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Comparison of Various Devices Used in the Evaluation of Vertical Jump Height

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ABSTRACT

This study aimed to compare force plate, motion analysis, and mobile application methods for calculating vertical jump height. Twenty-nine male college students (age: 22.4 ± 1.0 years; height: 178.1 ± 6.2cm; body weight: 71.2 ± 8.0 kg) voluntarily participated in the study. Two countermovement jumps (CMJ) with 1-minute intervals on a force platform (BERTEC 4060-10) were performed. The countermovement jump performances were captured using an iPhone 11 (Apple Inc., USA). The experimental setup involved using three high-speed cameras, specifically the My Jump 2 and SIMI Motion 7.5. Obtained results from hip displacement (HD) data with motion analysis system showed that participants had significantly lower vertical jump height calculated from motion capture (p = 0.01; -8.3 ± 3.86, 95%CI; MyJump2-SIMI_HD = 1.24/3.30). It was also found that calculations from left and right foot displacement were higher than My Jump 2 results (95%CI; MyJump2-SIMI_RF = 0.66/2.93) and 95%CI (MyJump2-SIMI_LF) = (-0.63/2.65). In contrast, force plate calculations, known as the gold standard in the literature, were very similar to My Jump (95%CI; MyJumpII-FP) = (2.38/4.01). The findings indicate that the My Jump 2, used for assessing vertical jump height, may be a reliable alternative for determining vertical jump height instead of setting up gold standard methods. Individuals' athletic performance abilities and birth, gender, and sports preferences should be considered. Finally, when coaches or sports scientists intend to measure CMJ, My Jump 2 application can be recommended as a laboratory application as well as a practical and valid measurement method, especially for field applications.

INTRODUCTION

Vertical jump performance is frequently applied in studies for evaluating power and strength. Thus it is important to make sure that how vertical jump height is measured is accurate and consistent (Cronin et al., 2004). A counter-movement jump (CMJ) is a type of vertical jump that is often used to measure the explosive power and jumping ability of a person's lower body. CMJ has significant importance in all areas of sports science, fitness assessments, and biomechanics research. Vertical jump height can be measured using a variety of methods and equipment. Motion capture systems, force plates, inertial measurement units (IMUs), and jump mats are used in sports to measure or predict the height of a jump (Dias et al., 2011; Magnúsdóttir et al., 2014). The main difference amongst measurement types lies in methods and variables used to estimate or measure vertical jump height. Apart from directly measurement the height reached by the athlete during the jump, calculations may be based on the time the athlete spends in the air, ground reaction forces while take-off and landing, or the analysis of kinematical data obtained from the displacement of joints from motion analysis systems. In motion analysis, hip, knee, foot, or centre of mass (COM) displacement can be used to calculate vertical jump height. In vertical jump height calculations hip joint or COM are commonly used. However, it is important to realize that the movement of the knee and ankle joints also contributes to the significant vertical displacement during a jump. During the upward phase of a jump, the knee joint exhibits rapid extension, which is important in optimizing vertical jump height. Ankle plantar flexion plays a vital role in generating ground reaction forces (Chiu & Dæhlin, 2020; Giustino et al., 2022; Yamashita et al., 2020). The selection of the joint to prioritize depends on the specific study or training goals, as well as the capabilities of the motion analysis system used.

The initial conditions of the free fall equation, such as take-off height and velocity, can be determined by assessing the instantaneous vertical acceleration of the centre of mass. Therefore, the preferred method for evaluating vertical jump performance is the application of 3D motion analysis instruments together with a force platform, which is a gold standard (McLaughlin, 2013). A previous study investigated the correlations and differences between 3D video analysis and force platform analysis in terms of predicting vertical centre of mass (COM) displacement during take-off compared to maximum COM. The use of maximum centre of mass (COM) velocity in the computation of vertical COM displacement has been determined with comparable reliability to the assessment conducted using three-dimensional (3D) video analysis (Nordin, 2013). Yet, due to the requirement of an efficient laboratory, extensive testing procedures, and an important purchase cost, its applicability in environments such as athletic facilities or other unstructured conditions is limited (Castagna et al., 2013).

The vertical jump height may be determined using many different methods to calculate vertical ground reaction force based on take-off velocity with a force platform. On the other hand, using an equation of constant acceleration, measuring flight time (FT) is a typical way of estimating vertical vertical jump height (Linthorne, 2001). While the current approach for calculating vertical jump height takes consideration of the placement of the centre of mass at both take-off and landing, it is worth noting that this accordance is not often achieved. However, FT measurement has several advantages, including the fact that it only requires an application and a simple and accessible method for physical trainers and sports scientists (Garci´a et al., 2013). With the improvement of smartphone technology, applications (apps) allowing measuring vertical jump height from video footage have recently been developed. High-speed cameras have been integrated into mobile phones. With the increase in smartphone usage and improved accessibility, the application of mobile applications in sports science research and practice is experiencing an increase in popularity. The cost-effective mobile software known as My Jump has demonstrated successful application in both sports science research and training. Furthermore, its suitability for use on iOS devices has consistently been verified in terms of its validity and reliability. My Jump II uses phone cameras in capturing slow-motion images that perform different jump tasks. Users can determine the take-off and landing frames to obtain vertical jump height information. Several groups have previously reported on its accuracy and reliability (Balsalobre-Fernández et al., 2015; Cruvinel-Cabral et al., 2018; Haynes et al., 2019). Other Android apps include Jumpo, whose reliability and accuracy were evaluated using squat jumps (SJ), single- and double-leg countermovement (CMJ), and other exercises. Due to a significant relationship between its flight time measurements and those obtained from a force platform, the Jumpo App provided a reliable indicator of jump performance. The Jumpo's flight time was slightly underestimated. This shows that using the calibration equation when comparing Jumpo and force platform data is beneficial. Previous studies have found statistically significant but insignificant errors when comparing CMJ data from a force platform to data from another mobile app, My Jump for iOS (Balsalobre-Fernández et al., 2015). Unlike previous research, the current investigation compared the vertical jump heights obtained from the My Jump 2 application based on the time in the air on the force platform and the displacement of different joints via a motion analysis system, meaning that kinetic and kinematic data were used. Considering these studies, this study aimed to determine the difference amongst vertical jump measurements from the force plate using the time-in-air method, the motion analysis system using tracking markers from three different joints, and the My Jump 2 application using the time-in-air method.

METHODS

Study Group

The study sample consisted of 29 recreationally active male students in the sports sciences faculty who volunteered for participation (age: 22.4 ±1.0 years; height: 178.1 ± 6.2 cm; body weight: 71.2 ±8.0 kg). The study protocol complied with the Declaration of Helsinki for Human Experimentation. Participants were informed regarding the procedure and written informed consent was obtained.

Data Collection Process

Each participant was given one day to familiarise themselves with the jump procedure and equipment before beginning the measurements. On measurement day, participants had a 10-minute warm-up that comprised running, lower-body stretching, and vertical jumps before the countermovement jump (CMJ) test and were familiarised with the jumping procedures. Subsequently, each participant performed two countermovement jumps (CMJ) on a force plate (BERTEC 4060-10) while performances being captured using an iPhone 11 (Apple Inc., USA) using the My Jump II application and SIMI Motion 7.5 (SIMI Reality Motion Systems GmbH) with two high-speed cameras (Basler A 602f). A 1-minute passive rest duration separates each jump. The participants were told to perform vertical jumps with maximal effort during the data collection process (Häkkinen et al., 1985).

During a singular testing session, individuals performed the countermovement jump (CMJ) while assuming a static standing posture with their hands placed on their hips and their legs fully extended during the flight phase of the jump. The landing manoeuvre was performed with simultaneous contact of both feet while ensuring the maintenance of ankle dorsiflexion throughout the entire process. Two high-speed cameras recording at 100 frames per second were used to record the participants' attempts (Basler A 602f high-speed camera). Captured 3-dimensional jump views digitized in SIMI Motion 7.5 (SIMI Reality Motion Systems GmbH-Germany) by tracking seven anthropometrical markers which were attached on both the side of the body, the lateral condyle of the femur (knee), the lateral malleolus (ankle), and the fifth metatarsal (toe) and trochanter major before jump performances. The cameras were positioned on the right and left sides of the force plate in such a way as to create a 90-degree angle between them. The highest jump was selected for subsequent analysis. The SIMI and iPhone devices were successfully synchronized with a flashlight. The same researcher conducted my Jump II record for all participants as previously described (Balsalobre-Fernández et al., 2015). Likewise, the same researcher made the digitization of the markers.

Calculation

The participants' vertical jump height was calculated using the following equipment and methods: 1a) Motion analysis system (SIMI Motion 7.5, GER) according to the vertical displacement of the right toe (SIMI_RF), 1b) left toe from instant take-off to land on (SIMI_LF) and 1c) according to hip displacement from instant take-off to land on (SIMI_HD) by Motion analysis system (SIMI Motion 7.5, GER); 2) My Jump 2 app with time in air method concerning toe displacement from instant take-off to land on; 3) Force Plate (Force Plate [FP];BERTEC 4060-10, USA) according to flight time (FT) from instant take-off to land on.

To calculate vertical jump height (JH) with the motion analysis system, recorded images from the motion analysis system were tracked and digitized frame by frame in SIMI and processed by following markers during the task—instant take-off and landing on predetermined moments were defined, and the displacement data collected was utilized to calculate vertical jump height.

The vertical jump height (JH) for the data acquired from the force plate (FP) was calculated using equation ($JH=g*AT^2/8$) where JH was vertical jump height, AT was the spent in air time, and g was the acceleration due to gravity g= -9.81 (m/s^2) published in the literature (Bosco et al., 1983). A low-pass, fourth-order Butterworth filter with a 4Hz cut-off frequency was used to filter obtained kinetic and kinematic data. The My Jump II data were collected using the same phone and by the same researcher. The recordings were obtained at an equal height of approximately one meter and approximately one and a half meters from the participants, ensuring an accurate analysis of their lower extremities. In contrast to the point of view provided by the frontal plane, the sagittal plane allows for easier observation of the different phases of take-off and landing (Stanton et al., 2017).

Data Analysis

All data are presented as the mean value (M) and the standard deviation (SD). 95 % limits of agreement were used to measure the accuracy and reliability of My Jump 2, and the other calculation methods 95 % LOA (Bland & Altman, 1999) and the coefficient of variation

(Atkinson & Nevill, 1998). were calculated, respectively. The Bland-Altman method was used to estimate the bias and the 95% limits of agreement (bias ± 1.96 x Sd). The 95% limits include 95% of the difference between the two measurement methods used (Myles & Cui, 2007). The coefficient of variation (CV) value (<10%) was calculated by Atkinson and Nevill (1998). Before using parametric tests, the assumption of normality was verified using the Shapiro-Wilk test ($p > 0.05$). A one-way analysis of variance for repeated measures was used to determine differences between My Jump 2 and other measurement methods. To make pairwise comparisons between My Jump 2 and the various measurement methods, the Bonferroni Post Hoc test was used. The level of statistical significance was set at $p < 0.05$. Effect sizes (η2) were also calculated to determine the practical difference between My Jump II and other measurement methods. Small, medium, and large differences were defined as ES values of 0.01, 0.06, and 0.14 and above, respectively (Cohen, 1988). The 95%CI was also calculated for the difference between the means for each estimated variable.

RESULTS

The means of the jump data (±SD), the CV (%), and the 95% LOA values for vertical jump height in cm across three different measurement devices are presented in Table 1 and Table 2. There is no significant difference in vertical jump height based on using the My Jump 2 force platform and RFD and LFD of the motion analysis system through SIMI (Table 1). The only statistically significant difference was in HD data versus the data obtained from all other measurements ($F = 139.658$, $p = 0.01$, $\eta^2 = 0.83$, η^2 represents a significant change)

Table 1
Comparison of Vertical Jump Heights (cm) Amongst My Jump 2, Force Plate, and SIMI

Variable	SIMI RF	SIMI LF	My Jump 2	SIMI HD	FP	ES	M_oC
Vertical jump height(cm)	28.46 ± 6.24	28.59 ± 5.60	29.60 ± 4.94	27.32 ± 5.15*	29.32± 4.48	0.833	Large

* Significantly different to Flight Time Force Plate ($p < 0.05$)
Note. FT = Flight Time; SIMI_HD = SIMI Hip Displacement; SIMI_RF = SIMI_Right Toe Displacement; SIMI_LF = SIMI Left Toe Displacement; FP = Force Plate; ES = Effect Size; M_oC = Magnitude of Change

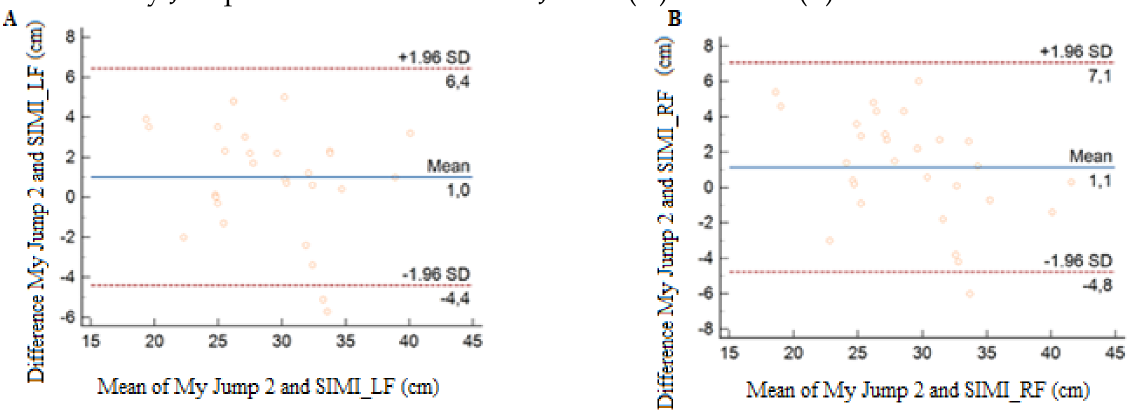
Table 2
Bland-Altman Bias (SD) and 95% Limits of Agreement Amongst Measurement Methods

Variable	My Jump 2-SIMI-RF		My Jump2-SIMI LF		My Jump2-FP		My Jump2-SIMI HD	
	CV (%)	95% LOA (Bias±1,96xSd)	CV (%)	95% LOA (Bias±1,96xSd)	CV (%)	95% LOA (Bias±1,96xSd)	CV (%)	95% LOA (Bias±1,96xSd)
Vertical Jump Height(cm)	7.74	1.14 ±5.91	7.05	1.01 ± 5.42	2.45	0.60 ± 1.60	17.79	-8.3± 3.86

Note. SIMI_HD = SIMI Hip Displacement; SIMI_RF = SIMI_Right Toe Displacement; SIMI_LF = SIMI Left Toe Displacement; FP = Force Plate; CV = Coefficient of Variation, 95%IOA = 95% Limits of Agreement

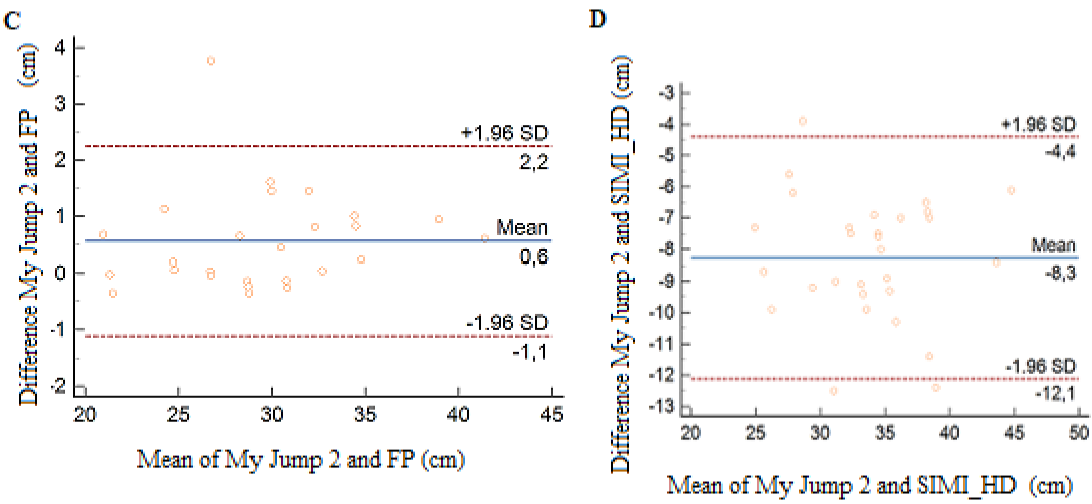
Bland-Altman plots were created for all conditions. The largest mean difference (-8.3 cm) was found in vertical jump height data calculated from HD. The 95% LOA values suggest an underestimation of HD values compared to My Jump 2 data (-8.3 ± 3.86, 95%CI; MyJump2-HD) = 1.24/3.30), while RFD and LFD values were similar to My Jump 2 data (1.14 ± 5.91, 95%CI; MyJump2- -0.66/2.93 RFD); (1.01 ± 5.42, 95%CI; MyJump2-LFD = -0.63/2.65). A positive mean difference for RFD, LFD, and My Jump II conditions indicated that the calculated height from the My Jump 2 data was like the vertical jump height measured by SIMI. In addition, vertical jump height values of My Jump II were very similar to those calculated from force platform data, known as the gold standard in literature (0.6 ± 1.60, 95%CI; MyJump2-FP= 2.38/4.01)

Figure 1
Bland-Altman with 95% Limits of Agreement (Dashed Lines) and Mean Difference (Solid Line) between My Jump 2 and the SIMI for CMJ from (A) LFD and (B) RFD



Note. SIMI RF = SIMI Right Toe Displacement; SIMI LF = SIMI Left Toe Displacement; SD = Standard Deviation

Figure 2
Bland-Altman with 95% Limits of Agreement (Dashed Lines) and Mean Difference (Solid Line) Between My Jump 2 and the FT of (C) FP and (D) HD for CMJ



Note. SIMI HD = SIMI Hip Displacement; FP = Force Plate; SD = Standard Deviation

DISCUSSION

The aim of this study was to determine the difference amongst vertical jump measurements from the force plate using the time-in-air method, the motion analysis system using tracking markers from three different joints, and the My Jump 2 application using the time-in-air method. The findings indicate that My Jump 2 demonstrated a greater level of concurrence with SIMI RF and LFD in the assessment of vertical jump height during a CMJ. Furthermore, the Bland Altman plots (Figures 1 A and B) illustrate that a great deal of countermovement jump (CMJ) values is closely correlated with the mean of the differences observed between My Jump 2 and SIMI. Furthermore, Bland–Altman plots (Figures 1 A and B) show that many of the results are close to the mean difference between My Jump II and SIMI based on toe displacement, indicating a good level of agreement (Bland & Altman, 1999). The presented figure illustrates a consistent bias (Figure 1 A and B), where the values obtained from the SIMI indicate a slight increase compared to those obtained from the My Jump II application for all countermovement jumps (CMJ), which generates positive differences in scores. In regard to the CMJ analysis, the mean bias observed between the My Jump 2 and SIMI systems was found to be lower than 1.1 cm (1.14 ± 5.91cm RFD; 1.01 ± 5.42cm LFD). The similarities between SIMI and My Jump II are not significant, even though the importance of manually performing the take-off and landing frame selection, has the potential of creating measurement errors. Similarly, both measurement methods measure the vertical jump height by taking the toe as a reference. Therefore, these slight differences between the right and left toes can be explained by the contrast of the participants' dominant legs.

However, the results of My Jump II appear to be underestimated compared to the vertical jump height calculated from SIMI according to HD (-8.3 ± 3.86cm Figure 2 D). This difference could be the reference point in the calculation of My Jump II, which was the toe. Simultaneously, the analysis conducted by SIMI relied on the differences in hip position during the time when the feet are in the air and when they contact the ground again. The main difference between this study and previous ones relates to the methodology used to calculate vertical jump height. Specifically, the vertical jump height in this study is determined by the displacement of three different joints using the SIMI motion analysis program. With one of these points being the foot. The vertical jump height data in the My Jump application is collected through the computation of the duration between the foot's take-off and initial contact. According to the obtained results, FP and My Jump II CMJ heights were very similar. The data demonstrate a consistent bias (shown in Figure 2 D) where, regardless of the vertical jump height, the values obtained from the My Jump 2 application displayed a slight increase compared to those obtained from the force platform, resulting in positive difference scores. The mean differences in CMJ height between My Jump 2 and the force platform were determined to be less than 0.6 cm.

Moreover, the observed minimal bias in our study is consistent with prior research that has compared My Jump to force platforms, where the average bias ranged from 0.2 to 1.1 centimeters (Driller et al., 2017; Gallardo-Fuentes et al., 2016).

As known to the authors, there are limited studies comparing vertical jump height calculations amongst the displacement of different body joints in a motion analysis system, force plate, and My Jump 2 application.

CONCLUSION

The results of the study suggest that the My Jump II application demonstrates validity and reliability as an alternative to force plates and motion analysis systems. The My Jump 2 application can be utilized by coaches to assess vertical jump height during athletic events, providing an applicable and practical solution.

Authors' contributions

All authors carried out the research design together. All authors were involved in the data collection, took responsibility for data analysis and interpretation of the data. The second author supervised and reviwed the original draft. First author took responsibility all writing process beginning from the manuscript's preparation to approval of the final draft.

Conflict of interest declaration

The author(s) declared no potential conflicts of interest concerning the research, authorship, and/or publication of this article.

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