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Thomas M. Comyns
University of Limerick, Ireland

Jennifer Murphy
Technological University Dublin, Ireland, jennifer.murphy@tudublin.ie

Dylan O'Leary
University of Limerick, Ireland

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Reliability, Usefulness, and Validity of Field-Based Vertical Jump Measuring Devices

Thomas M. Comyns,^{1,2} Jennifer Murphy,³ and Dylan O'Leary¹

¹Department of Physical Education and Sport Sciences, University of Limerick, Limerick, Ireland; ²Sport and Human Performance Research Centre, University of Limerick, Limerick, Ireland; and ³Centre of Applied Science for Health, Technological University Dublin, Dublin, Ireland

Abstract

Comyns, TM, Murphy, J, and O'Leary, D. Reliability, usefulness, and validity of field-based vertical jump measuring devices. *J Strength Cond Res* 37(8): 1594–1599, 2023—The purpose of this study was to examine the test-retest reliability, usefulness, and validity of field-based devices, in determining jump height (JH) during a countermovement jump (CMJ). Twenty-one male (22.8 ± 2.4 years; 1.82 ± 0.07 m; 86.0 ± 10.4 kg) and 7 female field sport athletes (20.5 ± 1.5 years; 1.65 ± 0.06 m; 65.4 ± 7.2 kg) performed 3 CMJs with data simultaneously recorded using a force plate (criterion measure), Optojump, Output Capture, and Push-Band 2.0. Reliability was determined by intraclass correlation (ICC) and coefficient of variation (CV) analyses. Usefulness was assessed by comparing typical error (TE) with the smallest worthwhile change (SWC), and the validity analyses involved repeated measures analysis of variance with post hoc analysis, Pearson correlation coefficient (r), coefficient of determination, and Bland-Altman 95% limits of agreement analyses. All 3 field-based devices were deemed reliable in assessing CMJ height as the respective ICCs ≥ 0.80 and the CV $\leq 10\%$. Only the Optojump and Output Capture devices were rated as “good” at detecting the SWC in performance (Optojump SWC: $1.44 > TE: 1.04$; Output Capture SWC: $1.47 > TE: 1.05$). The Output Capture device demonstrated acceptable validity for CMJ height assessment, whereas the Push-Band 2.0 showed systematic bias when compared with the criterion force plate data. Systematic difference was also evident for the Optojump potentially due to the optical switching-cell position on the Optojump. Although all 3 devices showed excellent reliability, the Optojump and Output Capture devices offer practitioners a cost effective, reliable, and valid method of assessing the smallest worthwhile change in CMJ performance in an applied setting.

Key Words: performance testing, strength and conditioning, strength testing, technology, stretch-shortening cycle, plyometrics

Introduction

Vertical jump performance, particularly jump height (JH), is regarded as an important functional parameter for athletic populations (13). The countermovement jump (CMJ) is used to assess vertical jump performance as it can distinguish between populations of different training status (6), provide insight into an athlete's stretch-shortening cycle capacities (21), and effectively monitor neuromuscular fatigue (12). Countermovement jump assessment has extensively been performed on force plates in research and practice (21), as they are generally considered the “gold standard” for CMJ assessment (6,10). Strength and conditioning (S&C) coaches, however, have sought cheaper alternatives to assess their athlete's neuromuscular capacities (21) as limited access, cost, and time constraints make force plate CMJ assessment unsuitable for field-based settings (6).

The alternative field-based technologies and devices that have been developed and used in research and practice provide a more cost-effective, portable, instantaneous, and simplistic method of vertical JH assessment. Such devices include an optical timing system (6) (i.e., Optojump, Microgate, Bolzano, Italy) and inertial measurement units (IMU), e.g., Push-Band 2.0 (Push Inc., Toronto, ON, Canada) and Output Capture (Output Sports, Dublin, Ireland). It is essential, however, that any of these devices when used to assess CMJ performance and derive JH have adequate

validity and reliability (4,13). Data obtained from these devices are often used to prescribe, monitor, or alter an athlete's program and thus must have adequate reliability (4). Aligned to this is the need to assess the capability of these devices to determine the smallest worthwhile change (SWC) in performance, thus allowing practitioners to make a well-informed decision on whether a change in JH is both of practical significance and real (4). In general, research on field-based assessment of CMJ performance has failed to conduct such an analysis, and there is a need to establish and compare noise (typical error [TE]) and signal (SWC) derived by these field-based devices to allow inferences to be made on the true magnitude of individual changes in performance (5).

The Optojump system is a photoelectric cell system that consists of photoelectric circuits that are activated by interrupting infrared/laser beams (11). Such a system has advantages over the force plate as they are less expensive, can be used in a field-based setting, provide real-time data, and can be operated on any flat sport-specific surface, thus increasing its ecological validity (11,14). Research has indicated that the Optojump system has excellent test-retest reliability as reflected in intraclass correlation coefficients (ICCs) ranging from 0.982 to 0.989 and low coefficients of variation (2.2%) (13). Glatthorn et al. (13) also demonstrated that the system has excellent concurrent validity, but a level of systematic difference was evident between the force plate and Optojump system. Recently, Montalvo et al. (22) reported excellent reliability and validity for the Optojump when measuring JH by the CMJ. These studies, however, did not examine the usefulness of the system in detecting meaningful change, and

Address correspondence to Dr. Thomas M. Comyns, tom.comyns@ul.ie.

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further research is needed to assist practitioners in the applied setting. Sawczuk et al. (24) did examine the usefulness of the CMJ height derived using the Optojump system and reported this as “good,” but this study was performed with a youth cohort, and the findings may not translate to alternate population groups.

Recently, IMU devices have been used in the assessment of CMJ performance in the practical and research settings (20,23). These IMUs are small, inexpensive sensors consisting of accelerometers, gyroscopes, and magnetometers and help to bridge the gap between laboratory and “real-world” assessment of performance (23). The Push-Band 2.0 is one such IMU device and has been used previously in the assessment of CMJ performance (22,23). Research on the reliability and validity of this device is lacking, and only one paper to date has examined this with respect to CMJ height performance (22). This study by Montalvo et al. (22) reported high test-retest reliability for the CMJ, but the device showed both proportional and systematic bias, with an average overestimation of the CMJ height when compared with the force plate. No research to date has examined the usefulness of CMJ height derived through the Push-Band 2.0 device.

Output Capture is a newly developed IMU from Output Sports which uses machine learning algorithms to assess compound exercises, movement screening, track barbell velocity, assess reactive strength index, and jumping ability. Machine learning is the automated process that allows a device to learn from past experiences and make adjustments for better determination of future experiences without human interference (19). With Output Capture, these machine learning algorithms automatically detect take-off and landing phases of a jump, based off accelerometer signals. When developing this method, a data set, which captures a wide variety of movement patterns and JHs, synchronizing IMU signals with gold standard force plates is required. The time between the detected take-off and landing phases is considered flight time, and from this, JH is derived and displayed through the Output Sports app. As this device is new to the commercial market, research is limited, and this is the first study to examine and report the reliability, validity, and usefulness of CMJ height data derived through Output Capture.

Owing to the importance of CMJ measurements to practitioners, any field-based device needs to be deemed reliable, useful, and valid in assessing CMJ height performance. Previous research using IMUs and photoelectric cell systems has generally lacked the investigation of the usefulness of the devices in determining the SWC. In addition, research is limited regarding the reliability and validity of these devices in the calculation of CMJ height with no research to date on Output Capture and only 1 paper on the Push-Band 2.0. Therefore, this study aimed to determine the reliability, usefulness, and validity of the 3 field-based devices for measuring CMJ height and is the first to include the newly developed Output Capture device.

Methods

Experimental Approach to the Problem

A cross-sectional study design with repeated measures was used. All subjects took part in 2 testing sessions. Session 1 was the familiarization day, and session 2 was the testing day. On both days, 3 trials of the CMJ were completed, and data were simultaneously recorded by a force plate (AMTI OR6-5), photoelectric cell system (Optojump, Microgate), and 2 IMU devices, namely, Push-Band 2.0 (Push Inc.) and Output Capture (Output Sports). The data sets from the testing day were subsequently analyzed to determine the reliability and usefulness for all 4 devices in recording JH. In addition, the validity of the

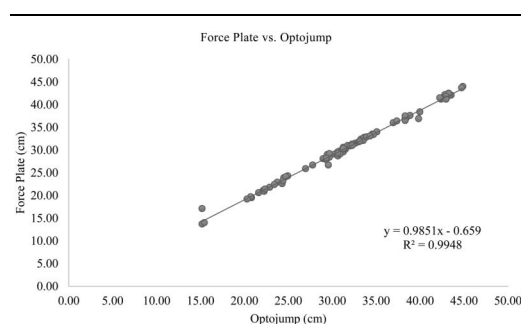


Figure 1. Scatter plot for force plate vs. Optojump.

photoelectric cell system and the 2 IMU devices for recording JH was determined in comparison with the force plate. The familiarization and testing day were separated by a 1-week period.

Subjects

Twenty-one males (mean $\pm$ SD, 22.8 $\pm$ 2.4 years; 1.82 $\pm$ 0.07 m; 86.0 $\pm$ 10.4 kg) and 7 females (mean $\pm$ SD, 20.5 $\pm$ 1.5 years; 1.65 $\pm$ 0.06 m; 65.4 $\pm$ 7.2 kg) participated in the study. The subjects came from various field-based sports such as Gaelic Football ($n = 12$), American Football ($n = 9$), Rugby ($n = 2$), Camogie ($n = 2$), Soccer ($n = 1$), Hurling ($n = 1$), and Tag Rugby ($n = 1$). All subjects competed at the collegiate level, had at least 6 months experience of resistance and plyometric training, and were familiar with bilateral vertical jumping training. Before the commencement of the study, subjects read and signed informed consent and completed the Physical Activity Readiness Questionnaire (PAR-Q). All subjects answered “No” to all questions on the PAR-Q. Approval for the study design was obtained before the commencement of the study from the University of Limerick’s Institutional Ethical Review Board, and all procedures were in accordance with the Declaration of Helsinki.

Procedures

The familiarization and testing sessions followed the same format and took place on the same day of the week and at the same time of the day to control for circadian variation (1). The subjects were instructed to wear running shoes and appropriate apparel for the testing sessions. They were tested individually in the biomechanics laboratory of the university. The sessions began with a standardized warm-up consisting of repetitions of bodyweight squats, lunges, and single leg gluteal bridging. This was followed by repetitions of the CMJ at increasing intensity. Visual demonstrations of the CMJ were provided during the familiarization session.

Once the warm-up was completed, the subjects completed 3 trials of the CMJ on the force plate. There was a 2 minute rest period between the end of the warm-up and trial 1 of the CMJ, and during this time, the Output Capture and the Push-Band 2.0 devices were placed on the subject. The subjects were instructed to complete each trial with maximum effort and to “dip down and up quickly with no

Table 1

Jump height (mean $\pm$ SD) descriptive data for all 4 devices.

Subjects	Force plate	Optojump	Push-band 2.0	Output Capture
Jump height (cm)	31.7 $\pm$ 7.1	30.6 $\pm$ 7.0	39.6 $\pm$ 6.5	31.3 $\pm$ 7.2

Table 2
Reliability and usefulness for JH collected and derived by the 4 devices.*

Variable	ICC	Lower 95% CI	Higher 95% CI	CV%	Lower 95% CI	Higher 95% CI	TE	SWC (0.2)	Rating	SWC (0.5)	Rating
Force plate	0.98	0.96	0.99	4.0	3.3	5.1	1.07	1.46	Good	3.64	Good
Optojump	0.98	0.96	0.99	4.4	3.6	5.6	1.04	1.44	Good	3.59	Good
Push-band 2.0	0.96	0.92	0.98	3.4	2.8	4.3	1.41	1.34	Marginal	3.36	Good
Output capture	0.98	0.96	0.99	3.8	3.1	4.8	1.05	1.47	Good	3.64	Good

*JH = jump height; ICC = intraclass correlation coefficient; 95% CI = 95% confidence interval; CV = coefficient of variation; TE = typical error; SWC = smallest worthwhile change.

pause at the bottom of the crouch, to explode off the ground, and jump to the roof" (8). No performance-related feedback was provided to the subjects during the completion of all 3 trials.

The JH for each trial was simultaneously collected by the force plate, Optojump, Output Capture, and Push-Band 2.0 devices. For all devices, JH was derived from the flight time (FT) data and determined using the equation $JH = (9.81 \times FT^2)/8$ from Bosco et al. (3) An AMTI OR6-5 ground-mounted force plate sampled at 1,000 Hz was used to record ground reaction force measurements for each jump, which was subsequently analyzed to determine flight time and derive JH. The Optojump (Microgate) system used in the data collection consists of 2 parallel bars connected to a laptop with one bar acting as a transmitter unit containing 96 light-emitting diodes positioned 0.003 m above the ground and the other bar acting as a receiver unit (14). When a jump is performed within the parallel bar configuration, the light is interrupted, which triggers the timer in the unit and records with a precision of 1 millisecond (14). The total time between interruptions is a measure of flight time, and from this, JH is derived as previously outlined. The Optojump bars were set up 1 meter apart lateral to the AMTI OR6-5 force plate.

Two IMU devices were also used during the trials to calculate JH during the CMJ. The Push-Band 2.0 (Push Inc.) is a wearable wireless IMU and is an accelerometer-based system that can be worn on the forearm, barbell, or on a waist belt (20). For this study, the Push-Band 2.0 was placed in line with the spine above the sacrum using the device-specific elastic waistband as per manufacturer guidelines. The Push-Band 2.0 was connected with the Train with Push app (version 4.6.2) on a personal Apple iPad. Output Capture (Output Sports) is an IMU that consists of a triaxial accelerometer, gyroscope, and magnetometer with a sampling rate of 1,024 Hz for CMJ analysis. The device was placed on the subject's left foot for all trials using a device-specific band as per manufacturer's recommendations. During testing, the Output device was connected to the Output Sports app (version 0.2.5) using Bluetooth on a personal smartphone device. The Output system uses a machine-learning algorithm which identifies take-off and landing phases of CMJ performance. From this, flight time is determined and JH is derived as previously outlined.

Statistical Analyses

Statistical analyses were performed using SPSS (Version 26; SPSS, Inc., Chicago, IL). Data were normally distributed as assessed by

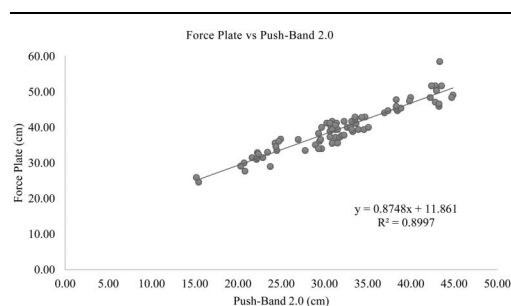
Table 3
Pearson's correlation coefficients and coefficient of determination results for the field-based devices.

	Force plate- Optojump	Force plate-Push- band	Force plate-Output Capture
<i>r</i>	0.997	0.949	0.982
<i>R</i> ²	0.994	0.900	0.964

the Shapiro-Wilk's test ($p > 0.05$). Reliability of the JH data collected for the 4 devices was calculated by determining the coefficient of variation (calculated as the typical error and expressed as a CV) and the ICC with 95% confidence intervals (95% CIs) using a Microsoft Excel spreadsheet (17). Acceptable reliability was determined at an ICC ≥ 0.8 and a CV $\leq 10\%$ (15).

Usefulness was determined by comparing TE to the SWC using a Microsoft Excel spreadsheet (15). The SWC was calculated by multiplying the between-subject SD by 0.2 (SWC_{0.2}), which represents a typical small effect and by 0.5 (SWC_{0.5}) which is an alternate moderate effect. In line with recommendations from Hopkins (16), the test was rated as "good" if the TE was below the SWC, as "ok" if the TE was similar to the SWC and as "marginal" in detecting a meaningful change if the TE was higher than the SWC.

All trials were used for the validity analysis. There were 28 subjects who each completed 3 trials, and therefore, 84 CMJ trials were analyzed to determine the validity of the JH data collected and derived by the Optojump, Push-Band 2.0, and Output Capture devices. The force plate was considered the gold standard method of JH determination. The validity analysis involved a repeated measures analysis of variance (ANOVA) with post hoc analysis, Pearson correlation coefficient (r), coefficient of determination (R^2), Cohen's d effect size (ES), and Bland-Altman 95% limits of agreement analysis. The repeated ANOVA analysis, r , and R^2 were computed through SPSS. The repeated ANOVA with post hoc analysis adjusted by Bonferroni correction was used to determine if there were any significant statistical differences in JH between the force plate and the field-based devices. Cohen's d ES were calculated and then interpreted as "trivial" ($ES < 0.2$), "small" ($0.2 \leq ES < 0.5$), "moderate" ($0.5 \leq ES < 0.8$), and "large" ($ES \geq 0.8$) according to the proposed scale by Cohen (7). The relationship between the force plate and field-based devices was assessed using r and R^2 , and this relationship was classified as "trivial" (0–0.1), "small" (0–0.3), "moderate" (0.3–0.5), "large" (0.5–0.7), "very large" (0.7–0.9), and "nearly perfect" (0.9–1.0) (18). Bland-Altman 95% limits of agreement analysis were computed using Microsoft Excel 2019 and used to

**Figure 2.** Scatter plot for force plate vs. Push-Band 2.0.

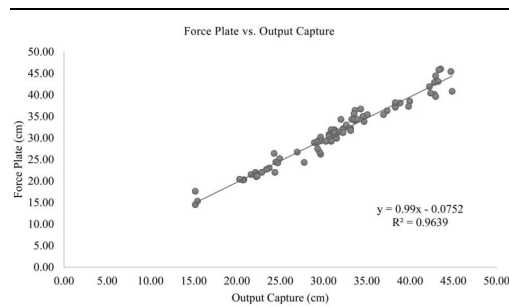


Figure 3. Scatter plot for force plate vs. Output Capture.

detect any systematic bias and difference between the force plate and field-based devices (2).

Results

In Table 1, the JH scores (mean [SD]) attained by the 4 devices are presented. In Table 2, the results pertaining to the reliability and usefulness analysis are detailed. Specifically, this table outlines the ICC, CV, TE, SWC_{0.02}, and SWC_{0.05} results. These results indicate that all 4 devices are reliable for measuring JH. The force plate, Optojump, and Output Capture devices were able to detect a “small” worthwhile change in JH. All devices were rated as “good” for detecting a “moderate” change in JH.

Regarding the validity results, the repeated ANOVA reported a statistically significant main effect for JH ($p < 0.001$). The post hoc pairwise comparisons identified that the JH derived by the Push-Band 2.0 was significantly larger than the JH reported by the force plate ($p < 0.001$). The percentage difference was 24.9%, and the Cohen's d effect size was 1.16, which is considered a “large” effect size (22). In addition, the post hoc pairwise comparison indicated that the Optojump measured a statistically significant lower JH than the force plate-derived JH ($p < 0.001$). The percentage difference in this case was 3.6%, and the effect size was 0.15, which is considered a “trivial” effect size (7). In Table 3, the results pertaining to the Pearson's correlation coefficients and coefficient of determination are presented, which show a “nearly perfect” and significant ($p \leq 0.01$) correlation

between the force plate and the field-based devices. These correlations are also presented in the scatter plots in Figures 1–3. A combined scatter plot highlighting the comparison of the results for all devices is presented in Figure 4.

The Bland-Altman 95% limits of agreement (LOA) analysis between the force plate and the Optojump device showed a mean bias $\pm 95\%$ LOA of 1.13 ± 1.02 (Figure 5). The mean bias $\pm 95\%$ LOA between the force plate and the Push-Band 2.0 was 7.9 ± 4.5 cm (Figure 6). For the analysis of the force plate with the Output Capture device, the reported mean bias $\pm$ LOA was 0.4 ± 2.7 cm (Figure 7).

Discussion

The aim of this study was to determine the reliability, usefulness, and validity of 3 field-based devices used to assess CMJ height. Limited research has been conducted in this area with no published research on the use of the newly developed Output Capture device in assessing CMJ performance. Establishing the reliability, usefulness, and validity of these field-based devices for measuring CMJ performance is paramount as the vertical jump is frequently used as a measurement of lower-body power in the S&C practical setting (22). Vertical JH is considered one of the essential athletic skills (13,22).

The Optojump, Push-Band 2.0, and the Output Capture devices all reported acceptable reliability for CMJ height assessment. The devices clearly met the threshold of ICC ≥ 0.8 and CV $\leq 10\%$ (15). The ICC and CV results for the Optojump photoelectric cell system (ICC = 0.98, CV = 4.4%) are in alignment with previous research by Glatthorn et al. (13) who reported an ICC of 0.989 and CV of 2.2%. Similarly, the Push-Band 2.0 showed acceptable reliability for CMJ height assessment as reflected by an ICC of 0.96 and CV of 3.4%. This result is consistent with previous research that has reported an ICC of 0.98 and CV of 7.05% for the Push-Band 2.0 (22). In addition, the Output Capture device is deemed reliable in this study for assessing CMJ height performance due to the reported ICC of 0.98 and CV of 3.8%. This result is in line with the reported reliability for the Push-Band 2.0 and Optojump devices. The reliability findings from this study provide further insight into the reliability of the CMJ height data derived

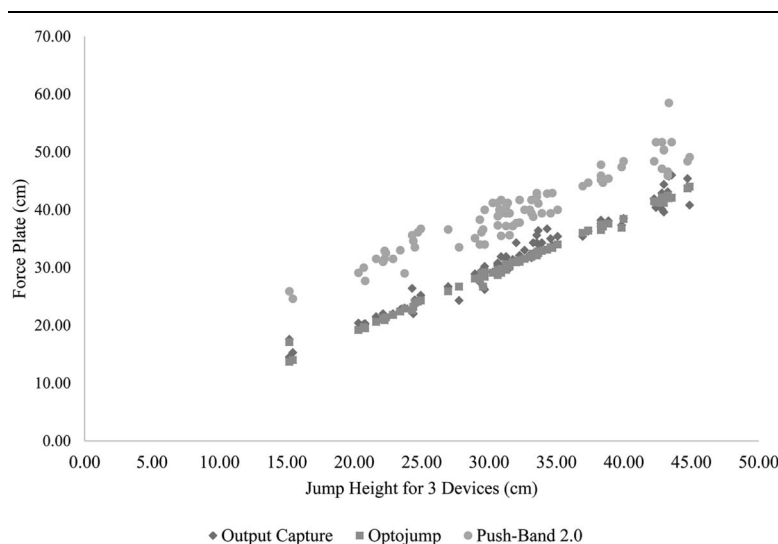


Figure 4. Scatter plot comparison for all devices.

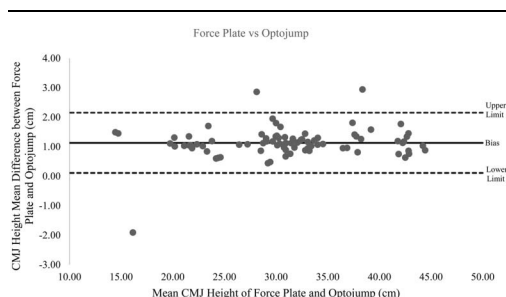


Figure 5. Bland-Altman plot for comparison between force plate and Optojump. Solid line is the mean bias, and dashed lines are the 95% upper and lower limits of agreement.

through these field-based assessment methods and indicate that all devices can provide excellent test-retest CMJ height reliable data for researchers and practitioners.

To assist practitioners in making decisions on whether a change in JH performance from one test to another is of practical significance, meaningful, and real, the testing protocol should demonstrate a “good” ability to detect the SWC (4,16). Weekly monitoring tests and associated protocols, such as CMJ height assessment by field-based devices, should be sensitive to small changes in performance to offer coaches the opportunity to precisely monitor and manage training loads and optimize preparedness (9). The Optojump and the Output Capture devices demonstrated a “good” ability to detect this smallest worthwhile change in CMJ height performance as the TE reported for both devices was lower than their respective $SWC_{0.2}$. This result pertaining to the Optojump is in agreement with Sawczuk et al. (24). No research has previously been conducted on the usefulness of Output Capture in assessing changes in CMJ height performance, and this study indicates that this IMU device has the potential to detect meaningful and small changes in CMJ performance. The Push-Band 2.0, however, was not able to detect the $SWC_{0.2}$ in CMJ height as the TE (1.41) was greater than the respective $SWC_{0.2}$ (1.34). In this case, any change in performance may be lost within the measurement error of the device. The analysis in this study also looked at the ability of the devices to detect a moderate change in performance ($SWC_{0.5}$), and all devices, including the Push Band 2.0, were rated as “good” for detecting this moderate change in CMJ height. These results provide insight into practitioners as they demonstrate that the Optojump and Output Capture can detect small changes in CMJ height performance which can subsequently assist practitioners in the monitoring, planning, and altering of athletes’ training programs.

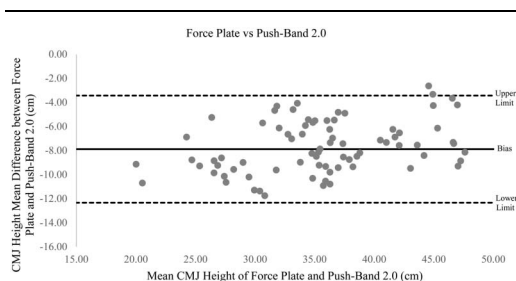


Figure 6. Bland-Altman plot for comparison between force plate and Push-Band 2.0. Solid line is the mean bias, and dashed lines are the 95% upper and lower limits of agreement.

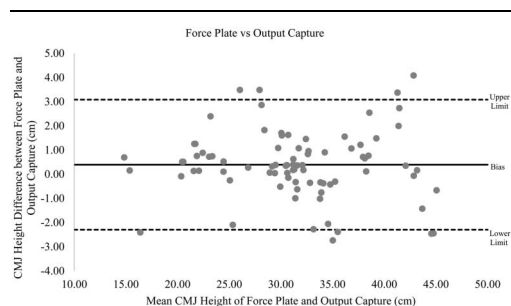


Figure 7. Bland-Altman plot for comparison between force plate and Output Capture. Solid line is the mean bias, and dashed lines are the 95% upper and lower limits of agreement.

The JH data from the field-based devices was compared with the “gold standard” force plate criterion data to ascertain if they are valid and thus measuring what is intended to measure. The correlation analysis indicated a “nearly perfect” and significant correlation between the force plate data and all 3 field-based devices. The coefficient of determination for the Optojump was 0.994, which is in agreement with a R^2 of 0.997 reported by Glatthorn et al. (13). The ANOVA and subsequent post hoc analysis revealed a systematic difference between the force plate JH data and the Push-Band 2.0 data and between the force plate and the Optojump JH data sets. Such a difference was not evident between the JH data derived from the criterion force plate and the Output Capture device. The mean JH data derived through the Output Capture device was similar to the force plate data with no significant difference reported.

The bias reported for the Push Band 2.0 was also evident in the Bland-Altman plot analysis, where a mean bias of 7.89 cm was reported with 95% LOA of 4.45 cm. This is higher than the mean bias and 95% LOA reported for both the Optojump and the Output Capture devices. This systematic bias evident here for the Push Band 2.0 aligns with the bias reported for this device in similar research (22). The finding regarding the Optojump aligns with previous research where systematic differences were noted with the Optojump generally recording lower JH scores mainly because of the position of the optical switching-cell position on the Optojump bars (6,13). The difference found in this current study had an associated “trivial” effect size with a mean bias of 1.13. It could be inferred that the Optojump has potentially acceptable validity and that any systematic difference is due to the optical switching-cell position on the Optojump. The validity analysis in our study, therefore, would indicate that the Optojump and the Output Capture possess convergent validity and thus can be used in the applied setting to assess vertical JH while performing a CMJ. This is the first study to assess and report on the validity of CMJ height derived from the Output Capture device. In line with research by Montalov et al. (22), the current findings question the validity of the Push-Band 2.0 in assessing JH during a CMJ performance.

All 3 field-based devices are able to reliably determine CMJ height. The photoelectric cell system, i.e., Optojump, and the Output Capture IMU possess convergent validity regarding CMJ height assessment when compared with the criterion force plate and are rated as “good” regarding their usefulness in detecting a meaningful change in performance. The Push-Band 2.0 showed systematic bias when measuring CMJ height and

lacks the sensitivity to detect the smallest worthwhile change in performance.

Practical Applications

Practitioners regularly assess vertical JH through the completion of the CMJ as a means of monitoring and tracking an athlete's preparedness, progression, and response to the training stimuli. Although the force plate is considered the "gold standard" device for determining CMJ height, it is generally not practical or feasible in the applied setting. Thus, there is the need for the use of field-based devices that can reliably and accurately determine the smallest worthwhile change in CMJ height. This study demonstrated that although the Optojump, Push-Band 2.0, and Output Capture can be used to reliably collect CMJ height data, only the Optojump and Output Capture can detect the smallest worthwhile change in performance. In addition, to obtain accurate and valid data without evidence of bias, the practitioner should aim to use either the Optojump or the Output Capture in the applied settings. Both devices can be used to monitor, assess, and track vertical jump performance during the execution of the CMJ. Caution must be exercised when using the Push-Band 2.0 for assessing CMJ height as it significantly overestimates CMJ height and can only detect a moderate change in performance.

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