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Concurrent validity and reliability of in-field vertical jump performance measures on sand surfaces

Svenja Wirtz[1],

Ross Julian[1,2],

Rieke Schmale[1],

Eric Eils[1], corresponding author

[1]Department of Neuromotor Behavior and Exercise, Institute of Sport and Exercise Sciences, University of Münster, Germany

[2] School of Sport and Exercise, University of Gloucestershire, England

Correspondence to:

Prof. Dr. Eric Eils,

Institute of Sport and Exercise Sciences,

University of Muenster,

Horstmarer Landweg 62b,

48149 Muenster, Germany

Phone: +49-251-8332468

Fax: +49-251-8332466

Email: eils@uni-muenster.de

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Validity and reliability of jumping performance on sand

Abstract

Beach sports, such as handball, volleyball, and soccer, involve dynamic actions, primarily jumps. Nonetheless, a need for more established measurement devices that are both valid and feasible in accurately evaluating jumping performance on sand surfaces. This study aims to assess the reliability and concurrent validity of My Jump 2 and an inertial measurement unit (VERT®) for quantifying countermovement jump performance on the sand. Twenty-one subjects performed five countermovement jumps on the sand. Jumping height was measured simultaneously by a force plate, VERT®, and MyJump2. The VERT® and MyJump2 reliability measures were evaluated using the intraclass correlation coefficients $ICC_{2.1;\,3.1}$. The day-to-day reliability of both devices and the inter- and intra-rater reliability of the MyJump2 was performed. The concurrent validity of the VERT® and MyJump2 were performed using $ICCs_{2.1,\,3.1}$, and Bland-Altman plots. A near-perfect agreement was seen for intra-rater (ICC= 0.98) and inter-rater reliability (ICC= 0.98) of the MyJump2. Moreover, a near-perfect agreement was also observed when comparing the MyJump2 to the force plate (ICC= 0.92), with a mean bias of -2.31 cm. The VERT® device only demonstrated a moderate agreement (ICC= 0.55) with a mean bias of 6.31 cm compared to the force plate, despite showing good day-to-day reliability (ICC= 0.79). The study's results indicate that MyJump2 is valid and reliable for assessing jump heights on sand surfaces, whereas VERT® cannot be recommended.

Keywords: Athlete monitoring; Beach sports; Testing; Counter-movement jump; Mobile measurement devices; Unstable surface

INTRODUCTION

Beach volleyball and emerging beach sports such as handball and soccer are becoming increasingly popular, resulting in noteworthy developments, such as in training and athlete management (15, 21, 24). All three-beach sports can be characterized by explosive accelerations, short sprints, frequent changes in direction, and a significant emphasis on diverse jumping techniques while being performed on the sand (9, 32-34).

Various types of jumps, including countermovement jumps (CMJ), squat jumps, and sport-specific jumps utilizing a run-up and/or arm motions, can quantify (vertical) jump ability in athletes. Studies conducted on firm surfaces have shown significant correlations between different types of jumps, indicating that jumping ability may not be limited to a specific jumping method but rather a more comprehensive overview of athletic ability (12, 28, 45). However, it is important to exercise caution when applying findings related to rigid surfaces to other types of surfaces. Sand surfaces are characterized by a low stiffness (2), resulting in higher absorbance of forces (17). Further, the uneven surface can lead to a greater range of motion of the ankle, hip, and knee and restricts the force transfer of the ankle due to its instability (17, 39). These factors may contribute to lower jumping heights within an individual compared to performance on rigid surfaces (3, 7, 14, 25). Research has attempted to relate jumping performance on rigid to sand surfaces; for example, Buscà and colleagues (7) examined the transfer of jumping ability between sand and rigid surfaces among experienced (national level) and amateur beach volleyball players. The study found lower coefficients of variation among experienced participants (CV= 1.82) compared to amateur players (CV= 4.26) in block jumps on the sand, suggesting that experienced athletes are better adapted to the unique demands of the sand surface, resulting in greater movement efficiency and higher jump heights. These findings explain that jump heights attained on firm ground correlate positively with those executed on sand surfaces among proficient beach athletes. However, such transferability may exhibit variability among less experienced players. Moreover, performance assessments conducted on sport-specific surfaces, such as sand in this case, more precisely align with the unique demands of beach sports. These considerations emphasize the significance of applying sand surface-specific testing to discern players' beach sports performance accurately.

However, it should be noted that the sand itself presents distinct challenges when performing valid and reliable testing. Sophisticated equipment such as force plates and motion capture systems are commonly used in sporting environments and provide a ‘gold standard’ measurement of jump performance. However, they are often confined to laboratory settings, may not be available or affordable to amateur and sub-elite teams, and are not often used to asses performance on the sand. Mobile methods for assessing jumping performance, such as optical measurement systems commonly employed for in-field testing (19), have frequently been underutilized in accurately quantifying performance. Previous studies have attempted to solve the challenge. For example, Bishop (3) used a Yardstick measuring device that can be easily placed on a sand surface. While the results exhibit promising correlations, it is important to note a mean difference of approximately 8%. While this difference might appear modest, this finding can be considered significant when contextualized within comparisons involving athletic populations. Furthermore, it is essential to acknowledge the limitations inherent in interpreting jump heights through these particular devices. Hence, these findings should be considered with caution. (31).

Conversely, Buscà and colleagues (7) used a high-speed video camera system and noted that overall, cameras and visual inspections of jumps are suitable for evaluating performance on sand surfaces. However, the use of the system can be deemed as limited as the immediacy of testing results (data transfer and utilization of further programs to obtain jump height) while requiring a specialized setup, minimizing its feasibility for regular usage. Nevertheless, technological advancements have made cameras accessible and readily available on phones and tablets. To further simplify the process, mobile-based applications with predefined algorithms can be used and thus allow for more immediate results. MyJump2, a mobile-based application, is a low-cost, practical application requiring no specialist equipment or training and uses a phone or tablet video camera to measure vertical jump performance (40). This tool has been previously shown to possess excellent reliability (ICC= 0.99) and agreement with force plates on firm ground (ICC= 0.99) (1). Moreover, it is validated across various populations (1, 4, 8, 16) and sporting types (16, 22). Although the tool shows promise, it is unknown whether it can be used on other surfaces, such as sand. Therefore, validation appears necessary to confirm its accuracy and reliability.

A recent study by Schleitzer and colleagues (36) found a sensor-based IMU system to be a valid device for measuring jumping performance on the sand compared to force plates in a self-designed sandbox in the lab (ICC= 0.95). However, this technology for the application of measuring jumps is still in its infancy and requires specialists to analyze the signals, which limits its direct applicability. Possible solutions include the emergence of user-friendly systems based on inertial measurement units (IMU), which already exist for in-field measurements of jumping. The VERT® is a user-friendly commercially available IMU technology that is a discrete wearable that directly measures vertical jumping height through vertical displacement using a proprietary algorithm (11). The device has been primarily used to assess jumping performance in sports such as volleyball on rigid surfaces but not on sand. VERT® was previously considered a valid tool to evaluate CMJ performance (ICC= 0.93) (38). However, there remains doubt over the quality and consistency of jumping measures with this device (11), especially on a sand surface.

Even with the existence of previously validated methods for assessing jump performance on sandy surfaces, there remains an ongoing requirement to develop practical techniques that can be readily employed in field settings by teams with diverse performance levels while consistently delivering reliable and valid data. To address this need, the current study evaluates the concurrent validity and reliability of two techniques, MyJump2 and VERT®, compared to the established gold standard of a force plate. This evaluation will be conducted within a standardized laboratory environment, ensuring a robust and controlled assessment of these methods' performance.

METHODS

Experimental Approach to the Problem

The general design of the study was to evaluate the quality criteria of in-field devices to measure jumping performance on an ecologically valid surface for sand-based sports. Subjects performed five maximal CMJs in a custom-built sandbox on two consecutive days (day-to-day reliability). These jumps were simultaneously measured by two portable measurement devices (app-based, MyJump2, and IMU-based, VERT®) and compared to a criterion measure, force plates (concurrent validity).

Subjects

Twenty-one subjects (6 females, 15 males) (age: 19.8 ± 1.5 years, height:182.1 ± 9.6 cm; weight: 75.7 ± 10.1 kg) participated in the study. All were University sports science students and physically active as they performed a minimum of 2 (range: 3-7) exercise sessions per week (endurance and strength training); three performed at the semi-professional level. However, no subject has participated regularly in sports performed on sand surfaces. All participants refrained from strenuous activity 24h before measurements and were free of injury on the day of testing. Before the measures, subjects were informed of the benefits and risks of the investigation before providing their informed consent. All procedures performed were per the Declaration of Helsinki and were approved by the local ethics committee (ID 2021-53-EE).

Procedures

Sand measurements were performed on force plates using a customized and authenticated sandbox (size 1.0 m x 1.0 m x 0.3 m) placed on three force plates (36). The sand used (grain size: 0.1-1.0 mm; grain form: round to rounded edges; grain distribution: even; ($CaC0_3 \leq 2$-3%; $SiO_2 \geq 95$-98%) was approved by the Federal Institute of Sports Science (BISp) and the German Beach Volleyball Federation (DVV) as indoor sand (5). The filled box weighed approximately 1000 kg. The force plates (Type: 9287C, Kistler, Switzerland) recorded ground reaction forces with a sampling frequency set at 1500 Hz. An iPad (7th generation, IOS 15.6.1, 128 GB, MW772FD/A) with the app MyJump2 (Version: 1.0.5) was placed on a tripod in front of the sandbox. The iPad had a camera with a quality of 720 px with 120 fps. MyJump2 advises users to level the camera with the ground and foot to detect take-off and landing adequately.

However, this is not suitable for sand surfaces as the feet sink into the sand. The iPad was adjusted on a tripod to observe the participant's feet during take-off and landing. Additionally, it was centered 80 cm in front of the sandbox at the height of 95 cm (it should be noted that the sandbox had a height of 30 cm) and tilted to an 80° angle. In addition, a VERT® sensor (VERT®; version 2.0, Mayfonk Inc., Fort Lauderdale, FL, USA) was placed in an elastic belt worn at hip height and used to detect jumping height. VERT® is a proprietary system including an IMU equipped with a 3-axis gyroscope and a 3-axis accelerometer. All measurements were performed simultaneously. The experimental setup is shown in Figure 1.

Firstly, subjects were equipped with the VERT® sensor. Participants were instructed to perform two consecutive CMJs in the sandbox to familiarize themselves with jumping on the unstable surface. Participants started in a hip-wide stance with fully extended knees. Hands were placed on hips throughout the jump. The technique for executing a CMJ involves initiating the movement with a rapid downward motion to a self-selected depth that does not exceed a knee angle of 90 degrees (4, 27). This is followed by a direct extension of the legs, generating upward jump movement. While in the air, the legs were required to be straight, and an ankle plantarflexion should be performed during the landing phase. When incorrect executions were observed, they were corrected immediately, and the jump had to be repeated. Five maximal CMJs were performed for the measurements with a break of 1.5 min between each jump (subjects had to leave the sandbox). The sand surface was leveled to standardize jumps and ease push-off detection for later analysis during the break. Each jump was recorded with force plates, MyJump2 and VERT® simultaneously. This procedure was conducted on two consecutive days (days 1 and 2) with 24h in-between measurements. Participants refrained from exercising between the two measures.

Figure 1. A custom-built sandbox (size 1.0 m x 1.0 m x 0.3 m) was placed on three force plates to measure jumping performance on the sand surface in a controlled laboratory under consistent environmental and sand conditions. The iPad (7th generation, IOS 15.6.1, 128 GB,

MW772FD/A) with the MyJump2-software is shown on the left border of the figure (on the tripod).

Force plate data was processed via MatLab (The MathWorks Inc., Natick, USA). First, relevant parts of the ground reaction force data's raw, unfiltered vertical component were visually inspected. Next, an algorithm automatically detected flight time (force values less than or greater than 20 N). A threshold of 20 N was used to account for oscillations in the vertical force data due to the vibration of the sandbox. The steep slope of the GRF curve just before take-off or landing, in combination with the high measuring frequency of 1500 Hz, assured that deviations between the occurrence of 20 N and around 0 N were at a maximum of 1-2 ms. Previous studies have extensively validated this algorithm (13, 36). Three individual raters (Rater 1, Rater 2, and Rater 3) analyzed the recorded videos of the jumps and manually rated each jump's take-off and landing frames. All raters followed specific instructions to select the first frames displaying both feet off the ground and at least one foot touching the ground to indicate take-off and landing. Two raters were classified as experts (Rater 1, Rater 2) who had previous experience analyzing jumps on rigid and sand surfaces. In contrast, one rater was considered a novice (Rater 3) as he had no prior experience. Jumping height for both the force plates and MyJump2 was calculated via the equation: $h= t^2 \times 1.22625$, with the being the flight time in ms (6). VERT® calculated jumping height via a proprietary algorithm with accompanying sampling frequency. Data was immediately transferred via Bluetooth to the linked computer file. Eighteen jumps were not detected by VERT®, leaving fewer jumps for analysis (N=192, 91.4%).

Statistical Analyses

Statistical analyses were performed using an open-access program, Jamovi (Version 2.2.2, The Jamovi project (2021), https://www.jamovi.org), and the SymplyAgree-package reliability analysis. For each device, data are presented as means ± standard deviations (SD) (Force plate and MyJump2, n=210; VERT®, n = 192). Two-way random, single-rating model intraclass correlation coefficients for absolute agreement ($ICC_{2,1}$) was used to determine the intra-rater reliability of rater 2 (randomly selected rater). To determine the inter-rater reliability of MyJump2, a two-way random, single-rating model for both absolute agreement ($ICC_{2,1}$) and consistency ($ICC_{3,1}$) was used. The day-to-day reliability of the VERT® and MyJump2 was determined using the $ICC_{3,1}$. VERT® and MyJump2 were assessed against the force plate using the ICC for absolute agreement ($ICC_{2,1}$) and consistency ($ICC_{3,1}$). ICCs were conducted with their associated confidence intervals [CI] set at 95%. The determination of the ICCs was in accordance with Koo and colleagues (23) and interpreted according to the following criteria: <0.50, poor; 0.50-0.74, moderate; 0.75-0.90, good; ≥0.90, excellent (23). To assess the validity of the MyJump2 and VERT®, Bland-Altman plots were used to visually display systematic bias between the force plate and the measurement methods.

RESULTS

Intra-rater reliability of MyJump2 resulted in mean jumping heights of 27.8±6.6 cm (day 1) and 27.6±6.5 cm (day 2). Intra-rater-reliability ICC estimates and 95% confidence intervals showed excellent reliability ($ICC_{2,1}$= 0.98 [0.97-0.98]).

Inter-rater-reliability ICC estimates and 95% CI were excellent among expert raters both for absolute agreement and consistency and showed a minimal absolute difference between results. Between experts and novices, ICCs for absolute agreement indicated *good* reliability; however, their CIs ranged from *poor* to *excellent.* Regarding consistency, ICCs, and their 95% CI were *excellent* between experts and between experts and novices (Table 1).

Table 1 - Inter-rater reliability of jumping performance for MyJump2-app. Data are expressed as absolute difference ± standard deviation and ICC with accompanying 95% confidence intervals

	Absolute difference (cm)	ICC absolute agreement	ICC consistency
Rater 1 vs Rater 2	0.1 ± 1.3	0.98 [0.98-0.98]	0.98 [0.98-0.98]
Rater 1 vs Rater 3	2.9 ± 1.6	0.88 [0.13-0.96]	0.97 [0.96-0.98]
Rater 2 vs Rater 3	2.8 ± 1.8	0.88 [0.21-0.96]	0.96 [0.95-0.97]

Results for one randomly selected rater (Rater 1) evaluating measurements for days one and two showed mean jumping heights of 27.9±6.3 cm and 27.9±6.9 cm for days 1 and 2 for MyJump2, and 35.9±5.8 cm and 35.7±6.3 cm for day one and two for the VERT®, respectively. ICC estimates for consistency and 95% confidence intervals revealed *good* to *excellent* ($ICC_{3,1}$= 0.91 [0.87-0.93]) for MyJump2 and *moderate* to *good* ($ICC_{3,1}$= 0.79 [0.72-0.84]) results for the VERT®, respectively.

Inter-device ICC estimates for absolute agreement, and 95% CI revealed *poor* to *excellent* and *poor* to *good* for force plates against MyJump2 or VERT®, respectively.

Regarding consistency, ICCs were *excellent* for MyJump2 and *good* to *excellent* for VERT® (Table 2).

Table 2 - Reliability between measuring systems (force plates-the gold standard, the MyJump2-App and the VERT®-system. Data are expressed as mean ± standard deviation and ICC with accompanying 95% confidence intervals [CI].

	Jump height (cm)		Bland Altmann parameters			ICC	
			Bias	LoA -	LoA +	absolute agreement	consistency
MyJump2 vs Force plates	29.6 ± 6.6	30.2 ± 6.5	-2.3	-5.2	0.5	0.92 [0.30-0.97]	0.98 [0.97-0.98]
VERT® vs Force plates	35.8 ± 6.0	29. 7 ± 5.6	6.2	0.2	12.1	0.55 [-0.05-0.80]	0.86 [0.83-0.89]

The Bland-Altman Plots (Figures 2 and 3) indicated a bias of -2.3 cm was identified for MyJump2 against the criterion measure, with limits of agreement (LoA- and LoA+) ranging between -5.2 to 0.5 cm. VERT® indicated a systematic bias of 6.2 cm, with limits of agreement (LoA- and LoA+) ranging from 0.2 to 12.3 cm.

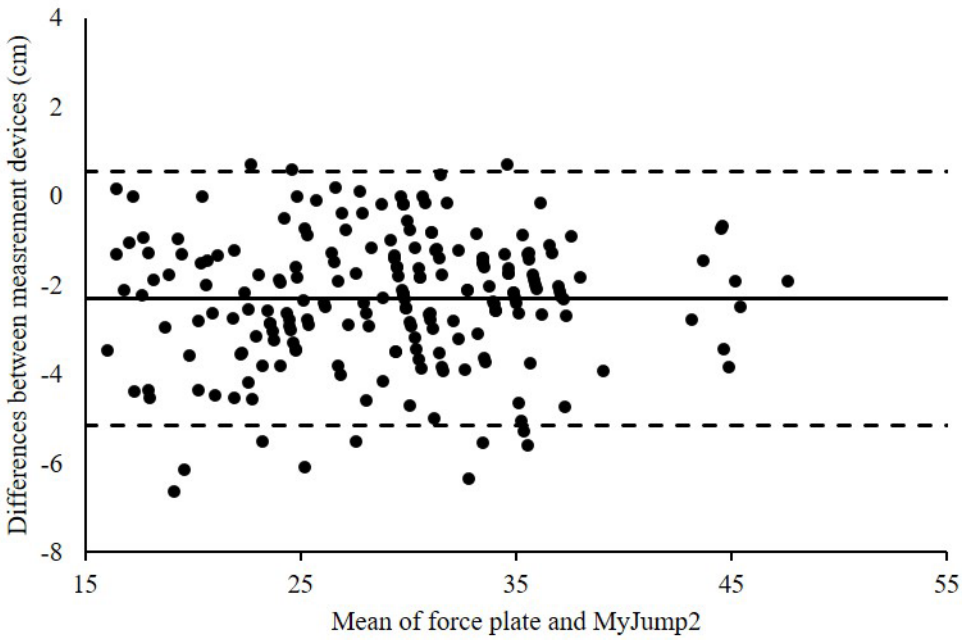

Figure 2. Bland-Altman plot for comparison of system pairs: Force plate against MyJump2. Every data point represents the average (x-axis) and the difference (y-axis) of the two systems on the mean outcomes for a single jump.

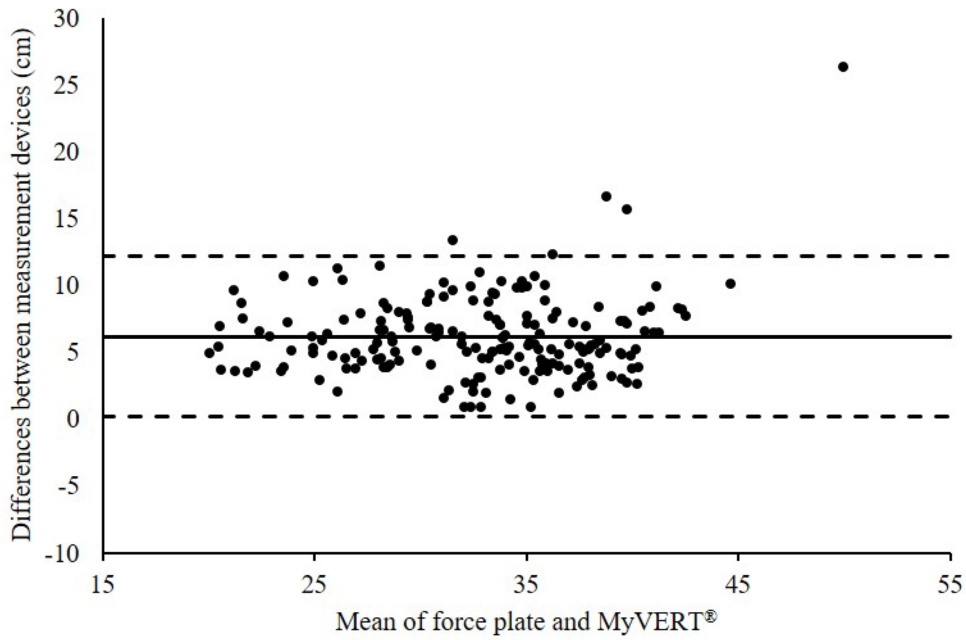

Figure 3. Bland-Altman plot for comparison of system pairs: Force plate against VERT®. Every data point represents the average (x-axis) and the difference (y-axis) of the two systems on the mean outcomes for a single jump.

DISCUSSION

In the present investigation, a comprehensive evaluation of the concurrent validity and reliability of MyJump2 and VERT® was performed within a standardized laboratory environment. The results indicate that the MyJump2 was highly reliable and held strong convergent validity for CMJ measurements on the sand surface, with a minor average jump height overestimation of 2.3 cm. In contrast, the IMU (VERT®) system was less reliable and systematically overestimated jump heights with a mean bias of 6.2 cm.

The video-based assessment MyJump2 showed *excellent* intra-rater reliability (absolute agreement). Mean differences were 0.2 cm (same data, same rater, one week later) and 0 cm, 0.8 cm, or 0.9 cm for day-to-day reliability of Rater 1, 2, and 3, respectively. Thus, the occurrence of a random error can be kept minimal, and only the systematic error must be controlled for. Although the error was not assessed, Bishop (3) reported a strong to very strong correlation between CMJs, squat jumps, block jumps, and spike jumps on land in state-level beach volleyball players, thus leading to the conclusion that vertical jump ability can be seen as a general athletic ability. Further, correlations between sand and land were reported as very strong. However, it is important to note that while the jump height was consistently lower on the sand, there was considerable variation in the ranges of individual athletes and differences in ranges depending on the type of jump. More experienced players showed a lower variation of jump heights than novices. The correlation reported by Buscà and colleagues (6), although also significant ($p < .05$) for block jumps on sand and rigid ground, is considered only moderate ($r= 0.67$). Accordingly, though previous modalities like the vertec device and fixed position video camera system have shown some usefulness in field sand testing, their effectiveness is considered less robust when compared to the current findings, suggesting that MyJump2 is a more accurate tool for assessing jumping performance on the sand.

To further reduce variation the level of agreement between raters is essential for practical purposes, meaning that comparisons between individuals or teams can be afforded when different raters complete the MyJump2 assessments despite the difficulties of measuring on a sand surface. Notably, Stanton and colleagues (41) showed intra-rater reliability of ICC= 0.99 and a mean difference of 0.4 cm on firm ground, further suggesting that it could be advantageous to minimize the random error if the same rater evaluates the jump performances. The inter-rater reliability of CMJ performance measurements on sand surfaces using MyJump2 (see Table 1) was *good* to *excellent* for absolute agreement and *excellent* for consistency between expert raters (Rater 1 and Rater 2). It is important to note that using a standardized protocol for take-off and landing times, as provided by the app's instructions, is crucial for obtaining quality outcomes, especially when measuring on sand surfaces. Familiarization trials for raters are also recommended to ensure consistent detection of take-off and landing. While the reliability between expert raters and the novice rater (Rater 3) showed lower ICC values, it was still considered *good*. The mean deviation of Rater 3 results from the expert raters' mean was 3 cm on average. However, when Rater 3's results were removed, the absolute agreement between the expert raters was *excellent*. These findings contrast with a study by Pueo et al. (35), who found no difference in reliability between trained and untrained raters when measuring jumps on firm ground, highlighting the challenges of measuring jumping performance on sand surfaces. Still, with the help of an adequate protocol for take-off and landing detection, MyJump2 provides reliable results highlighting the applicability of coaches to obtain data on sand surfaces.

It is important to note that the results obtained from the present study cannot be directly compared to the existing literature evaluating the reliability of MyJump2, as no validation on unstable and– especially- the sand surface has been conducted for MyJump2. Yet, the results of MyJump2 are in line with studies conducted on firm ground with ICCs ranging from *good* to *excellent* (1, 4, 8, 10). The mean difference exceeds the values by Stanton and colleagues (41) and Gallardo-Fuentes and colleagues (16) of -0.21 cm ± 0.84 cm and 0.1 cm ± 0.7 cm, respectively. It was anticipated that the mean difference might augment due to the complexity of detecting take-off and landing events in the presence of airborne sand particles that obscure visibility and the difficulty of detecting foot movement when sinking in occurs. Despite the technical detection aspect, jumps produced by the participants can show a higher variability from a biomechanical standpoint due to the uneven surface.

Although Buscà and colleagues (7) used a video approach to detect jumping heights on the sand, their camera system was set at the level of the sand surface. Yet, the authors do not address that differences in flight time detections of block jumps on sand might be skewed based on detection difficulties. If the participant exerts a significant amount of force on their forefoot, this will cause the sand to compress, resulting in a depression below the original sand level. Consequently, a take-off could occur beneath the initial baseline level of the sand surface and first contact with the surface when landing. Employing an elevated, angled video camera configuration, while contrasting to the preliminary instructions of MyJump2 for firm ground, proved to be effective in addressing the challenge. Overall, MyJump2 underestimates jumping performance (see Figure 2 BAP 1), and the Bland-Altman plots show a range of 7 cm (95% CI), which is not optimal when accounting for maximal jumping performance. One potential explanation for the underestimation and increased range is the measuring frequency (fps of the video camera) in contrast to the high measuring frequency of the force plates (120 Hz vs 1500 Hz). An increased fps rate in future smartphone models may reduce this bias and increase take-off and landing frame accuracy. While this range might be a limitation for single-time maximal performance assessments, longitudinal measurements across a season can add value to the athlete's development as *good* to *excellent* inter-rater reliability can be reported. Moreover, measurements can be an initial marker for discerning proficient athletes in an ecologically valid setting.

In contrast, the VERT® measurement device appears unsuitable for jump performance diagnostics on sand surfaces due to the extensive LoA (12.3 cm) (see Figure 2 BAP). These large LoA values exceed the acceptable range for high-level performance diagnostics in sports and the accurate interpretation of test results following training or intervention. The findings align with Schmidt and colleagues (37), reporting an LoA of 15.3 cm for volleyball block jumps and 13.2 cm for attack jumps. An individual analysis by Schmidt and colleagues (37) revealed a broad range of LoA for individual participants. A possible factor could be different performance levels and resulting jumping techniques of participants (sixth to first German division); moreover, specific jumping techniques (block and spike) might also play a role compared to conventional jumps. In the current study, VERT® presented lower values of reliability when compared with force plates. It can be assumed that VERT® has not been programmed for jump detection on sand surfaces. This is important as measured peak acceleration signals on sand can be lower, and the sand surface equalizes a longer force generation as force is differently transmitted through the surface (18). This may account for the failure to detect 18 jumps (8.5%) in the present investigation. Similarly, Schmidt and colleagues (37) found as little as an 83% jump detection accuracy depending on the sand surface's jump type. MacDonald and colleagues (26) also reported a difference between visually counted and detected jumps on firm ground. Possibly, VERT® did not pick up several jumps, as a pre-set minimal vertical displacement of 15 cm is pre-programmed within the device (26). Some jumping heights in our study were under 20 cm, which might not meet the programmed acceleration rate of the device. Further, VERT® unsystematically measures jumping heights with a broad range of 12 cm. Therefore, the current study's findings suggest that there are too many limitations to recommend the use of VERT® on sand surfaces. A recent paper by Schleitzer and colleagues (36) used an IMU system programmed to measure jumping height on sand surfaces and thus accounting for priorly mentioned components in its algorithm. Considering that further improvements are implemented, IMUs are promising devices to detect jump load and height on the sand in athletes, as *good* ($ICC_{all\ trials}$= 0.86) to *excellent* ($ICC_{corrected\ for\ coefficient\ of\ variation}$=0.92) reliability compared to force plates was reported (36).

Studies investigating other mobile measurement devices assessing vertical jumping performance have also reported similarly high or even higher mean differences on the firm ground than those reported in the present study (20, 43). This addresses the complexity of measuring jumping performance as different calculations and parameters are possible for height calculations (30). Further, even the participant's movement execution can have an influence, as previously demonstrated by the research of Yamashita and colleagues (44); however, movement excursion has been modulated by standardized instructions in the current study. Efficient jumping on sand requires a lower knee angle than on the firm ground, and push-off over the feet might be altered via the ankle joint (17, 18, 42). A result could be a higher intra- and inter-participant variability. Measuring jumping performance on sand surfaces presents unique challenges, as the take-off and landing positions vary largely compared to firm ground. This variability arises due to the sinking and shifting nature of the sand (2). Video-based approaches have emerged as an effective means to address this concern. Therefore, employing methods such as MyJump2 as an in-field measurement tool holds excellent promise. Future research should aim to comprehensively validate the potential of MyJump2 and ensure accurate evaluations on sandy surfaces; conducting further longitudinal research with practical implementation across various types of jumps would be highly beneficial.

LIMITATIONS

This study poses some limitations which must be addressed. In the scope of this experiment, the force plates are set as the gold standard for measuring vertical jumping performance, supported by literature for measurements on firm ground (8, 16, 20, 29) without indications for the sand surface. However, whether this method is considered the gold standard is still being determined, albeit with increasing research using methodologies similar to the present study (13, 17, 25, 36). Yet, it should be noted that the sand is limited within a sandbox and might behave differently in an on-field situation. However, this is unlikely when performing simple vertical jumping actions.

Furthermore, a wooden-sand box picks up vibrations generated by the forces acting during the push-off and landing and from the movement of the sand itself. Those vibrations will be picked up by the force plates and controlled. In the present study, Matlab algorithms account for these vibrations in detecting the flight time of athletes.

Another aspect that can highly influence the performance of sand is sand moisture. A different moisture level changes the surface's properties and allows for an additional force generation between sands (8); the measures were performed in the same and controlled environment. However, small changes in moisture could not be controlled.

PRACTICAL APPLICATIONS

MyJump2 is a valid and reliable tool for assessing CMJ height on the sand. However, this cannot be suggested for the VERT®. Therefore, MyJump2 can be used confidently to monitor within-group changes over multiple measurements, which can be important for monitoring fitness, the success of specific training interventions, and determining fatigue. Moreover, it could also be considered an effective tool for comparing jumping performance cross-sectionally. This could be important for talent identification (for example, establishing reference ranges for different competitive levels). MyJump2 could also be considered an affordable, more user-friendly, and more appropriate portable application. However, it is recommended that practitioners follow similar instructions when determining take-off and landing.

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