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Original Article

Concurrent validity and reliability of iVMES portable force plate for measuring vertical jump height

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Abstract:
This study examined the validity and intrarater reliability of a newly developed portable force platform designed to estimate vertical jump height. Thirty-two healthy, recreationally active sports science students (20 males and 12 females) participated. A total of 64 countermovement jumps (with arm swing) were simultaneously recorded using 2 instruments: the Optojump photoelectric system (Microgate, Bolzano, Italy) as the criterion instrument, and the portable force plate (iVMES, Ankara, Turkey) as the practical instrument, to evaluate validity and reliability. The concurrent validity of the iVMES portable force plate system was examined using the Pearson's correlation coefficient with 95% confidence intervals and limits of agreement. The typical error of estimate was reported, and Bland-Altman plots were created to evaluate the agreement between the 2 measurement devices. The test-retest reliability of the iVMES force plate was assessed using the intraclass correlation coefficient with a 95% confidence interval. Additionally, metrics such as the smallest error of measurement, smallest worthwhile change, minimum detectable change, and root mean square error were calculated to assess the absolute reliability. Compared with the criterion instrument, the iVMES force plate produced vertical jump height values with an excellent intraclass correlation coefficient (0.98) and a very low bias (0.14 cm). Furthermore, the test-retest reliability was outstanding, with a low coefficient of variation (3.8%) and a strong intraclass correlation coefficient (0.96) for vertical jump height. The measurements from the 2 devices displayed extremely low smallest error of measurement and smallest worthwhile change values (both 0.05), as well as minimum detectable change (0.14) values. These findings confirmed a minimal and acceptable margin of error between the 2 measurements. In conclusion, the iVMES portable force plate demonstrated strong concurrent validity and excellent test-retest reliability for estimating vertical jump height.
Keywords: force plate, countermovement jump, validation, measurement error

Introduction

With the rapid advancement of technology in recent years, many new technologies have been integrated into sports science for various purposes, including fatigue assessment, monitoring training, and performance testing for various purposes (Thornton et al., 2019). These technologies are frequently used to determine the adaptation of the athletes because of the training, make the right training plans, and perform sports performance tests (Crowcroft et al., 2020; Gabbett et al., 2017). In recent years, it can be seen that a lot of research focus on the validity and reliability analysis of newly developing tools such as performance tracking systems (Pino-Ortega et al., 2024), eccentric force assessment tools (Akarçeşme et al., 2024), and athletic performance measurement device (Multhuaptff et al., 2024) under different testing condition.This shows that it is important for practitioners, coaches and sports scientists to be able to take not only accurate but also precise measurements in terms of the theoretical and practical use of developing technologies.

Vertical jump test, in particularly vertical jump height (VJH) is one of the critical tools for athletes and coaches aiming to enhance athletic performance, and it is essential in various sports, including basketball (Sanpasitt & Apanukul, 2023), volleyball (Rojano-Ortega et al., 2021), soccer (Torreblanca-Martínez et al., 2020), track and field (Albano et al., 2019; Yuan et al., 2023).

VJH determine the muscle stiffness (Song et al., 2024) which is an important factor in athletic performance. Increased muscle stiffness can enhance the storage and release of elastic energy during the stretch-shortening cycle, leading to improved jump performance. By analyzing vertical jump height, researchers can gain insights into the neuromuscular adaptations and changes in muscle stiffness over time, which can inform training and rehabilitation programs. Monitoring VJH is a reliable method for assessing neuromuscular fatigue in athletes (Bishop et al., 2023). Decreases in VJH can indicate the onset of fatigue, allowing coaches and sports scientists to make informed decisions about training load, recovery, and performance optimization. VJH test, particularly unilateral jump assessments, can be used to identify lower limb asymmetries (Michailidis et al.,

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2020). Differences in VJH or power output between the dominant and non-dominant limbs can indicate muscular imbalances or neuromuscular deficits, which may increase the risk of injury and negatively impact athletic performance. VJH is also a key indicator of an athlete's power and explosiveness, which are crucial for many sports (Dietze-Hermosa et al., 2020; Montalvo, Conde, et al., 2021). By monitoring vertical jump performance, coaches and sports scientists can evaluate the effectiveness of training programs, nutritional interventions, and recovery strategies in enhancing an athlete's physical capabilities. Finally, VJH provide valuable data for kinematic analysis (Policastro et al., 2020; Sahabuddin et al., 2021), allowing researchers to study the biomechanics of the jump movement. This information can be used to identify technical flaws, optimize technique, and develop targeted training programs to improve jump performance.

Various devices are employed for VJH, each with its own strengths and limitations (Nakazato et al., 2011). Motion capture systems use cameras and markers to track an athlete's movements during a jump, providing detailed data on the position, velocity, and acceleration of different body parts (Merrigan et al., 2022). Accelerometry-based technologies, such as wearable sensors, offer insights into the forces and movements of the body during a jump (Monnet et al., 2014). Among the diverse technologies for managing fatigue, monitoring training, and conducting performance tests, force platforms are frequently used by sports scientists and coaches (Cardinale & Varley, 2017; García-Pinillos et al., 2021).

Force platforms measure the ground reaction forces generated by an athlete during a jump, which provides data on the amount of power and energy transferred during the movement (MacDonald et al., 2017). Force platforms are popular tools for jump analysis due to their accurate and reliable measurements of ground reaction forces (Xu et al., 2023). However, ongoing research aims to verify their validity and reliability. Certain studies have identified potential sources of error, such as calibration and athlete technique, which must be considered when using force platforms for jump analysis (Hansen et al., 2011). However, the accuracy and consistency of force platform data can be influenced by various factors, including calibration errors, noise, and signal drift. Since these devices' data are frequently used to recommend, track, or modify an athlete's training, their reliability needs to be acceptable. This is consistent with the requirement to evaluate these devices' ability to identify the smallest worthwhile change (SWC) in performance, enabling practitioners to decide with confidence if a change in VJH is real and of practical consequence (Comyns et al., 2023). Various brands and models of force platforms are available in the market, and the differences in the technology and software used by different brands raise questions about the accuracy and reliability of the data (Merrigan et al., 2022). A more cost-effective, portable, instantaneous, and straightforward approach to VJH evaluation is offered by the alternative field-based technologies and tools that have been created and employed in research and practice (Comyns et al., 2023), but many companies need to provide users with information about the accuracy and reliability of their equipment (Currell & Jeukendrup, 2008).

Therefore, it is crucial to assess the validity and reliability of force platform data to ensure its usefulness and applicability for research and athletic performance analysis. This research aims to investigate the validity and intra-rater reliability of the newly developed portable force platform for estimating VJH.

Materials & Methods

Participants

The sample size was estimated a priori using G*Power (version 3.1.9, University of Kiel, Germany), assuming a large effect size of 0.5, a power (1-β) of 0.90, and a significance level of 0.05, based on previous studies (Balsalobre-Fernández et al., 2015; Montalvo, Gonzalez, et al., 2021). Thirty-two recreationally active sports sciences students (20 males and 12 females) participated voluntarily in the study. None of the participants had a history of lower limb injuries. The physical characteristics of the participants are summarized in Table 1. All participants provided written informed consent before participating in the study. The study was approved by the local ethics committee of Gazi University (Code: 2022-1423) and conducted in accordance with the ethical principles of the Declaration of Helsinki for human research.

Table 1. The physical characteristic of the participants

	Males (*n*=20)	Females (*n*=12)
Age (year)	21.8 ± 2.39	21.5 ± 1.62
Height (m)	1.76 ± 0.04	1.66 ± 0.40
Body weight (kg)	75.9 ± 5,56	61.6 ± 4.11
Body mass index (kg/m^2)	24.3 ± 0.75	22.2 ± 1.05

Procedure

The study employed an instrumental design. All participants performed two maximal trials of the bilateral countermovement jump (CMJ) with arm swing, following an unstandardized 10-minute warm-up. The passive rest interval between the trials was set at two minutes (Bogataj et al., 2020; Glatthorn et al., 2011). A total of 64 jumps were simultaneously recorded using two instruments to assess validity and reliability: the Optojump photoelectric system (Microgate, Bolzano, Italy) as the criterion instrument and a portable force plate (iVMES, Ankara, Turkey) as the practical instrument.

The Optojump photoelectric system consists of a two-bar optical measurement system, with a transmitting and receiving bar, each containing 96 LEDs, positioned approximately 1 meter (m) apart and parallel to each other. The LEDs on the transmitting bar continuously communicate with those on the receiving bar. This system detects and calculates any interruptions in communication between the bars, allowing for the measurement of flight and contact times during jumps with an accuracy of 1/1000 of a second.

The iVMES force platform (www.ivmes.com) is a low-cost, portable, one-dimensional force platform measuring 50x50x9.3 cm and weighing 17 kg. It was positioned on the ground to measure vertical ground reaction forces (VGRFs) during jumping (range 0-9,000 N; sampling rate 100 Hz). The force platform was connected to a personal computer, and the accompanying software (iVMES athlete software, version 1.0.1) facilitated the quantification of vertical jump height (VJH) using time of flight calculations.

The concurrent test protocol followed methodologies from prior research (Glatthorn et al., 2011; Montalvo, Gonzalez, et al., 2021), and the experimental setup is depicted in Figure 1. The Optojump bars were aligned at the same height as the surface of the iVMES force platform (about 10 cm above the ground) to simultaneously capture flight time with both systems, facilitating data comparison. Both devices were synchronized for each measurement to evaluate VJH accurately. The procedure, recommended by Hartmann et al. (2012), required participants to jump from a preferred starting push-off position, bending their knees. Any inaccurate jumps were excluded, and a repeat jump was performed.

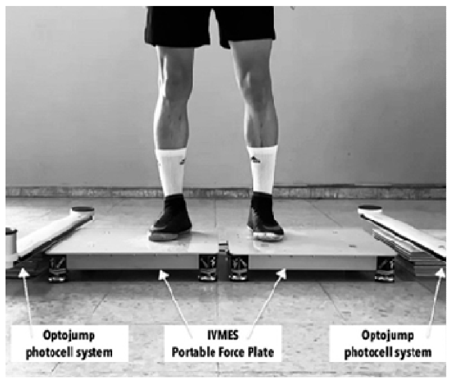

Figure 1. Experimental setup showing the measurement tools

Statistical analysis

According to the Shapiro-Wilk test results, the data did not show normal distribution and descriptive statistics were presented as means ± *SD*. The concurrent validity of the iVMES portable force plate system was examined using Pearson's correlation coefficient with 95% confidence intervals (CI) and Bland-Altman plots with limits of agreement (LoA) were also created to represent the agreement between two measurement devices (Bland & Altman, 1986; Bland & Altman, 1999). Typical error of estimate (TEE) was reported as a standardized score, and the magnitude of the TEE was interpreted using the following scale: <0.20, trivial; 0.2–0.6, small; 0.6–1.2, moderate; 1.2–2.0, large; >2.0, very large (Hopkins, 2011). Effect sizes (ES) were then calculated to assess the meaningfulness of difference (Hopkins, 2000), and Cohen's scale was used to interpret each ES (< 0.2 = trivial; 0.2 to 0.5 = small; 0.5-0.8 = moderate; > 0.8 = large).

Test-retest reliability of the iVMES force plate was assessed using the intraclass correlation coefficient ($ICC_{2,k}$) with 95% CI. Criteria thresholds for ICC reliability were as follows: <0.50, poor; 0.50-0.75, moderate; and >0.7, good (Koo & Li, 2016). The smallest error of measurement (SEM) was calculated by dividing the *SD* of the difference between test and retest by $\sqrt{1-\mathrm{ICC}}$ (Weir, 2005). The smallest worthwhile change (SWC) was determined to establish the meaningful change of the test-retest by multiplying the between-subject *SD* by the standardized effect size (ES) of 0.2 (Hopkins et al., 2009; Hopkins, 2004). If the SEM was smaller than the SWC, the ability to detect a change was considered "*good*"; if the SEM equaled SWC, the test was "*satisfactory",* but if the SEM was more significant than the SWC, then the test was rated a "*marginal"*. The Minimum detectable change (MDC) was calculated using the following formula; $\mathrm{MDC} = \mathrm{SEM}\,\mathrm{x}\sqrt{2}\;\mathrm{x}\;1.96$ (Haley & Fragala-Pinkham, 2006). Furthermore, the Root Mean Square Error (RMSE) was calculated to assess the measurement error for analyzing absolute reliability.

All analyses were performed using the Microsoft Excel (2019) statistical package using a Hopkins spreadsheet (Hopkins, 2017), and Number Cruncher Statistical Systems (NCSS) Statistical Software, Version 2022, for Windows. The significance level was set at $p<0.05$.

Results

A total of 64 jumps were simultaneously analyzed with two measurement devices. The VJH were 40.45 ± 5.22 cm and 41.19 ± 5.17 cm; the CMJ flight times were 573.13 ± 37.22 milliseconds and 578.5 ± 36.58 milliseconds for the Optojump and iVMES force plate, respectively (Table 2).

Concurrent validity

The ICC for the relationships between the two measurement tools was 0.98 (95% CI 0.97– 0.99). The ES of the mean difference (Optojump vs. iVMES) was trivial (ES = 0.14), and the TEE for the Optojump and iVMES force plate relationship was trivial (TEE = 0.18; 2.5%) (Table 2).

Table 2. Concurrent validity between two measurement devices for the measurement of VJH

	Optojump	iVMES force plate
VJH (Mean ± *SD*), cm	40.45 ± 5.22	41.19 ± 5.17
Flight time (Mean ± *SD*), msec	573.13 ± 37.22	578.5 ± 36.58
ICC (95% CI)	0.98 (0.97 – 0.99)	
Standardized bias (95% CI), cm	-0.14 (-0.19 – 0.10)	
± 95% LoA	1.83	
Pearson's *r*	0.98	
TEE (CV%)	0.18 (2,5%)	
Effect size (Cohen-*d*)	0.14	

VJH: Vertical jump height, CI: Confidence intervals; LoA: Limit of agreement TEE: Typical error of estimate

A nearly perfect correlation was found between the two measurement devices (r = 0. 6; p<0.001). The regression equations for the relationship between Optujump and iVMES force plate were as follows: $VJH_{iVMES\ force\ plate} = 0.53 + 0.97 \times VJH_{Optojump}$ ($r^2 = 0.96$, $p<0.01$) (Figure 2).

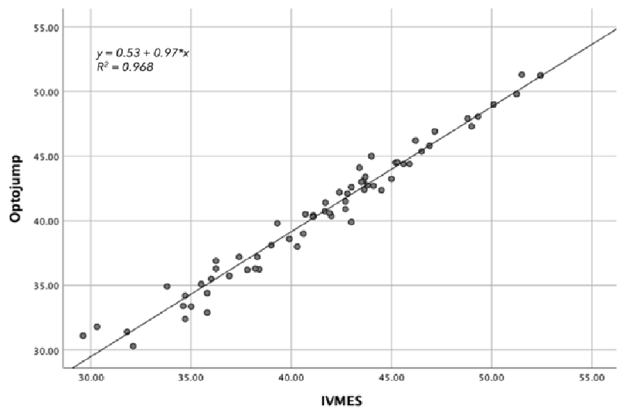

Figure 2. Pearson correlation of VJH between Optojump and iVMES force plate. Data dots represent CMJ values.

The Bland and Altman plot revealed significant systematic bias between the Optojump and the iVMES force platform. There were high agreements between the Optojump and iVMES force plate for assessing VJH (Figure 3).

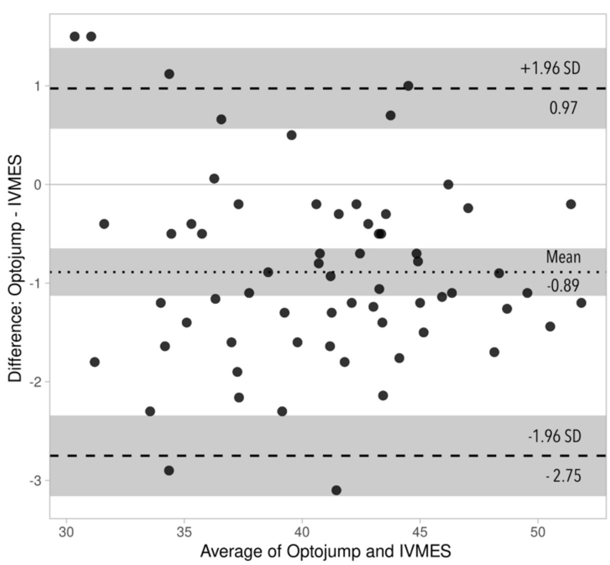

Figure 3. Bland-Altman plot with upper and lower LoA between VJH measured by Optojump and iVMES force plate

Test-retest reliability

Repeated measurements of VJH for the VMES force plate were 40.63 ± 5.31cm and 41.76 ± 5.05 cm, respectively, and test-retest reliability was excellent, with low CV (3.8%) and high ICC (0.96) for the VJH (Table 3).

Table 3. Test-retest reliability measurement of iVMES force plate for VJH estimation

	Test	Retest
Mean ± *SD* (cm)	40.63 ± 5.31	41.76 ± 5.05
ICC (95% CI)	0.96 (0.93 – 0.98)	
CV%	3.80	
SEM	0.05	
SWC	0.05	
MDC	0.14	
RMSE	1.85	

ICC: Intraclass correlation coefficient; CI: confidence intervals; CV: coefficient of variation; RMSE: Root mean square error

The VJH measurement acquired from the two devices had extremely low SEM, SWC (SEM equal to SWC; 0.05), and MDC (0.14) values, according to the reliability analysis. These investigations proved a very small, acceptable margin of error between the two measurements.

Discussion

According to literature, while it appears that the portable force plate systems may provide a realistic alternative to established systems it is necessary to quantify its validity and reliability. The primary objective of this study was to evaluate the concurrent validity and reliability of the iVMES portable force plate for assessing vertical jump height (VJH). The results demonstrated high concurrent validity and reliability of the iVMES force plate in comparison with the Optojump photoelectric system. Our findings align with previous studies that have investigated the validity and reliability of various laboratory and field-based force plates across different brands. Relative to the gold standard laboratory force platform, the Optojump has shown strong concurrent validity for jump height (ICC = 0.989; 95% CI = 0.97–0.99) low coefficients of variation (2.2%) and is recognized as a reliable tool for field-based VJH measurements (Attia et al., 2017; Glatthorn et al., 2011).

The accuracy and reliability of technologies utilized by sports scientists and trainers are critical for ensuring the quality of their measurements (Currell & Jeukendrup, 2008). It is crucial that the jump height values obtained from force platforms are both valid and reliable (Lake et al., 2019; Lombard et al., 2017). Previous studies have examined the validity and reliability of equipment measuring various jump heights (McMaster et al., 2021; Villalón-Gasch et al., 2024; Watkins et al., 2020). Notably, the validity and reliability of the Optojump photoelectric systems, which were used for validation in our research, have been established in previous study (Glatthorn et al., 2011). Additionally, in a study examining the concurrent validity and reliability of another portable force platform, it was determined that the portable platform positioned on the laboratory-based force platform had a high correlation (Lake et al., 2018). Test-retest reliability is as critical as the validity and internal reliability of measurements. Given that variations in biological conditions could influence daily measurement values, this study also incorporated test-retest reliability analyses, yielding an ICC of 0.96 across two separate sessions, with a coefficient of variation (CV) of 3.80%, a standard error of measurement (SEM) of 0.05, and a smallest worthwhile change (SWC) of 0.05.

Based on the findings of this study, the iVMES force plate has proven to provide accurate and reliable data. These findings clearly demonstrate that practitioners can utilize this very affordable portable force plate system instead of a laboratory-based force plate system to obtain appropriate measurements of vertical jump height. A limitation of this study is that it only focuses on measuring jump height due to limitations in current verification equipment. Future studies should investigate the validity and reliability of the newly developed iVMES portable force plate across different jumping protocols (e.g., drop jumps, squat jumps) and measurements (e.g., mechanical strength, reactive power index). It is also recommended that future research compare values at different stages of jumping with values obtained using gold standard methods.

Conclusion

As a conclusion, the scores obtained from the newly developed portable force plate exhibited high concurrent validity and reliability for measuring vertical jump height. The iVMES portable force platform, which is both lighter and less costly than its counterparts, has been validated as a reliable and effective device for both researchers and practitioners. The findings of this study confirm that it can serve as a trustworthy tool for measuring athlete performance and monitoring fatigue, and in order to record precise measurements of several vertical jump metrics, including CMJ, drop jump, and squat jump, practitioners can use this portable device instead of the laboratory-based force plate systems. This underscores its potential utility in sports science applications, providing accessible solution for ongoing athletic assessment. Sports scientists and coaches can use the iVMES portable force plate to assess the VJH of athletes with confidence, knowing that the device provides accurate and consistent measurements. This enables objective evaluation of athletic potential, identification of strengths and weaknesses, and individualized performance enhancement strategies. In adition, researchers can utilize the iVMES portable force plate for investigating various aspects of vertical jump performance, neuro-muscular fatigue, and training interventions. The availability of a validated measurement tool enhances the quality and credibility of research findings in the field of sports science and athlete monitoring.

Conflicts of interest

The authors declared no potential conflicts of interest with respect to the research, authorship, and/or publication of this article.

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