International Journal of Strength and Conditioning

Grob, D., Henriks, A., Fransen, J., & Kempe, M. (2025). None are Accurate but Some are Useful: A Comparison of Different Systems Used to Assess Jump Height in Volleyball. International Journal of Strength and Conditioning
https://doi.org/10.47206/ijsc.v5i1.359

None are Accurate but Some are Useful: A Comparison of Different Systems Used to Assess Jump Height in Volleyball

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ABSTRACT

Training load monitoring and performance testing are crucial components within high-performance sports. In volleyball, jump height both contributes to the training load and is an important performance measure to monitor. In practice, various different measurement systems, each with their own methods of estimation, are used. Therefore, the aim of this study is to compare the accuracy of different approaches in order to provide a "best practice" suggestion. To answer this research question, sixteen elite male volleyball players (16-18 years) completed several jumps for seven different (sport-specific) jump types. The jumps were measured with the following systems: three direct flight time (FT) based systems (force plate, high-speed camera, and Optojump), two wearable inertial measurement units (IMUs; Vert and Kinexon), two take-off velocity (TOV) based systems (force plate and high-speed camera), and two direct displacement systems (high speed camera and Yardstick). Validity was examined with the (standardized) typical error of the estimate and Bland Altman statistics with Optojump as the Benchmark system. The results show that FP FT, Kinexon, Vert and Yardstick can be use almost interchangeable showing trivial or small differences in sTEE (.10- 0.35). In contrast Video TOV, FP TOV and Video disp were less accurate with medium to large sTEE differences (0.66-1.31). In practice, care should be taken when different measurement systems are used alongside one another given different degrees of agreement between different measurement systems.

Keywords: Jumping, Validation, Wearables, Performance Testing, Load Monitoring

INTRODUCTION

In a high-performance sports environment, the sports science staff provides athletes and coaches with training load monitoring and performance testing. Both of these are considered relevant in the context of training design and injury prevention. To enable both aspects, measurement systems need to be accurate to draw reliable conclusions. For (external) load monitoring most team sports use global positioning systems (GPS) or local positioning systems (LPS), for which validity for sports like soccer has previously been shown[1]. However, a recent overview paper by Robertson[2] considered that these findings might not be easily transferable to other sports and that not all variables obtained treasured value. Based on this reasoning, this study will compare different measurement systems to quantify jump height, a commonly used parameter for performance testing and load monitoring in volleyball.

Metrics such as the velocity of movement, the distance covered and the extent to which the athlete engages in decelerations and accelerations undoubtedly contribute to the inference of external load in many sports. However, these might be less applicable to volleyball due to the relatively small playing field and the nature of the sport, especially when compared to football or hockey. However, volleyball players do engage in a large number of jumps[3]. Hence, jump count and jump height contribute to the external load experienced by volleyball players, as well as by other team sport athletes prone to jumping such as basketball, Australian Football and team handball players. Furthermore, the high frequency of jumps in these sports has been linked to the onset of jumper's knee[4].

Because volleyball players engage in a large number of jumps and jump height is a vital aspect of volleyball performance, jump height should be assessed periodically. There are four common ways to estimate jump height: using take-off velocity (TOV), flight time (FT), numerical double integration and directly measuring vertical displacement. Firstly, TOV and jump height are directly related through an equation of uniform acceleration (see Table 3, Equation 3). Ways to measure/estimate TOV are: with a force plate (FP) through the impulse-momentum theorem[5], or with an IMU[6], among other options. Secondly, FT is also directly related to jump height through an equation of uniform acceleration (see Table 3, Equation 1). This relation comes with the assumption that the posture at take-off is equal to the posture at landing, and doesn't hold true when an athlete lands with bent knees (therefore delaying the moment of landing). FT can be measured/estimated through for example a FP, Optojump (Microgate, Bolzano, Italy[7]), a jump mat[8], or an IMU[6]. Previous research has shown Vert to be a valid and practical IMU based system[7,9]. Kinexon (Kinexon GMBH, Munich, Germany) is another wearable sensor that combines LPS with an inertial measurement unit (IMU), therefore providing both tracking data and jump-related data. To the author's knowledge, no previous research has validated jump height estimations obtained from Kinexon. Thirdly, the vertical acceleration can be integrated twice to get the vertical displacement, where the maximal displacement is equal to the estimated jump height. Vertical acceleration can be measured with a FP[10] or an IMU[6]. Lastly, vertical displacement can be measured directly to estimate jump height. This can be done through a belt mat[10], a motion capture system[11] or a jump-and-reach protocol[9]. Currently, there is no consensus on gold standard. 3D motion capture is seen as gold standard in several studies[8,9,12], while others state that jump height measured with a force plate based on TOV or FT is the gold standard[6,7,10,13].

In conclusion, there are different methods that can be used to measure or estimate jump height. Furthermore, between these measures, there are differences in how jump height is estimated. Because each system has its own strengths and weaknesses when it comes to ease of use, freedom of movement and cost, they all circulate in practice. To be able to compare jump height estimations of different systems, it is useful to know how the different systems relate to one another. Therefore, the aim of this study is to compare the accuracy of different approaches and systems and make a "best practice" suggestion for sport practice. It is hypothesized that systems that share the same method for jump height estimations will be more closely related to one another than to systems that use a different method.

METHODS

To answer the research question, a sample of sixteen elite male volleyball players (mean [range] = 18 [16-20] years, mean height = 196.59 ± 9.44 m & mean weight = 86.92 ± 10.21 kg) who are part of the development program of the Dutch Volleyball Federation were recruited. The participants performed a procedure including seven different jump types (see Table 1) with five jumps per type (total: n = 35 jumps) over a period of three days. The jump types were considered relevant to volleyball jump testing and training after careful discussion with coaching staff.

All experiments were performed in accordance with the Declaration of Helsinki (Holm, 2013). Ethical approval was provided by the local Central ethics Review Board (CTc; Research Register number: 202000298).

Procedure

Before each set of jumps, the participants performed a self-selected warm-up procedure until they felt ready to perform the jumps without risk of injury. Following, the participants were asked to stand still in the same plane as where the jump would take place for five seconds (as indicated by the experimenter) for reference of the subsequent

Table 1. Description of the different jump types.

Jump type	Description
CMJ	The participant starts standing upright with their shoulders back and arms by their sides. From there, the participant moves into a squat position from where the participant jumps with arm swing (i.e., hands were free to move. All movements are fluidly made without a pause moment in any position (as opposed to a squat jump).
CMJ yardstick	Similar to CMJ with the addition of reaching for the yardstick with one outstretched arm.
Spike yardstick	Volleyball-specific jump with a three-step approach towards the net. Participant reaches for the yardstick with one outstretched arm.
Spike	Volleyball-specific jump with a three-step approach towards the net. The experimenter tosses a ball parallel to the net, which the participant spikes over the net into the opponent's field.
Serve	Volleyball-specific jump with a three-step approach from behind the baseline of the field. Participants toss up the ball themselves before hitting a top-spin jump serve.
Block step	Volleyball-specific jump performed at the net with the aim of blocking an opponent's spike. Preceded by one lateral step parallel to the net. There was no opposing attacker present during this test.
Block cross	Volleyball-specific jump performed at the net with the aim of blocking an opponent's spike. Preceded by a three-step approach parallel to the net including a crossover step. There was no opposing attacker present during this test.

Note. CMJ = Countermovement Jump

Table 2. Measurement devices used per jump type. An X denotes the measurement instrument or protocol was used for the associated jump type.

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
CMJ	X	X	X	X	X	X	X	X	
CMJ yardstick	X	X	X	X	X	X	X	X	X
Spike yardstick	X	X		X	X	X		X	X
Spike	X	X		X	X	X		X	
Serve	X	X		X	X	X		X	
Block step	X	X		X	X	X		X	
Block cross	X	X		X	X	X		X	

Note. disp = displacement

analysis of the high-speed camera videos. For all jump types, participants were asked to perform five jumps at a self-preferred height with a rest period of 10 to 15 seconds in between each jump trial (as indicated by the experimenter). All jumps were conducted across three days (A-C). Both countermovement jumps (CMJs) were performed on day A, both spike jumps and the serve jump on day B, and both block jumps on day C. The order was uniform for all participants.

Minimal sample size per jump type was set to 70 jumps. Han[15] did a systematic review on sample sizes used with different statistical methods. The median number of observations for Bland Altman Limits of Agreement (BA LOA) was 69. Furthermore, a sample size calculation for BA LOA based on Lu[16] indicated a minimum number of 17 jumps. For this sample size calculation, an expected mean difference, expected standard deviation of differences, and a maximum allowed difference between methods was needed. The expected mean and standard deviation were taken from an article that compared two flight time (FT) based jump heights[13]. The maximum allowed difference was set to 4 cm after consulting with the sport science staff.

Measurement devices

For all jump types, several different systems were incorporated. However, it was not possible to use all measurement systems with all jump types. Table 2 gives an overview of the used systems per jump type.

Kinexon

Kinexon (KINEXON Precision Technologies, Munich, Germany) is a local position measurement system consisting of sensors and antennas that are installed in the volleyball gym. The sensor is worn by the participants in a custom harness between the shoulder blades (see Figure 1) and includes an IMU (frequency: 20 Hz). FT is estimated using the

Figure 1. Participant wearing the Kinexon harness (with red semi sphere attached over the sensor) and Vert elastic band

data from the IMU and used to estimate the jump height (through Equation 1 from Table 3).

Vert

Vert (VERT Wearable Jump Monitor, USA) is a wearable IMU that is attached to the lower back using an elastic band (see Figure 1). It contains a tri-axial accelerometer and a tri-axial gyroscope, a proprietary algorithm is used to estimate jump height[12]. One of the variables that is used in the proprietary algorithm is FT. The exact algorithm used is not publicly available.

Optojump

All jumps were recorded using Optojump (Microgate, Bolzano, Italy). This system consists of a transmitting bar with light emitting diodes (LEDs), which are received by the opposing receiving bar. The participants stood between these bars blocking the light towards the receiving bar before the jump and when landing. When the participant is in the air, the light is not obstructed and thus received by the receiving bar. This way, the time of flight can be deduced and the jump height can be estimated using Equation 1 in Table 3. To allow for optimal movement execution the following setups for Optojump were chosen: widths and lengths: CMJ, 1m x 1m; block, 2m x 6m; spike and serve, 3m x 12m. For all CMJs, the Optojump bars were elevated to the level of the force plate (FP) to allow simultaneous measurement (similar to Glatthorn[13]).

High speed camera

A high-speed camera (Casio EXILIM High Speed EX-FH100, framerate = 240 Hz) on a tripod was used to record every jump. The camera was positioned so that it captured the plane in which the jump was performed. This means that both CMJs and both block jumps were captured from the back while the other jumps were captured from the side. All participants wore a plastic red semi sphere attached to the Kinexon sensor to track in further analysis (see Figure 1). The video files were used to calculate jump height based on FT, take-off velocity (TOV), and displacement

Force plate

A portable FP (ForceDecks, VALD Performance, Australia; frequency: 1000 Hz) was used to estimate the jump height in both CMJs. Two different methods were used: FT and TOV. For FT, the FP senses the moment of take-off and landing and estimates jump height using Equation 1 from Table 3. With the TOV method, body mass and impulse are measured with the FP, and TOV can be calculated with the impulse-momentum theorem5 (Table 3 Equation 2). Jump height is then derived from this TOV with Equation 3 from Table 3. All jumps were recorded with the VALD ForceDecks Jump software (version 2.0.8245) on a personal computer and sent to the VALD ForceDecks server (version 2.0.8245). The VALD ForceDecks Jump software performed all calculations automatically.

Table 3. Formulas used to determine jump height

Number	Formula	Variables
1	$Jump\ Height = \frac{g}{8}t^2$	g = 9.81 m/s^2; t = flight time
2	$v_{takeoff} = \frac{Ft}{m}$, where $Ft = impulse$	v = velocity; F = force; t = time; m = mass
3	$Jump\ height = \frac{{v_{takeoff}}^2}{2g}$	v = velocity; g = 9.81 m/s^2

Yardstick

A yardstick (Swift Performance, Australia) was used with a reach-and-jump protocol to measure jump height for CMJ and spike. The yardstick is a metal pole with supports that has swivel vanes the participants push away. First, the reach height of the participant is measured by standing underneath the yardstick and pushing away as many vanes as possible with one outstretched arm. The height of the lowest vane is known so the absolute reach height can be calculated. Second, the participant jumps and the absolute jump height is noted (height of lowest vane + number of displaced vanes). Jump height is estimated by subtracting the absolute jump height from the reach height.

Data processing

The raw video files were loaded into Kinovea (version 0.9.5, https://www.kinovea.org) for further analysis. The calibration in Kinovea was done using a known distance of three meters marked on the ground in the same plane as the jump. The 'Track path'-feature was used to track the location of the red semi sphere during every jump, and the five seconds of standing still before starting the jump sequence. Kinovea automatically filters the positional data using a forward and backwards pass with a second-order Butterworth filter (cutoff frequency is automatically picked based on minimizing the autocorrelation of residuals[17]). Using the 'Linear kinematics'-tool, both the vertical position and vertical velocity were exported to a custom Excel-spreadsheet. Jump height was estimated using three different methods: vertical displacement, TOV, and FT. First, jump height according to vertical displacement was estimated by subtracting the mean sensor height of the middle three seconds of standing still from the maximum sensor height. Second, jump height was estimated by finding the frame of take-off (first frame where neither foot touches the ground), and the corresponding vertical velocity. Jump height according to TOV was estimated using Equation 3 from Table 3. Finally, using Kinovea's 'Stopwatch'-feature, the time between take-off and landing (first frame where either foot touches the ground, framerate 240 Hz) was manually annotated and noted in the Excel-spreadsheet. Jump height was estimated using Equation 1 from Table 3.

To match all jumps from different measurement systems, a custom designed Python-script (Python version 3.10.6) was created that matched jumps based on the timestamps provided with each jump. Erroneous jump heights were filtered based on a deviation in z-score. For every jump, the z-score, specific to the measurement system and jump type of that specific jump, was calculated. This z-score was compared to the mean z-score for every jump type of that specific jump. When this difference was greater than two, the jump was filtered.

Statistical analysis

For the statistical analysis, BA statistics (mean difference and 95% limits of agreement (LOA)) were calculated as well as typical error of the estimate (TEE, including the correction equation/regression formula), and standardized TEE (sTEE). A custom Python-script was created to perform all calculations. Calculations for LOA and (s)TEE were based on Bland & Altman[18], and Hopkins[19]respectively. For the (s)TEE, 95% confidence intervals (CIs) were calculated. The magnitude of the sTEE was interpreted as <0.2 – trivial, 0.2-0.6 – small; >0.6-1.2 – moderate; >1.2-2.0 – large; >2.0 – very large[9]. sTEE values were used to examine the random error while the mean difference of the BA statistics were used for the systematic error. Descriptive statistics are described as mean ± standard deviation.

Results

In total, 485 jumps were performed by a total of 16 participants. The number of jumps included in the analysis can be found in Supplement A Table 1. For all video-based measurement systems, only 458 jumps were analysed. Fifteen jumps were not included because the setup of the camera was incorrect, ten jumps were not included because the camera wasn't recording at the time of measurement, and finally, two jumps were omitted from the dataset because the video files were corrupted (3,1%, 2,1%, and 0,4% of the 485 jumps respectively). For video displacement, one other jump was filtered due to erroneous measurement (0.2% of all 485 jumps). Only 467 jumps recorded by Vert were analysed. Ten jumps were not included because the Vert system was not recording, six jumps were filtered because of erroneous measurement, and two jumps were not identified although the Vert system was recording (2,1%, 1,2%, and 0,4% of the 485 jumps respectively). For Kinexon, 479 jumps were included. Four jumps were not identified although the Kinexon system was recording, and another two jumps were filtered due to erroneous measurement (0,8%, and 0,4% of the 485 jumps respectively). A more detailed version of this table, including number of jumps analysed for every jump type, can be found in Supplementary Table 2.

The mean jump height for all jump types and measurement systems was 53.13 cm with a standard deviation of 10.65 cm. The mean jump height and standard deviation for every jump type and measurement system can be found in Table 4. The sTEE between FP FT, video FT, and Optojump are considered trivial (0.10 and 0.13, respectively). Similarly, the mean differences between these three systems are very close to zero. For readability of the next sections, and because of the fact these three measures agree so well (and can be concluded to measure the same construct), Optojump will be used to compare to the other systems. Optojump is chosen over FP FT because FP FT is only available for two of the seven jump types (see Table 2).

The sTEE for every measurement system in relation to the “benchmark” Optojump can be found in Table 5. A more detailed version of this table including the sTEE for every jump type separately can be found in Supplement A Table 3. A table with the TEE for every jump type separately can be found in Supplement A Table 4.

BA statistics for every measurement system in relation to the “benchmark” Optojump can be found in Table 6. A more detailed table including all jump types separately can be found in Supplement A

Table 4. Descriptive statistics of jump heights for every jump type and measurement system in centimetres. Given as mean (standard deviation).

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick	All systems
CMJ	46.97 (6.83)	47.37 (7.26)	48.40 (6.87)	55.96 (7.27)	55.18 (8.06)	54.46 (8.82)	46.52 (6.75)	61.01 (6.85)		51.89 (8.90)
CMJ yardstick	43.51 (5.91)	43.79 (6.08)	45.12 (5.85)	53.14 (6.46)	53.36 (7.16)	48.54 (8.06)	46.23 (6.85)	57.94 (5.96)	50.43 (7.86)	49.05 (8.19)
Spike yardstick	58.39 (8.05)	60.45 (7.06)		68.44 (8.30)	67.16 (8.58)	56.28 (7.99)		69.92 (7.31)	63.24 (8.59)	63.42 (9.37)
Spike	54.11 (7.22)	55.81 (7.01)		62.57 (8.12)	60.79 (7.96)	49.26 (8.87)		63.56 (8.17)		57.72 (9.39)
Serve	47.67 (7.23)	48.95 (6.99)		56.32 (9.81)	55.59 (7.32)	38.28 (8.00)		55.93 (7.54)		50.48 (10.15)
Block step	38.89 (5.85)	39.56 (5.85)		48.60 (6.48)	46.87 (5.48)	41.47 (7.57)		54.45 (6.00)		44.97 (8.35)
Block cross	46.82 (6.22)	47.95 (6.50)		57.29 (7.55)	56.65 (6.79)	52.16 (8.40)		61.57 (6.20)		53.73 (8.75)
All jumps	48.43 (9.10)	49.42 (9.38)	46.76 (6.59)	57.75 (9.83)	56.90 (9.50)	48.68 (10.32)	46.38 (6.81)	60.78 (8.50)	57.06 (10.44)	48.43 (9.10)

Note. CMJ = Countermovement Jump; FT = Flight Time; TOV = Take-Off Velocity; FP = Force plate; disp = displacement
For the ‘All systems’-column, all jumps for a certain jump type were pooled before calculation mean and standard deviation.

Table 5. Standardized Typical Error of the Estimate (sTEE) for every measurement system in relation to the Optojump system with 95% Confidence Interval (CI). Given as sTEE (lower CI - higher CI).

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Optojump		0.10 (0.09-0.11)	0.13 (0.11-0.15)	0.29 (0.26-0.31)	0.28 (0.26-0.31)	1.31 (1.13-1.53)	0.75 (0.61-0.93	0.66 (0.59-0.74)	0.35 (0.29-0.41)

Note. FT = Flight Time; TOV = Take-Off Velocity; FP = Force plate; disp = displacement

Table 6. Bland Altman statistics for every measurement system in relation to the Optojump system in centimetres. Given as mean difference ± 1.96 × standard deviation of the difference. Mean - 1.96 × standard deviation of the difference corresponds to lower limit of agreement, while plus corresponds to the higher limit of agreement. A negative values indicates the row is smaller than the column.

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Optojump		-0.73 ± 1.88	-1.52 ± 1.63	-9.46 ± 5.40	-8.52 ± 5.06	0.02 ± 17.09	-1.14 ± 8.32	-12.10 ± 10.08	-5.85 ± 6.74

Note. FT = Flight Time; TOV = Take-Off Velocity; FP = Force plate; disp = displacement

Table 5. A table with all correction equations for every combination of measurement system and jump type can be found in Supplement A Table 6.

DISCUSSION

The aim of this study is to compare the accuracy of different approaches and systems and make a "best practice" suggestion for sport practice. Given that all video-based methods showed similar results and the Optojump system has demonstrated strong concurrent validity and excellent test-retest reliability for the estimation of vertical jump height in earlier research[13], it was used the benchmark system for further comparisons. Our results show that FP FT, Kinexon, Vert and Yardstick can be use almost interchangeable showing trivial or small differences in sTEE (0.10- 0.35). In contrast Video TOV, FP TOV and Video disp were less accurate with medium to large sTEE differences (0.66-1.31). It should be noted that only Vert and Kinexon can be used for training load monitoring and that all systems can theoretically be used for performance testing. The results for the individual systems will be discussed in more detail in the following section and practical recommendations for training load monitoring and performance testing are made in the practical relevance section.

Comparison video-based methods

As mentioned in the results sTEE between FP FT, video FT, and Optojump are considered trivial. Similarly, the mean differences between these three systems are very close to zero. These results show that the three different systems agree very well. This met expectations as all systems use the same method to estimate jump height (being FT), and measure this FT directly. Previous research compared jump height from FP FT and Optojump, and found a mean difference of 1.0 cm with the LOA at ± 0.9 cm[13]. This is close to the current findings of 1.52 ± 1.63 cm. For readability of the next sections, and because of the fact these three measures agree so well (and can be concluded to measure the same construct), only Optojump will be used to compare to the other systems. Optojump is chosen over FP FT because FP FT is only available for two of the seven jump types (see Table 2).

Comparison IMU-based systems

Both Vert and Kinexon show a sTEE with Optojump that is considered small (0.28 and 0.29 respectively). The mean differences suggest that both Vert and Kinexon overestimate jump height when compared to Optojump (8.52 and 9.46 cm respectively). The low mean difference of 1.03 cm between Vert and Kinexon suggests that there is no systematic difference between the two. A possible explanation for the difference between Vert and Kinexon is the different placement of the sensors (lower back for Vert and upper back for Kinexon) as earlier research showed larger differences in high-speed movements between shoulder and hip placement[20]. A second explanation could be the differences in the estimation algorithm used. Kinexon estimates the FT from the IMU data and bases the jump height solely on this, whereas Vert includes FT and more unknown variables to get the jump height estimation. Previous research has compared Vert and yardstick and found a sTEE of 0.40 and BA-statistics of 2.70 ± 10.97 cm[7]. This is similar to the current results between Vert and yardstick of 0.38 (sTEE) and 3.47 ± 7.50 cm (BA-statistics). This same research also compared Vert and FP TOV and found a sTEE of 0.32 and BA-statistics of 10.76 ± 8.06 cm. This is similar to the current BA-statistics (8.12 ± 8.63 cm), but not to the current sTEE of 0.69. A difference between the research of Brooks[7] and this study is that Brooks[7] log transformed the jump heights before calculating the sTEE. This was done to avoid bias that may result from nonuniformity of errors. The nonuniformity of errors in this study was checked by visual inspection of BA-plots and deemed adequate. When the current data was log transformed, no major changes incurred. There was no overall increase or decrease in sTEE, and most values changed with an amount of around 0.02 (with a maximum change of 0.05). This doesn't seem to explain the difference in sTEE between the research of Brooks[7] and the current study. Another possible explanation is the difference in instruction given to the participants. Brooks[7] instructed the participants to jump maximally, whereas the participants in the current study were simply asked to jump. The reason for not instructing to jump maximally was to not add to the already high jump load experienced by the current participants. This change in instruction could have led to different jumping techniques which, in turn, could have led to the difference in sTEE. This is supported by the research of MacDonald et al.[12], who found an increase in mean difference between Vert and a motion capture system when comparing maximal and submaximal jump (2.5 to 4.1 cm).

Yardstick method

The yardstick method yielded higher sTEE values than expected. There are some possible explanations for this bigger sTEE. The first is execution of the jump-and-reach protocol for yardstick. When the participant doesn't reach for the vanes maximally, an error creeps into the jump height estimation of the yardstick. This error is not present in the video displacement method since this tracks the red semi sphere between the shoulder blades. There are two reasons the participants might not have reached maximally. First, almost half of the jumps for yardstick were performed on a force plate. The task of having to land on the force plate may have led to the participants not reaching maximally. In other words, the constrained landing space, and the balance requirements may have altered the coordination pattern used to jump. This seems confirmed by the higher sTEE for CMJ yardstick compared to spike yardstick when comparing yardstick to Optojump (0.53 and 0.33 respectively). A second reason for not reaching maximally might be because the instruction was to jump, and not to jump maximally. Another source of error could be the result of the video displacement method. When tracking movement with a camera, the camera has to be placed orthogonal to the plane in which the participant is moving. Additionally, the participant has to move within the same plane as the plane used for calibration. Comparing the sTEE between video displacement and Optojump for spike and spike yardstick seems to confirm that these assumptions are at least partly violated. In the spike jump without yardstick, a ball is thrown by the experimenter which increases the chance of moving out of the plane. Therefore, you would expect a higher sTEE for spike with ball compared to spike with yardstick, which is confirmed by the data (sTEE of 1.10 and 0.68 respectively). A reason for differences between the displacement-based methods and the FT- and TOV-based systems, is that the FT- and TOV-based systems estimate the displacement of the COM. The video displacement method estimates the displacement of the semi sphere positioned over the Kinexon sensor on the upper back and yardstick estimates the displacement of the outstretched arm. Moreover, the results suggest that both displacement methods overestimate the jump height compared to the direct FT methods (mean difference of 12.10 and 8.85 cm for video displacement – Optojump and yardstick – Optojump respectively). This may have been caused by the vertical displacement during take-off (between the time the heel leaves the ground and when the toe leaves the ground). This vertical displacement is taken into account in the estimations based on displacement, while it is not for the FT methods.

Force-platform method

The sTEE between FP TOV and Optojump really highlights that the method used for estimating jump height has a significant influence. The sTEE of 0.77 is considered moderate but it is much higher than the sTEE observed between FP FT and Optojump (0.13). This difference comes from the assumption underpinning FT-based estimations. This assumption states that the posture at take-off is equal to the posture at landing, which is not necessarily always the case. Another source of error could be the body weight measured by the force plate. This body weight is needed to derive net force from force, which is used with the impulse-momentum theorem to estimate the TOV of the centre of mass[5]. Street[21] found that a change in body mass as small as 0.25% could change the estimated jump height by 6.5%.

Differences based on jump type

When comparing the results for differences between jump types, no systematic difference is observed, with two exceptions. First, the sTEE between CMJ and CMJ yardstick for Optojump and FP FT almost quadruples (from 0.05 to 0.19). This can be explained by the effect of the yardstick on the technique of the jump. When reaching for the yardstick the participants are less balanced than when performing a regular CMJ. Therefore, some participants may have landed just slightly out of the FP resulting in a bigger sTEE. Second, both measures that require the participant to remain in a certain plane (video displacement and video TOV), show an increase in sTEE for the jumps where this requirement is likely most violated (both jump types including a ball, spike and serve).

While this study has significant strengths such as including nine different measurement systems simultaneously and including sport specific jumps, this study's results should be viewed in light of some of this study's limitations. A possible limitation of this study is the number of samples for the specific jump types. Although the minimal sample size was determined beforehand with a sample size calculator and by comparing with other research, the data suggests that the sample size might be low for some comparisons. This can be seen, when looking at the sTEE between yardstick and video displacement. The combined sTEE is lower than the sTEEs for the specific jump types (0.51

compared to 0.70 and 0.75 for CMJ yardstick and spike yardstick respectively). This suggests that the sample size of the specific jump types was not high enough to overcome the effect of extreme values, while this was the case when the two jump types were pooled. Another possible weakness is that part of the statistical methods are really similar to each other. The amount added/subtracted to the systematic bias to create the BA LOAs is almost identical to the TEE multiplied by 1.96. The TEE is calculated by calculating the correction equation and taking the standard deviation of the difference from this line. The BA LOA are calculated by taking the standard deviation of the difference and multiplying this by 1.96 (to ensure that 95% of the data points falls within this range based on a normal distribution). This standard deviation of the difference is essentially the TEE with the constraint that the slope of the correction equation is 1. Both were included to ensure comparability with other research.

PRACTICAL RELEVANCE

This study has shown that the direct FT systems (FP FT, Optojump, video FT) can all be used interchangeably (TEE of around 0.9 cm and systematic difference of around 1 cm). If FP FT or Optojump is available and work within the constraints of the jump, these would be more practical than video FT, since manual selection of the moment of take-off and landing is required for video FT. Both video displacement and video TOV are not recommended since they require substantial manual labour (a point on the participant has to be tracked for every frame of the approach and subsequent jump), and because the results suggest that the systems don't agree with the other systems that well. This is most likely caused by the participant moving out of the plane captured with the high-speed camera. FP TOV is recommended to be used if there is reason to believe the assumption of equal posture at take-off and landing is violated. Care should be taken to ensure precise measurement of body weight as it has been shown to have a big impact on the jump height estimations[21]. FP TOV and FP FT can't be used interchangeably (TEE = 4.12 cm), although there is no systematic difference (mean difference = 0.38 cm), which is most likely caused by a difference in posture between take-off and landing. Future research should investigate how a change in posture (i.e. joint angles) influences the jump height estimations in FT-based systems (and perhaps TOV-based systems). Kinexon and Vert both overestimate jump height compared to the direct FT methods by around 8.5 cm. When this overestimation is accounted for (by the correction equation), the sTEEs are considered small and correspond to TEEs of around 2.5 cm. Because Vert and Kinexon can be worn during training and matches, both systems are useful for monitoring jump load in volleyball. Yardstick (or another jump-and-reach protocol) is also useful as it provides the maximum height of the outstretched arm as opposed to the displacement of the COM (that all FT- and TOV-based systems estimate). This maximum height is the maximum height at which athletes can spike the ball and is therefore extremely relevant in volleyball.

CONCLUSION

The aim of this study is to compare the accuracy of different approaches and systems and make a "best practice" suggestion. It was hypothesized that systems that use a similar method are more closely related to one another than systems with a different method. This is partly confirmed by the results of this study. The direct FT systems are very closely related to each other. Both wearable sensors, Vert and Kinexon, are closely related to each other as well as to the direct FT methods. Moreover, these IMU-based systems tend to overestimate the jump height compared to the direct FT methods. Both TOV-based and both displacement-based systems, on the other hand, are not more closely related to each other than to the other systems. From the results of this study can be concluded that care should be taken when different measurement systems are used alongside each other since different measurement systems agree with each other to a different degree.

ACKNOWLEDGEMENTS

The authors like to thank all athletes that participated in this study.

CONFLICTS OF INTEREST

The authors report no conflicts of interest.

FUNDING DETAILS

The authors received no funding for this research.

ETHICAL APPROVAL

All experiments were performed in accordance with the Declaration of Helsinki (Holm, 2013). Ethical approval was provided by the local Central ethics Review Board (CTc; Research Register number: 202000298).

DATES OF REFERENCE

Submission - 12/04/2024
Acceptance - 28/11/2024
Publication - 25/04/2025

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SUPPLEMENTARY MATERIALS

Table 1. Number of jumps analysed for every combination of measurement systems.

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Optojump	485	458	140	479	467	458	140	457	145
Video FT	458	458	130	452	440	458	130	457	135
FP FT	140	130	140	140	129	130	140	130	70
Kinexon	479	452	140	479	461	452	140	451	142
Vert	467	440	129	461	467	440	129	439	139
Video TOV	458	458	130	452	440	458	130	457	135
FP TOV	140	130	140	140	129	130	140	130	70
Video disp	457	457	130	451	439	457	130	457	135
Yardstick	145	135	70	142	139	135	70	135	145

Note. CMJ = Countermovement Jump; FT = Flight Time; TOV = Take-Off Velocity; FP = Force plate; disp = displacement

Table 2. Number of jumps analysed for every combination of measurement systems.

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Optojump	485	458	140	479	467	458	140	457	145
CMJ (70)	70	65[A]	70	70	65[B]	65[A]	70	65[A]	
CMJ yardstick (70)	70	65[C]	70	70	64[DE]	65[C]	70	65[C]	70
Spike yardstick (75)	75	70[F]		72[G]	75	70[F]		70[F]	75
Spike (75)	75	69[HI]		75	72[J]	69[HI]		69[HI]	
Serve (75)	75	69[KL]		73[M]	71[NO]	69[KL]		68[KLP]	
Block step (60)	60	60		60	60	60		60	
Block cross (60)	60	60		59[Q]	60	60		60	
Video FT	458	458	130	452	440	458	130	457	135
CMJ (70)	65[A]	65[A]	65[A]	65[A]	60[AB]	65[A]	65[A]	65[A]	
CMJ yardstick (70)	65[C]	65[C]	65[C]	65[C]	59[CDE]	65[C]	65[C]	65[C]	65[C]
Spike yardstick (75)	70[F]	70[F]		67[FG]	70[F]	70[F]		70[F]	70[F]
Spike (75)	69[HI]	69[HI]		69[HI]	66[HIJ]	69[HI]		69[HI]	
Serve (75)	69[KL]	69[KL]		67[KLM]	65[KLNO]	69[KL]		68[KLP]	
Block step (60)	60	60		60	60	60		60	
Block cross (60)	60	60		59[Q]	60	60		60	
FP FT	140	130	140	140	129	130	140	130	70
CMJ (70)	70	65[A]	70	70	65[B]	65[A]	70	65[A]	
CMJ Yardstick (70)	70	65[C]	70	70	64[DE]	65[C]	70	65[C]	70
Kinexon	479	452	140	479	461	452	140	451	142
CMJ (70)	70	65[A]	70	70	65[B]	65[A]	70	65[A]	
CMJ yardstick (70)	70	65[C]	70	70	64[DE]	65[C]	70	65[C]	70
Spike yardstick (75)	72[G]	67[FG]		72[G]	72[G]	67[FG]		67[FG]	72[G]
Spike (75)	75	69[HI]		75	72[J]	69[HI]		69[HI]	
Serve (75)	73[M]	67[KLM]		73[M]	69[MNO]	67[KLM]		66[KLMP]	
Block step (60)	60	60		60	60	60		60	
Block cross (60)	59[Q]	59[Q]		59[Q]	59[Q]	59[Q]		59[Q]	
Vert	467	440	129	461	467	440	129	439	139
CMJ (70)	65[B]	60[AB]	65[B]	65[B]	65[B]	60[AB]	65[B]	60[AB]	
CMJ yardstick (70)	64[DE]	59[CDE]	64[DE]	64[DE]	64[DE]	59[CDE]	64[DE]	59[CDE]	64[DE]
Spike yardstick (75)	75	70[F]		72[G]	75	70[F]		70[F]	75

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Spike (75)	72[J]	66[HIJ]		72[J]	72J	66[HIJ]		66[HIJ]	
Serve (75)	71[NO]	65[KLNO]		69[MNO]	71[NO]	65[KLNO]		64[KLNOP]	
Block step (60)	60	60		60	60	60		60	
Block cross (60)	60	60		59[Q]	60	60		60	
Video TOV	458	458	130	452	440	458	130	457	135
CMJ (70)	65[A]	65[A]	65[A]	65[A]	60[AB]	65[A]	65[A]	65[A]	
CMJ yardstick (70)	65[C]	65[C]	65[C]	65[C]	59[CDE]	65[C]	65[C]	65[C]	65[C]
Spike yardstick (75)	70[F]	70[F]		67[FG]	70[F]	70[F]		70[F]	70[F]
Spike (75)	69[HI]	69[HI]		69[HI]	66[HIJ]	69[HI]		69[HI]	
Serve (75)	69[KL]	69[KL]		67[KLM]	65[KLNO]	69[KL]		68[KLP]	
Block step (60)	60	60		60	60	60		60	
Block cross (60)	60	60		59[Q]	60	60		60	
FP TOV	140	130	140	140	129	130	140	130	70
CMJ (70)	70	65[A]	70	70	65[B]	65[A]	70	65[A]	
CMJ yardstick (70)	70	65[C]	70	70	64[DE]	65[C]	70	65[C]	70
Video disp	457	457	130	451	439	457	130	457	135
CMJ (70)	65[A]	65[A]	65[A]	65[A]	60[AB]	65[A]	65[A]	65[A]	
CMJ yardstick (70)	65[C]	65[C]	65[C]	65[C]	59[CDE]	65[C]	65[C]	65[C]	65[C]
Spike yardstick (75)	70[F]	70[F]		67[FG]	70[F]	70[F]		70[F]	70[F]
Spike (75)	69[HI]	69[HI]		69[HI]	66[HIJ]	69[HI]		69[HI]	
Serve (75)	68[KLP]	68[KLP]		66[KLMP]	64[KLNOP]	68[KLP]		68[KLP]	
Block step (60)	60	60		60	60	60		60	
Block cross (60)	60	60		59Q	60	60		60	
Yardstick	145	135	70	142	139	135	70	135	145
CMJ yardstick (70)	70	65	70	70	64	65	70	65	70
Spike yardstick (75)	75	70		72	75	70		70	75

Note. CMJ = Countermovement Jump; FT = Flight Time; TOV = Take-Off Velocity; FP = Force plate; disp = displacement

[A] : 5 jumps, video not recording; [B] : 5 jumps, Vert not recording; [C] : 5 jumps, video not recording; [D] : 5 jumps, Vert not recording; [E] : 1 jump, Vert did not record jump; [F] : 5 jumps, video setup not correct; [G] : 3 jumps, Kinexon did not record jumps; [H] : 5 jumps, video setup not correct; [I] : 1 jump, video file corrupted; [J] : 3 jumps, Vert jumps filtered; [K] : 5 jumps, video setup not correct; [L] : 1 jump, video file corrupted; [M] : 2 jumps, Kinexon jumps filtered; [N] : 3 jumps, Vert jumps filtered; [O] : 1 jump, Vert did not record jump, [P] : 1 jump, Displacement jump filtered; [Q] : 1 jump, Kinexon did not record jump.

Table 3. Standardized Typical Error of the Estimate (sTEE) for every jump type and measurement system (95% CI in brackets).

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Optojump		0.10 (0.09-0.11)	0.13 (0.11-0.15)	0.29 (0.26-0.31)	0.28 (0.26-0.31)	1.31 (1.13-1.53)	0.75 (0.61-0.93)	0.66 (0.59-0.74)	0.35 (0.29-0.41)
CMJ		0.07 (0.06-0.09)	0.05 (0.04-0.06)	0.35 (0.27-0.45)	0.29 (0.23-0.38)	0.90 (0.66-1.30)	0.77 (0.58-1.07)	0.50 (0.38-0.67)	
CMJ yardstick		0.08 (0.06-0.10)	0.19 (0.15-0.25)	0.34 (0.26-0.43)	0.39 (0.30-0.51)	0.95 (0.69-1.38)	0.58 (0.44-0.77)	0.45 (0.34-0.59)	0.53 (0.40-0.70)
Spike yardstick		0.16 (0.12-0.20)		0.32 (0.25-0.41)	0.25 (0.19-0.31)	1.02 (0.74-1.49)		0.68 (0.52-0.93)	0.33 (0.26-0.42)
Spike		0.13 (0.10-0.16)		0.36 (0.28-0.46)	0.45 (0.35-0.59)	1.37 (0.95-2.22)		1.10 (0.79-1.65)	
Serve		0.21 (0.16-0.26)		0.37 (0.29-0.47)	0.30 (0.24-0.39)	1.63 (1.09-2.90)		1.01 (0.73-1.48)	
Block step		0.10 (0.08-0.13)		0.30 (0.23-0.39)	0.26 (0.20-0.34)	0.61 (0.46-0.84)		0.44 (0.33-0.59)	

	Opto-jump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Block cross		0.11 (0.08-0.14)		0.27 (0.20-0.35)	0.32 (0.24-0.42)	0.97 (0.69-1.46)		0.42 (0.32-0.56)	
Video FT	0.10 (0.09-0.11)		0.14 (0.12-0.17)	0.30 (0.28-0.33)	0.29 (0.27-0.33)	1.28 (1.11-1.50)	0.77 (0.62-0.96)	0.66 (0.59-0.74)	0.36 (0.30-0.43)
CMJ	0.07 (0.06-0.09)		0.09 (0.07-0.11)	0.34 (0.26-0.44)	0.30 (0.23-0.40)	0.91 (0.66-1.32)	0.79 (0.58-1.11)	0.52 (0.40-0.70)	
CMJ yardstick	0.08 (0.06-0.10)		0.20 (0.16-0.26)	0.35 (0.27-0.45)	0.38 (0.29-0.51)	0.97 (0.70-1.42)	0.59 (0.45-0.80)	0.45 (0.35-0.60)	0.53 (0.40-0.71)
Spike yardstick	0.16 (0.12-0.20)			0.39 (0.30-0.52)	0.33 (0.26-0.43)	0.9 (0.72-1.42)		0.72 (0.54-0.98)	0.41 (0.32-0.53)
Spike	0.13 (0.10-0.16)			0.41 (0.32-0.54)	0.49 (0.38-0.66)	1.30 (0.91-2.07)		1.16 (0.83-1.77)	
Serve	0.21 (0.16-0.26)			0.47 (0.36-0.63)	0.40 (0.31-0.53)	1.40 (0.97-2.30)		0.93 (0.68-1.33)	
Block step	0.10 (0.08-0.13)			0.28 (0.22-0.37)	0.27 (0.21-0.36)	0.61 (0.46-0.84)		0.44 (0.33-0.58)	
Block cross	0.11 (0.08-0.14)			0.26 (0.20-0.34)	0.32 (0.25-0.43)	1.00 (0.71-1.50)		0.41 (0.31-0.55)	
FP FT	0.13 (0.11-0.15)	0.14 (0.12-0.17)		0.34 (0.29-0.41)	0.40 (0.33-0.48)	0.94 (0.75-1.21)	0.75 (0.61-0.94)	0.49 (0.41-0.60)	0.54 (0.41-0.72)
CMJ	0.05 (0.04-0.06)	0.09 (0.07-0.11)		0.34 (0.26-0.44)	0.31 (0.24-0.40)	0.93 (0.68-1.36)	0.78 (0.58-1.07)	0.49 (0.37-0.65)	
CMJ yardstick	0.19 (0.15-0.25)	0.20 (0.16-0.26)		0.36 (0.28-0.46)	0.47 (0.36-0.63)	1.08 (0.77-1.64)	0.59 (0.45-0.79)	0.53 (0.40-0.71)	0.54 (0.41-0.72)
Kinexon	0.29 (0.26-0.31)	0.30 (0.28-0.33)	0.34 (0.29-0.41)		0.35 (0.31-0.38)	1.46 (1.25-1.74)	0.82 (0.67-1.04)	0.73 (0.65-0.82)	0.41 (0.35-0.50)
CMJ	0.35 (0.27-0.45)	0.34 (0.26-0.44)	0.34 (0.26-0.44)		0.38 (0.29-0.50)	1.14 (0.81-1.75)	0.87 (0.64-1.22)	0.71 (0.53-0.98)	
CMJ yardstick	0.34 (0.26-0.43)	0.35 (0.27-0.45)	0.36 (0.28-0.46)		0.47 (0.35-0.62)	1.35 (0.93-2.22)	0.70 (0.53-0.96)	0.59 (0.45-0.81)	0.66 (0.50-0.89)
Spike yardstick	0.32 (0.25-0.41)	0.39 (0.30-0.52)			0.33 (0.26-0.42)	1.27 (0.89-2.02)		0.84 (0.62-1.19)	0.41 (0.32-0.53)
Spike	0.36 (0.28-0.46)	0.41 (0.32-0.54)			0.51 (0.39-0.67)	1.74 (1.15-3.23)		1.17 (0.83-1.78)	
Serve	0.37 (0.29-0.47)	0.47 (0.36-0.63)			0.46 (0.36-0.61)	2.12 (1.32-4.70)		1.31 (0.91-2.12)	
Block step	0.30 (0.23-0.39)	0.28 (0.22-0.37)			0.30 (0.23-0.40)	0.76 (0.56-1.08)		0.53 (0.40-0.72)	
Block cross	0.27 (0.20-0.35)	0.26 (0.20-0.34)			0.33 (0.25-0.44)	1.27 (0.87-2.09)		0.48 (0.36-0.64)	
Vert	0.28 (0.26-0.31)	0.29 (0.27-0.33)	0.40 (0.33-0.48)	0.35 (0.31-0.38)		1.24 (1.07-1.45)	0.69 (0.57-0.87)	0.65 (0.58-0.73)	0.38 (0.32-0.46)
CMJ	0.29 (0.23-0.38)	0.30 (0.23-0.40)	0.31 (0.24-0.40)	0.38 (0.29-0.50)		0.76 (0.56-1.09)	0.80 (0.59-1.13)	0.55 (0.41-0.75)	
CMJ yardstick	0.39 (0.30-0.51)	0.38 (0.29-0.51)	0.47 (0.36-0.63)	0.47 (0.35-0.62)		1.04 (0.74-1.60)	0.55 (0.42-0.75)	0.50 (0.38-0.68)	0.63 (0.47-0.86)
Spike yardstick	0.25 (0.19-0.31)	0.33 (0.26-0.43)		0.33 (0.26-0.42)		0.98 (0.72-1.41)		0.63 (0.48-0.85)	0.40 (0.31-0.51)
Spike	0.45 (0.35-0.59)	0.49 (0.38-0.66)		0.51 (0.39-0.67)		1.81 (1.17-3.51)		1.16 (0.82-1.80)	
Serve	0.30 (0.24-0.39)	0.40 (0.31-0.53)		0.46 (0.36-0.61)		1.92 (1.22-3.95)		1.15 (0.81-1.79)	
Block step	0.26 (0.20-0.34)	0.27 (0.21-0.36)		0.30 (0.23-0.40)		0.71 (0.52-0.99)		0.53 (0.40-0.72)	
Block cross	0.32 (0.24-0.42)	0.32 (0.25-0.43)		0.33 (0.25-0.44)		1.22 (0.84-1.97)		0.54 (0.40-0.73)	
Video TOV	1.31 (1.13-1.53)	1.28 (1.11-1.50)	0.94 (0.75-1.21)	1.46 (1.25-1.74)	1.24 (1.07-1.45)		1.28 (0.99-1.75)	0.99 (0.87-1.13)	1.05 (0.83-1.37)
CMJ	0.90 (0.66-1.30)	0.91 (0.66-1.32)	0.93 (0.68-1.36)	1.14 (0.81-1.75)	0.76 (0.56-1.09)		1.26 (0.88-2.01)	1.03 (0.74-1.54)	

	Opto-jump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
CMJ yardstick	0.95 (0.69-1.38)	0.97 (0.70-1.42)	1.08 (0.77-1.64)	1.35 (0.93-2.22)	1.04 (0.74-1.60)		1.10 (0.78-1.67)	0.97 (0.70-1.42)	1.36 (0.93-2.24)
Spike yardstick	1.02 (0.74-1.49)	0.98 (0.72-1.42)		1.27 (0.89-2.02)	0.98 (0.72-1.41)			0.99 (0.72-1.43)	1.32 (0.93-2.11)
Spike	1.37 (0.95-2.22)	1.30 (0.91-2.07)		1.74 (1.15-3.23)	1.81 (1.17-3.51)			1.98 (1.26-4.04)	
Serve	1.63 (1.09-2.90)	1.40 (0.97-2.30)		2.12 (1.32-4.70)	1.92 (1.22-3.95)			1.07 (0.77-1.60)	
Block step	0.61 (0.46-0.84)	0.61 (0.46-0.84)		0.76 (0.56-1.08)	0.71 (0.52-0.99)			0.88 (0.63-1.28)	
FP TOV	0.75 (0.61-0.93)	0.77 (0.62-0.96)	0.75 (0.61-0.94)	0.82 (0.67-1.04)	0.69 (0.57-0.87)	1.28 (0.99-1.75)		0.82 0.66-1.04)	0.68 (0.51-0.92)
CMJ	0.77 (0.58-1.07)	0.79 (0.58-1.11)	0.78 (0.58-1.07)	0.87 (0.64-1.22)	0.80 (0.59-1.13)	1.26 (0.88-2.01)		0.82 (0.60-1.16)	
CMJ yardstick	0.58 (0.44-0.77)	0.59 (0.45-0.80)	0.59 (0.45-0.79)	0.70 (0.53-0.96)	0.55 (0.42-0.75)	1.10 (0.78-1.67)		0.71 (0.53-0.98)	0.68 (0.51-0.92)
Video disp	0.66 (0.59-0.74)	0.66 (0.59-0.74)	0.49 (0.41-0.60)	0.73 (0.65-0.82)	0.65 (0.58-0.73)	0.99 (0.87-1.13)	0.82 (0.66-1.04)		0.51 (0.42-0.62)
CMJ	0.50 (0.38-0.67)	0.52 (0.40-0.70)	0.49 (0.37-0.65)	0.71 (0.53-0.98)	0.55 (0.41-0.75)	1.03 (0.74-1.54)	0.82 (0.60-1.16)		
CMJ yardstick	0.45 (0.34-0.59)	0.45 (0.35-0.60)	0.53 (0.40-0.71)	0.59 (0.45-0.81)	0.50 (0.38-0.68)	0.97 (0.70-1.42)	0.71 (0.53-0.98)		0.70 (0.52-0.97)
Spike yardstick	0.68 (0.52-0.93)	0.72 (0.54-0.98)		0.84 (0.62-1.19)	0.63 (0.48-0.85)	0.99 (0.72-1.43)			0.75 (0.56-1.03)
Spike	1.10 (0.79-1.65)	1.16 (0.83-1.77)		1.17 (0.83-1.78)	1.16 (0.82-1.80)	1.98 (1.26-4.04)			
Serve	1.01 (0.73-1.48)	0.93 (0.68-1.33)		1.31 (0.91-2.12)	1.15 (0.81-1.79)	1.07 (0.77-1.60)			
Block step	0.44 (0.33-0.59)	0.44 (0.33-0.58)		0.53 (0.40-0.72)	0.53 (0.40-0.72)	0.88 (0.63-1.28)			
Block cross	0.42 (0.32-0.56)	0.41 (0.31-0.55)		0.48 (0.36-0.64)	0.54 (0.40-0.73)	1.09 (0.77-1.70)			
Yardstick	0.35 (0.29-0.41)	0.36 (0.30-0.43)	0.54 (0.41-0.72)	0.41 (0.35-0.50)	0.38 (0.32-0.46)	1.05 (0.83-1.37)	0.68 (0.51-0.92)	0.51 (0.42-0.62)	
CMJ Yardstick	0.53 (0.40-0.70)	0.53 (0.40-0.71)	0.54 (0.41-0.72)	0.66 (0.50-0.89)	0.63 (0.47-0.86)	1.36 (0.93-2.24)	0.68 (0.51-0.92)	0.70 (0.52-0.97)	
Spike Yardstick	0.33 (0.26-0.42)	0.41 (0.32-0.53)		0.41 (0.32-0.53)	0.40 (0.31-0.51)	1.32 (0.93-2.11)		0.75 (0.56-1.03)	

Note. CMJ = Countermovement Jump; FT = Flight Time; TOV = Take-Off Velocity; FP = Force plate; disp = displacement

Table 4. Typical Error of the Estimate (TEE) for every jump type and measurement system in centimetres (95% CI in brackets), where the column is the criterion measure and the row the practical measure.

	Opto-jump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Optojump		0.96 (0.90-1.03)	0.83 (0.74-0.94)	2.71 (2.55-2.89)	2.59 (2.43-2.77)	8.22 (7.72-8.79)	4.11 (3.68-4.66)	4.69 (4.40-5.02)	3.44 (3.08-3.89)
CMJ		0.54 (0.46-0.65)	0.33 (0.28-0.40)	2.43 (2.08-2.92)	2.31 (1.97-2.80)	6.00 (5.11-7.27)	4.18 (3.58-5.02)	3.12 (2.66-3.78)	
CMJ yardstick		0.49 (0.42-0.59)	1.12 (0.96-1.35)	2.09 (1.79-2.51)	2.64 (2.25-3.20)	5.63 (4.80-6.82)	3.49 (2.99-4.19)	2.48 (2.11-3.00)	3.71 (3.18-4.46)
Spike yardstick		1.11 (0.95-1.33)		2.58 (2.21-3.09)	2.07 (1.78-2.47)	5.80 (4.97-6.97)		4.18 (3.58-5.02)	2.73 (2.35-3.26)
Spike		0.89 (0.76-1.07)		2.79 (2.40-3.33)	3.32 (2.85-3.98)	7.27 (6.22-8.75)		6.14 (5.25-7.39)	
Serve		1.43 (1.22-1.72)		3.41 (2.93-4.08)	2.17 (1.86-2.60)	6.92 (5.92-8.33)		5.44 (4.65-6.56)	
Block step		0.60 (0.51-0.73)		1.88 (1.59-2.30)	1.41 (1.19-1.72)	4.01 (3.39-4.90)		2.46 (2.08-3.01)	
Block cross		0.71 (0.60-0.87)		1.98 (1.67-2.42)	2.10 (1.78-2.57)	5.96 (5.05-7.28)		2.44 (2.07-2.98)	

	Opto-jump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Video FT	0.94 (0.88-1.01)		0.96 (0.86-1.09)	2.90 (2.72-3.10)	2.73 (2.56-2.92)	8.15 (7.65-8.72)	4.32 (3.85-4.92)	4.68 (4.39-5.01)	3.60 (3.21-4.09)
CMJ	0.53 (0.45-0.64)		0.63 (0.54-0.76)	2.45 (2.09-2.97)	2.47 (2.09-3.02)	6.03 (5.14-7.30)	4.40 (3.75-5.33)	3.23 (2.75-3.91)	
CMJ yardstick	0.49 (0.42-0.59)		1.22 (1.04-1.48)	2.22 (1.89-2.69)	2.65 (2.24-3.24)	5.69 (4.85-6.89)	3.66 (3.12-4.43)	2.50 (2.13-3.03)	3.82 (3.25-4.63)
Spike yardstick	1.16 (0.99-1.39)			2.89 (2.47-3.49)	2.50 (2.14-3.00)	5.68 (4.87-6.83)		4.33 (3.71-5.20)	2.92 (2.50-3.51)
Spike	0.90 (0.77-1.08)			3.18 (2.72-3.83)	3.49 (2.98-4.22)	7.14 (6.11-8.59)		6.28 (5.37-7.56)	
Serve	1.36 (1.16-1.64)			4.05 (3.46-4.89)	2.62 (2.23-3.17)	6.61 (5.66-7.95)		5.20 (4.44-6.27)	
Block step	0.60 (0.51-0.73)			1.78 (1.51-2.18)	1.47 (1.24-1.80)	4.01 (3.39-4.90)		2.44 (2.07-2.98)	
Block cross	0.68 (0.58-0.83)			1.94 (1.64-2.38)	2.13 (1.80-2.60)	6.03 (5.10-7.37)		2.39 (2.02-2.92)	
FP FT	0.84 (0.75-0.95)	0.98 (0.87-1.12)		2.28 (2.04-2.58)	2.86 (2.55-3.26)	6.17 (5.50-7.03)	4.12 (3.69-4.67)	2.93 (2.61-3.34)	3.79 (3.25-4.55)
CMJ	0.33 (0.28-0.40)	0.64 (0.55-0.78)		2.37 (2.03-2.85)	2.39 (2.04-2.89)	6.10 (5.20-7.39)	4.20 (3.60-5.05)	3.06 (2.61-3.71)	
CMJ yardstick	1.13 (0.97-1.36)	1.22 (1.04-1.48)		2.19 (1.88-2.63)	3.10 (2.64-3.76)	6.01 (5.12-7.28)	3.54 (3.03-4.25)	2.84 (2.42-3.44)	3.79 (3.25-4.55)
Kinexon	2.46 (2.31-2.63)	2.68 (2.52-2.87)	2.14 (1.91-2.43)		3.05 (2.86-3.26)	8.42 (7.90-9.01)	4.36 (3.90-4.94)	4.95 (4.65-5.30)	3.91 (3.50-4.43)
CMJ	2.28 (1.95-2.74)	2.36 (2.01-2.86)	2.24 (1.92-2.69)		2.92 (2.49-3.54)	6.73 (5.73-8.15)	4.49 (3.85-5.40)	4.03 (3.43-4.88)	
CMJ yardstick	1.91 (1.64-2.30)	2.02 (1.72-2.45)	1.99 (1.70-2.39)		3.07 (2.61-3.72)	6.58 (5.60-7.97)	4.00 (3.43-4.81)	3.09 (2.63-3.74)	4.38 (3.75-5.26)
Spike yardstick	2.37 (2.03-2.84)	2.45 (2.09-2.96)			2.56 (2.20-3.07)	6.24 (5.33-7.53)		4.65 (3.97-5.61)	3.20 (2.75-3.83)
Spike	2.48 (2.13-2.96)	2.72 (2.33-3.27)			3.68 (3.16-4.41)	7.81 (6.68-9.40)		6.29 (5.38-7.57)	
Serve	2.55 (2.19-3.05)	3.09 (2.64-3.73)			3.13 (2.68-3.77)	7.27 (6.21-8.78)		6.18 (5.27-7.47)	
Block step	1.70 (1.44-2.08)	1.61 (1.36-1.97)			1.61 (1.36-1.97)	4.66 (3.94-5.69)		2.86 (2.42-3.49)	
Block cross	1.62 (1.37-1.98)	1.65 (1.39-2.02)			2.17 (1.83-2.66)	6.61 (5.59-8.09)		2.68 (2.27-3.28)	
Vert	2.51 (2.36-2.68)	2.69 (2.52-2.88)	2.53 (2.25-2.88)	3.26 (3.06-3.49)		8.05 (7.55-8.62)	3.95 (3.52-4.50)	4.68 (4.39-5.01)	3.80 (3.40-4.31)
CMJ	2.03 (1.73-2.46)	2.22 (1.88-2.71)	2.11 (1.80-2.56)	2.73 (2.33-3.31)		5.44 (4.61-6.65)	4.38 (3.73-5.30)	3.46 (2.93-4.23)	
CMJ yardstick	2.25 (1.91-2.73)	2.28 (1.93-2.79)	2.61 (2.22-3.17)	2.84 (2.42-3.45)		6.05 (5.11-7.41)	3.37 (2.87-4.09)	2.78 (2.35-3.40)	4.44 (3.78-5.39)
Spike yardstick	1.94 (1.67-2.32)	2.25 (1.93-2.70)		2.63 (2.26-3.15)		5.67 (4.86-6.81)		3.95 (3.38-4.75)	3.20 (2.75-3.82)
Spike	3.04 (2.61-3.64)	3.19 (2.72-3.86)		3.78 (3.24-4.53)		7.91 (6.75-9.56)		6.17 (5.26-7.46)	
Serve	2.16 (1.85-2.59)	2.67 (2.27-3.23)		4.25 (3.64-5.11)		7.29 (6.21-8.83)		5.88 (5.00-7.13)	
Block step	1.51 (1.28-1.85)	1.57 (1.33-1.92)		1.90 (1.61-2.32)		4.45 (3.77-5.44)		2.84 (2.40-3.47)	
Block cross	1.92 (1.63-2.35)	2.04 (1.73-2.49)		2.40 (2.03-2.94)		6.61 (5.60-8.08)		2.98 (2.52-3.64)	
Video TOV	7.35 (6.90-7.86)	7.41 (6.96-7.92)	4.70 (4.19-5.36)	8.23 (7.73-8.81)	7.52 (7.05-8.05)		5.60 (4.99-6.38)	5.98 (5.62-6.40)	7.68 (6.86-8.73)
CMJ	4.81 (4.10-5.83)	4.96 (4.22-6.01)	4.93 (4.20-5.97)	5.74 (4.89-6.95)	5.16 (4.37-6.31)		5.57 (4.74-6.75)	5.00 (4.26-6.06)	
CMJ yardstick	4.26 (3.63-5.16)	4.29 (3.65-5.20)	4.51 (3.84-5.46)	5.44 (4.63-6.59)	5.39 (4.56-6.60)		5.34 (4.55-6.47)	4.21 (3.59-5.10)	6.60 (5.62-7.99)

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Spike yardstick	5.35 (4.58-6.43)	5.01 (4.29-6.02)		6.19 (5.28-7.47)	5.56 (4.76-6.68)			5.21 (4.46-6.26)	6.18 (5.29-7.43)
Spike	5.83 (4.99-7.02)	5.65 (4.83-6.80)		7.22 (6.18-8.69)	6.90 (5.88-8.34)			7.40 (6.33-8.91)	
Serve	5.76 (4.93-6.93)	5.78 (4.95-6.96)		8.55 (7.30-10.32)	6.24 (5.32-7.56)			5.60 (4.79-6.75)	
Block step	3.10 (2.62-3.79)	3.10 (2.62-3.79)		3.99 (3.38-4.88)	3.22 (2.73-3.93)			4.02 (3.40-4.91)	
FP TOV	4.00 (3.58-4.53)	4.24 (3.78-4.83)	3.99 (3.57-4.52)	4.50 (4.03-5.10)	4.42 (3.94-5.04)	7.11 (6.34-8.10)		4.21 (3.75-4.80)	4.47 (3.83-5.37)
CMJ	4.23 (3.62-5.08)	4.5 (3.88-5.52)	4.27 (3.66-5.13)	4.84 (4.15-5.82)	5.12 (4.36-6.20)	7.01 (5.97-8.49)		4.41 (3.76-5.34)	
CMJ yardstick	3.01 (2.58-3.62)	3.13 (2.67-3.79)	3.02 (2.59-3.63)	3.76 (3.22-4.52)	3.53 (3.00-4.28)	6.06 (5.16-7.34)		3.50 (2.98-4.24)	4.47 (3.83-5.37)
Video disp	5.10 (4.79-5.45)	5.18 (4.86-5.54)	3.03 (2.70-3.45)	5.87 (5.51-6.28)	5.27 (4.94-5.64)	7.25 (6.81-7.75)	4.50 (4.01-5.13)		4.84 (4.32-5.50)
CMJ	3.22 (2.74-3.90)	3.42 (2.91-4.14)	3.18 (2.71-3.85)	4.43 (3.77-5.37)	4.10 (3.47-5.01)	6.44 (5.49-7.80)	4.51 (3.84-5.46)		
CMJ yardstick	2.54 (2.16-3.08)	2.55 (2.17-3.09)	2.88 (2.45-3.49)	3.46 (2.95-4.19)	3.36 (2.84-4.11)	5.69 (4.85-6.89)	4.17 (3.55-5.05)		4.70 (4.00-5.69)
Spike yardstick	4.22 (3.61-5.07)	4.18 (3.58-5.02)		5.07 (4.33-6.12)	4.24 (3.63-5.10)	5.70 (4.88-6.85)			4.64 (3.97-5.58)
Spike	5.35 (4.58-6.44)	5.40 (4.62-6.50)		6.32 (5.41-7.61)	5.98 (5.10-7.23)	8.04 (6.88-9.68)			
Serve	4.80 (4.10-5.79)	4.86 (4.15-5.86)		7.53 (6.42-9.10)	5.29 (4.50-6.42)	5.94 (5.08-7.16)			
Block step	2.40 (2.03-2.93)	2.38 (2.01-2.91)		3.09 (2.62-3.78)	2.60 (2.20-3.18)	5.07 (4.29-6.20)			
Block cross	2.45 (2.07-2.99)	2.50 (2.12-3.05)		3.30 (2.79-4.04)	3.26 (2.76-3.98)	6.30 (5.33-7.70)			
Yardstick	3.38 (3.03-3.82)	3.64 (3.25-4.14)	2.82 (2.42-3.39)	4.11 (3.68-4.66)	3.78 (3.38-4.29)	6.49 (5.79-7.38)	3.90 (3.34-4.69)	4.12 (3.68-4.68)	
CMJ yardstick	2.79 (2.39-3.35)	2.88 (2.45-3.49)	2.82 (2.42-3.39)	3.60 (3.08-4.33)	3.88 (3.30-4.71)	6.59 (5.61-7.98)	3.90 (3.34-4.69)	3.48 (2.96-4.21)	
Spike yardstick	2.56 (2.20-3.05)	2.70 (2.31-3.24)		3.19 (2.74-3.82)	3.20 (2.75-3.82)	6.47 (5.54-7.77)		4.44 (3.80-5.34)	

Note. CMJ = Countermovement Jump; FT = Flight Time; TOV = Take-Off Velocity; FP = Force plate; disp = displacement

Table 5. Bland Altman statistics for every jump type and measurement system in centimetres. Given as mean difference ± 1.96 × standard deviation of the difference in centimetres. Mean - 1.96 × standard deviation of the difference corresponds to lower limit of agreement, while plus corresponds to the higher limit of agreement. A negative value indicates the row is smaller than the column.

	Optojump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Optojump		-0.73 ± 1.88	-1.52 ± 1.63	-9.46 ± 5.40	-8.52 ± 5.06	0.02 ± 17.09	-1.14 ± 8.32	-12.10 ± 10.08	-5.85 ± 6.74
CMJ		-0.43 ± 1.09	-1.43 ± 0.64	-9.00 ± 4.69	-8.38 ± 4.65	-7.52 ± 11.62	0.44 ± 8.59	-14.07 ± 6.29	
CMJ yardstick		-0.42 ± 0.95	-1.61 ± 2.19	-9.63 ± 4.05	-9.96 ± 5.23	-5.17 ± 10.87	-2.72 ± 6.74	-14.57 ± 4.95	-6.92 ± 7.45
Spike yardstick		-1.07 ± 2.29		-10.65 ± 5.01	-8.77 ± 4.04	3.10 ± 11.73		-10.53 ± 8.50	-4.85 ± 5.29
Spike		-1.01 ± 1.74		-8.45 ± 5.45	-6.83 ± 6.42	5.54 ± 14.51		-8.76 ± 12.28	
Serve		-0.40 ± 2.79		-8.70 ± 7.56	-8.13 ± 4.23	10.27 ± 14.22		-7.47 ± 10.83	
Block step		-0.66 ± 1.15		-9.71 ± 3.69	-7.97 ± 2.93	-2.57 ± 7.83		-15.56 ± 4.79	
Block cross		-1.12 ± 1.45		-10.32 ± 4.40	-9.83 ± 4.07	-5.34 ± 11.48		-14.75 ± 4.82	
Video FT	0.73 ± 1.88		-1.10 ± 1.90	-8.73 ± 5.70	-7.76 ± 5.37	0.75 ± 17.01	-0.73 ± 8.80	-11.36 ± 10.20	-5.21 ± 7.15
CMJ	0.43 ± 1.09		-1.00 ± 1.25	-8.48 ± 4.73	-7.82 ± 4.85	-7.09 ± 11.72	0.91 ± 9.17	-13.64 ± 6.65	
CMJ yardstick	0.42 ± 0.95		-1.20 ± 2.37	-9.17 ± 4.30	-9.32 ± 5.23	-4.75 ± 10.99	-2.38 ± 7.07	-14.15 ± 4.98	-6.55 ± 7.66
Spike yardstick	1.07 ± 2.29			-9.56 ± 5.72	-7.76 ± 4.89	4.17 ± 11.29		-9.46 ± 8.65	-3.96 ± 5.64

	Opto-jump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Spike	1.01 ± 1.74			-7.33 ± 6.24	-5.95 ± 6.74	6.54 ± 14.16		-7.75 ± 12.58	
Serve	0.40 ± 2.79			-8.47 ± 8.24	-7.66 ± 5.20	10.68 ± 13.57		-6.99 ± 10.47	
Block step	0.66 ± 1.15			-9.04 ± 3.52	-7.31 ± 3.04	-1.91 ± 7.82		-14.90 ± 4.75	
Block cross	1.12 ± 1.45			-9.18 ± 4.11	-8.70 ± 4.11	-4.21 ± 11.66		-13.62 ± 4.83	
FP FT	1.52 ± 1.63	1.10 ± 1.90		-7.79 ± 4.44	-7.64 ± 5.61	-4.82 ± 12.02	0.38 ± 8.33	-12.79 ± 5.97	-5.31 ± 7.61
CMJ	1.43 ± 0.64	1.00 ± 1.25		-7.57 ± 4.57	-6.94 ± 4.76	-6.10 ± 11.85	1.87 ± 8.65	-12.64 ± 6.21	
CMJ Yardstick	1.61 ± 2.19	1.20 ± 2.37		-8.01 ± 4.26	-8.35 ± 6.04	-3.55 ± 11.66	-1.11 ± 6.85	-12.94 ± 5.70	-5.31 ± 7.61
Kinexon	9.46 ± 5.40	8.73 ± 5.70	7.79 ± 4.44		1.03 ± 6.38	9.35 ± 18.41	8.17 ± 9.17	-2.69 ± 11.51	4.25 ± 8.01
CMJ	9.00 ± 4.69	8.48 ± 4.73	7.57 ± 4.57		0.75 ± 5.63	1.39 ± 13.41	9.44 ± 9.67	-5.16 ± 8.66	
CMJ yardstick	9.63 ± 4.05	9.17 ± 4.30	8.01 ± 4.26		-0.30 ± 5.93	4.42 ± 13.21	6.91 ± 7.90	-4.98 ± 6.69	2.71 ± 8.46
Spike yardstick	10.65 ± 5.01	9.56 ± 5.72			1.96 ± 5.10	13.61 ± 13.34		-0.04 ± 10.06	5.75 ± 6.28
Spike	8.45 ± 5.45	7.33 ± 6.24			1.62 ± 7.43	13.88 ± 16.80		-0.42 ± 13.41	
Serve	8.70 ± 7.56	8.47 ± 8.24			0.72 ± 8.86	18.82 ± 18.22		1.36 ± 15.06	
Block step	9.71 ± 3.69	9.04 ± 3.52			1.73 ± 3.93	7.13 ± 9.03		-5.85 ± 5.98	
Block cross	10.32 ± 4.40	9.18 ± 4.11			0.54 ± 4.68	4.89 ± 13.58		-4.43 ± 6.49	
Vert	8.52 ± 5.06	7.76 ± 5.37	7.64 ± 5.61	-1.03 ± 6.38		8.65 ± 16.92	8.16 ± 8.66	-3.56 ± 10.34	3.47 ± 7.50
CMJ	8.38 ± 4.65	7.82 ± 4.85	6.94 ± 4.76	-0.75 ± 5.63		1.20 ± 10.82	8.80 ± 9.94	-5.77 ± 7.91	
CMJ yardstick	9.96 ± 5.23	9.32 ± 5.23	8.35 ± 6.04	0.30 ± 5.93		4.91 ± 12.09	7.51 ± 6.90	-4.66 ± 6.54	2.94 ± 8.58
Spike yardstick	8.77 ± 4.04	7.76 ± 4.89		-1.96 ± 5.10		11.93 ± 11.72		-1.70 ± 8.30	3.92 ± 6.30
Spike	6.83 ± 6.42	5.95 ± 6.74		-1.62 ± 7.43		12.58 ± 16.70		-1.63 ± 12.91	
Serve	8.13 ± 4.23	7.66 ± 5.20		-0.72 ± 8.86		18.25 ± 15.39		0.53 ± 11.93	
Block step	7.97 ± 2.93	7.31 ± 3.04		-1.73 ± 3.93		5.40 ± 8.68		-7.59 ± 5.49	
Block cross	9.83 ± 4.07	8.70 ± 4.11		-0.54 ± 4.68		4.49 ± 13.05		-4.92 ± 6.30	
Video TOV	-0.02 ± 17.09	-0.75 ± 17.01	4.82 ± 12.02	-9.35 ± 18.41	-8.65 ± 16.92		5.19 ± 14.15	-12.06 ± 14.35	-5.08 ± 15.27
CMJ	7.52 ± 11.62	7.09 ± 11.72	6.10 ± 11.85	-1.39 ± 13.41	-1.20 ± 10.82		8.01 ± 13.85	-6.55 ± 12.50	
CMJ yardstick	5.17 ± 10.87	4.75 ± 10.99	3.55 ± 11.66	-4.42 ± 13.21	-4.91 ± 12.09		2.37 ± 12.15	-9.40 ± 10.98	-1.80 ± 14.26
Spike yardstick	-3.10 ± 11.73	-4.17 ± 11.29		-13.61 ± 13.34	-11.93 ± 11.72			-13.63 ± 11.45	-8.13 ± 13.67
Spike	-5.54 ± 14.51	-6.54 ± 14.16		-13.88 ± 16.80	-12.58 ± 16.70			-14.29 ± 17.53	
Serve	-10.27 ± 14.22	-10.68 ± 13.57		-18.82 ± 18.22	-18.25 ± 15.39			-17.53 ± 12.18	
Block step	2.57 ± 7.83	1.91 ± 7.82		-7.13 ± 9.03	-5.40 ± 8.68			-12.99 ± 9.79	
Block cross	5.34 ± 11.48	4.21 ± 11.66		-4.89 ± 13.58	-4.49 ± 13.05			-9.41 ± 12.19	
FP TOV	1.14 ± 8.32	0.73 ± 8.80	-0.38 ± 8.33	-8.17 ± 9.17	-8.16 ± 8.66	-5.19 ± 14.15		-13.16 ± 9.04	-4.20 ± 8.66
CMJ	-0.44 ± 8.59	-0.91 ± 9.17	-1.87 ± 8.65	-9.44 ± 9.67	-8.80 ± 9.94	-8.01 ± 13.85		-14.55 ± 9.15	
CMJ yardstick	2.72 ± 6.74	2.38 ± 7.07	1.11 ± 6.85	-6.91 ± 7.90	-7.51 ± 6.90	-2.37 ± 12.15		-11.77 ± 8.05	-4.20 ± 8.66
Video disp	12.10 ± 10.08	11.36 ± 10.20	12.79 ± 5.97	2.69 ± 11.51	3.56 ± 10.34	12.06 ± 14.35	13.16 ± 9.04		6.51 ± 9.44
CMJ	14.07 ± 6.29	13.64 ± 6.65	12.64 ± 6.21	5.16 ± 8.66	5.77 ± 7.91	6.55 ± 12.50	14.55 ± 9.15		
CMJ yardstick	14.57 ± 4.95	14.15 ± 4.98	12.94 ± 5.70	4.98 ± 6.69	4.66 ± 6.54	9.40 ± 10.98	11.77 ± 8.05		7.60 ± 9.16
Spike yardstick	10.53 ± 8.50	9.46 ± 8.65		0.04 ± 10.06	1.70 ± 8.30	13.63 ± 11.45			5.50 ± 9.26
Spike	8.76 ± 12.28	7.75 ± 12.58		0.42 ± 13.41	1.63 ± 12.91	14.29 ± 17.53			
Serve	7.47 ± 10.83	6.99 ± 10.47		-1.36 ± 15.06	-0.53 ± 11.93	17.53 ± 12.18			
Block step	15.56 ± 4.79	14.90 ± 4.75		5.85 ± 5.98	7.59 ± 5.49	12.99 ± 9.79			
Block cross	14.75 +- 4.82	13.62 +- 4.83		4.43 +- 6.49	4.92 +- 6.30	9.41 +- 12.19			
Yardstick	5.85 +- 6.74	5.21 +- 7.15	5.31 +- 7.61	-4.25 +- 8.01	-3.47 +- 7.50	5.08 +- 15.27	4.20 +- 8.66	-6.51 +- 9.44	
CMJ yardstick	6.92 +- 7.45	6.55 +- 7.66	5.31 +- 7.61	-2.71 +- 8.46	-2.94 +- 8.58	1.80 +- 14.26	4.20 +- 8.66	-7.60 +- 9.16	
Spike yardstick	4.85 +- 5.29	3.96 +- 5.64		-5.75 +- 6.28	-3.92 +- 6.30	8.13 +- 13.67		-5.50 +- 9.26	

Note. CMJ = Countermovement Jump; FT = Flight Time; TOV = Take-Off Velocity; FP = Force plate; disp = displacement

Table 6. Coefficients of the correction equation for every combination of jump type and measurement system based on simple linear regressions. The values can be interpreted as follows: system1 = a * (system 2) +b. Given as Column = a × Row + b

	Opto-jump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Optojump		a = 1.01, b = 0.18	a = 0.99, b = 2.08	a = 1.06 b = 6.65	a = 0.99, b = 8.87	a = 0.68, b = 15.59	a = 0.82, b = 9.14	a = 0.77, b = 23.40	a = 0.96, b = 7.92
CMJ		a = 1.02, b = 0.64	a = 1.00, b = 1.21	a = 1.01, b = 8.73	a = 1.10, b = 3.92	a = 0.92, b = 11.05	a = 0.78, b = 9.75	a = 0.87, b = 20.37	
CMJ yardstick		a = 0.99, b = 0.74	a = 0.97, b = 2.84	a = 1.04, b = 8.07	a = 1.10, b = 5.80	a = 0.96, b = 6.98	a = 1.00, b = 2.58	a = 0.89, b = 19.29	a = 1.18, b = 0.75
Spike yardstick		a = 0.94, b = 4.34		a = 1.04, b = 8.56	a = 1.03, b = 6.73	a = 0.76, b = 11.26		a = 0.82, b = 21.33	a = 1.01, b = 4.09
Spike		a = 0.98, b = 2.24		a = 1.06, b = 5.29	a = 1.00, b = 7.01	a = 0.74, b = 8.94		a = 0.77, b = 21.33	
Serve		a = 1.03, b = 1.00		a = 1.26, b = 3.60	a = 0.96, b = 10.09	a = 0.63, b = 7.82		a = 0.80, b = 17.28	
Block step		a = 1.00, b = 0.86		a = 1.06, b = 7.30	a = 0.91, b = 11.64	a = 1.10, b = 1.47		a = 0.94, b = 17.95	
Block cross		a = 1.04, b = 0.65		a = 1.18, b = 1.85	a = 1.04, b = 7.95	a = 0.97, b = 6.86		a = 0.92, b = 18.59	
Video FT	a = 0.98, b = 0.33		a = 0.97, b = 2.29	a = 1.03, b = 7.07	a = 0.97, b = 9.06	a = 0.68, b = 15.17	a = 0.81, b = 9.45	a = 0.76, b = 23.44	a = 0.93, b = 8.75
CMJ	a = 0.97, b = 0.88		a = 0.98, b = 2.09	a = 0.98, b = 9.37	a = 1.06, b = 4.81	a = 0.90, b = 11.93	a = 0.76, b = 10.57	a = 0.84, b = 21.39	
CMJ yardstick	a = 1.00, b = 0.47		a = 0.97, b = 2.30	a = 1.04, b = 7.62	a = 1.09, b = 5.43	a = 0.95, b = 6.80	a = 1.01, b = 2.03	a = 0.89, b = 18.81	a = 1.17, b = 1.05
Spike yardstick	a = 1.03, b = 3.05			a = 1.10, b = 3.80	a = 1.05, b = 4.46	a = 0.81, b = 7.40		a = 0.84, b = 19.08	a = 1.00, b = 3.85
Spike	a = 1.01, b = 1.41			a = 1.08, b = 2.87	a = 0.98, b = 7.01	a = 0.77, b = 6.30		a = 0.76, b = 21.19	
Serve	a = 0.93, b = 2.90			a = 1.19, b = 0.64	a = 0.91, b = 11.98	a = 0.66, b = 5.79		a = 0.79, b = 17.45	
Block step	a = 0.99, b = 0.46			a = 1.07, b = 6.42	a = 0.90, b = 11.14	a = 1.10, b = 2.22		a = 0.94, b = 17.27	
Block cross	a = 0.95, b = 1.16			a = 1.14, b = 2.60	a = 0.99, b = 8.96	a = 0.92, b = 8.23		a = 0.88, b = 19.23	
FP FT	a = 1.00, b = 1.36	a = 1.01, b = 1.42		a = 1.01, b = 7.37	a = 1.05, b = 5.23	a = 0.96, b = 6.82	a = 0.83, b = 7.77	a = 0.87, b = 18.88	a = 1.18, b = 2.89
CMJ	a = 0.99, b = 1.10	a = 1.02, b = 1.77		a = 1.00, b = 7.44	a = 1.09, b = 2.84	a = 0.91, b = 10.64	a = 0.78, b = 8.93	a = 0.86, b = 19.20	
CMJ yardstick	a = 0.99, b = 1.26	a = 0.99, b = 0.55		a = 1.04, b = 6.20	a = 1.08, b = 4.95	a = 0.90, b = 7.87	a = 1.01, b = 0.73	a = 0.87, b = 18.77	a = 1.18, b = 2.89
Kinexon	a = 0.87, b = 2.16	a = 0.89, b = 2.11	a = 0.89, b = 1.68		a = 0.88, b = 5.72	a = 0.58, b = 15.15	a = 0.75, b = 5.58	a = 0.68, b = 21.21	a = 0.88, b = 3.11
CMJ	a = 0.89, b = 2.67	a = 0.91, b = 3.70	a = 0.89, b = 1.67		a = 1.00, b = 0.63	a = 0.77, b = 11.28	a = 0.70, b = 7.28	a = 0.74, b = 19.52	
CMJ yardstick	a = 0.87, b = 2.59	a = 0.86, b = 1.87	a = 0.85, b = 0.24		a = 0.98, b = 1.32	a = 0.72, b = 10.43	a = 0.87, b = 0.06	a = 0.77, b = 17.20	a = 1.02, b = 3.59
Spike yardstick	a = 0.87, b = 2.07	a = 0.79, b = 5.07			a = 0.92, b = 3.33	a = 0.62, b = 12.55		a = 0.70, b = 20.72	a = 0.93, b = 0.87
Spike	a = 0.84, b = 1.77	a = 0.79, b = 5.89			a = 0.87, b = 6.78	a = 0.54, b = 15.25		a = 0.65, b = 22.65	
Serve	a = 0.70, b = 8.12	a = 0.69, b = 9.43			a = 0.67, b = 17.84	a = 0.36, b = 17.74		a = 0.50, b = 27.44	
Block step	a = 0.87, b = 3.15	a = 0.87, b = 2.68			a = 0.81, b = 7.54	a = 0.93, b = 3.70		a = 0.82, b = 14.72	
Block cross	a = 0.79, b = 1.66	a = 0.82, b = 0.92			a = 0.86, b = 7.65	a = 0.68, b = 13.52		a = 0.73, b = 19.66	
Vert	a = 0.93, b = 4.70	a = 0.95, b = 4.62	a = 0.82, b = 2.08	a = 1.01, b = 0.38		a = 0.67, b = 10.06	a = 0.73, b = 6.23	a = 0.74, b = 18.14	a = 0.94, b = 0.33
CMJ	a = 0.84, b = 0.45	a = 0.86, b = 0.15	a = 0.84, b = 1.73	a = 0.87, b = 7.67		a = 0.84, b = 7.69	a = 0.67, b = 9.54	a = 0.74, b = 20.06	
CMJ yardstick	a = 0.79, b = 1.13	a = 0.80, b = 1.17	a = 0.76, b = 4.39	a = 0.84, b = 8.33		a = 0.78, b = 6.93	a = 0.84, b = 1.26	a = 0.74, b = 18.56	a = 0.97, b = 1.14
Spike yardstick	a = 0.91, b = 2.83	a = 0.85, b = 2.17		a = 0.98, b = 3.43		a = 0.73, b = 6.53		a = 0.79, b = 16.10	a = 0.93, b = 0.71

	Opto-jump	Video FT	FP FT	Kinexon	Vert	Video TOV	FP TOV	Video disp	Yardstick
Spike	a = 0.83, b = 3.28	a = 0.82, b = 5.19		a = 0.92, b = 6.72		a = 0.55, b = 14.85		a = 0.67, b = 21.84	
Serve	a = 0.95, b = 5.59	a = 0.94, b = 4.55		a = 1.23, b = 12.11		a = 0.54, b = 7.73		a = 0.73, b = 14.77	
Block step	a = 1.03, b = 9.52	a = 1.03, b = 8.73		a = 1.13, b = 4.49		a = 1.13, b = 11.39		a = 0.97, b = 9.04	
Block cross	a = 0.87, b = 2.63	a = 0.91, b = 3.59		a = 1.05, b = 2.45		a = 0.78, b = 7.77		a = 0.80, b = 16.01	
Video TOV	a = 0.54, b = 22.26	a = 0.56, b = 22.17	a = 0.56, b = 18.08	a = 0.55, b = 31.14	a = 0.59, b = 28.72		a = 0.49, b = 21.31	a = 0.59, b = 32.16	a = 0.82, b = 14.71
CMJ	a = 0.60, b = 14.46	a = 0.61, b = 14.20	a = 0.59, b = 16.18	a = 0.56, b = 25.21	a = 0.75, b = 14.51		a = 0.49, b = 19.55	a = 0.54, b = 31.57	
CMJ yardstick	a = 0.55, b = 16.67	a = 0.54, b = 17.46	a = 0.51, b = 20.29	a = 0.49, b = 29.09	a = 0.62, b = 23.38		a = 0.59, b = 17.36	a = 0.53, b = 32.13	a = 0.59, b = 21.55
Spike yardstick	a = 0.65, b = 23.05	a = 0.63, b = 25.00		a = 0.61, b = 35.24	a = 0.70, b = 28.74			a = 0.65, b = 33.28	a = 0.58, b = 32.03
Spike	a = 0.47, b = 31.45	a = 0.48, b = 32.10		a = 0.46, b = 40.48	a = 0.42, b = 40.95			a = 0.42, b = 43.10	
Serve	a = 0.43, b = 31.92	a = 0.51, b = 29.54		a = 0.50, b = 38.03	a = 0.40, b = 41.33			a = 0.64, b = 31.22	
Block step	a = 0.66, b = 11.55	a = 0.66, b = 12.20		a = 0.68, b = 20.35	a = 0.59, b = 22.38			a = 0.60, b = 29.73	
FP TOV	a = 0.78, b = 9.16	a = 0.78, b = 9.46	a = 0.77, b = 10.90	a = 0.80, b = 17.64	a = 0.92, b = 11.95	a = 0.78, b = 15.34		a = 0.72, b = 25.92	a = 0.95, b = 6.57
CMJ	a = 0.80, b = 9.71	a = 0.81, b = 9.53	a = 0.80, b = 11.02	a = 0.81, b = 18.13	a = 0.91, b = 12.87	a = 0.78, b = 18.08		a = 0.76, b = 25.84	
CMJ yardstick	a = 0.75, b = 9.03	a = 0.74, b = 9.78	a = 0.73, b = 11.18	a = 0.77, b = 17.50	a = 0.92, b = 11.37	a = 0.76, b = 13.35		a = 0.68, b = 26.33	a = 0.95, b = 6.57
Video disp	a = 0.91, b = 6.48	a = 0.92, b = 6.70	a = 0.93, b = 8.42	a = 0.96, b = 0.27	a = 0.94, b = 0.17	a = 0.86, b = 3.76	a = 0.83, b = 2.88		a = 1.04, b = 9.35
CMJ	a = 0.92, b = 9.41	a = 0.94, b = 9.89	a = 0.93, b = 8.54	a = 0.89, b = 1.28	a = 1.04, b = 7.98	a = 0.89, b = 0.10	a = 0.79, b = 1.75		
CMJ yardstick	a = 0.93, b = 10.76	a = 0.93, b = 10.02	a = 0.90, b = 6.88	a = 0.96, b = 2.68	a = 1.08, b = 9.30	a = 0.97, b = 7.74	a = 0.97, b = 10.25		a = 1.11, b = 13.85
Spike yardstick	a = 0.83, b = 1.12	a = 0.78, b = 5.67		a = 0.83, b = 11.56	a = 0.91, b = 4.77	a = 0.78, b = 1.85			a = 0.84, b = 5.97
Spike	a = 0.59, b = 17.57	a = 0.56, b = 20.21		a = 0.65, b = 21.64	a = 0.63, b = 21.69	a = 0.49, b = 18.11			
Serve	a = 0.62, b = 13.72	a = 0.68, b = 10.63		a = 0.74, b = 15.90	a = 0.59, b = 23.43	a = 0.72, b = 2.01			
Block step	a = 0.89, b = 9.70	a = 0.89, b = 9.12		a = 0.95, b = 3.35	a = 0.81, b = 2.89	a = 0.95, b = 10.21			
Block cross	a = 0.93, b = 10.16	a = 0.97, b = 11.79		a = 1.11, b = 11.27	a = 0.97, b = 2.83	a = 0.91, b = 4.15			
Yardstick	a = 0.93, b = 1.90	a = 0.95, b = 2.25	a = 0.66, b = 12.08	a = 0.97, b = 5.85	a = 0.93, b = 7.44	a = 0.58, b = 18.89	a = 0.72, b = 9.80	a = 0.76, b = 20.41	
CMJ yardstick	a = 0.67, b = 9.94	a = 0.67, b = 10.24	a = 0.66, b = 12.08	a = 0.69, b = 18.50	a = 0.74, b = 16.05	a = 0.59, b = 18.74	a = 0.72, b = 9.80	a = 0.61, b = 27.47	
Spike yardstick	a = 0.89, b = 2.10	a = 0.86, b = 5.29		a = 0.92, b = 10.59	a = 0.93, b = 8.43	a = 0.63, b = 15.62		a = 0.77, b = 20.52	

Note. CMJ = Countermovement Jump; FT = Flight Time; TOV = Take-Off Velocity; FP = Force plate; disp = displacement