J.L.; Meeuwisse, W.H. Validation of an Inertial Measurement Unit for the Measurement of Jump Count and Height. *Phys. Ther. Sport* **2017**, *25*, 15–19. https://doi.org/10.1016/J.PTSP.2016.12.001.
59. Lake, J.; Augustus, S.; Austin, K.; Comfort, P.; McMahon, J.; Mundy, P.; Haff, G.G. The Reliability and Validity of the Bar-Mounted PUSH Band ™ 2.0 during Bench Press with Moderate and Heavy Loads. *J. Sports Sci.* **2019**, *37*, 2685–2690. https://doi.org/10.1080/02640414.2019.1656703.
60. McMahon, J.J.; Suchomel, T.J.; Lake, J.P.; Comfort, P. Understanding the Key Phases of the Countermovement Jump Force-Time Curve. *Strength Cond. J.* **2018**, *40*, 96–106. https://doi.org/10.1519/SSC.0000000000000375.
61. Weenk, D.; Stevens, A.G.; Koning, B.H.; van Beijnum, B.J.; Hermens, H.J.; Veltink, P.H. A Feasibility Study in Measuring Soft Tissue Artifacts on the Upper Leg Using Inertial and Magnetic Sensors. In Proceedings of the 4th Dutch Bio-Medical Engineering Conference sensors; BME, Egmond aan Zee, The Netherlands, 24–25 January 2013; pp. 154–154.
62. Miranda-Oliveira, P.; Branco, M.; Fernandes, O. Accuracy of Inertial Measurement Units When Applied to the Countermovement Jump of Track and Field Athletes. *Sensors* **2022**, *22*, 7186. https://doi.org/10.3390/S22197186.