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ORIGINAL ARTICLE

Validity and reliability of the VXSport (Omni) device on basketball movement parameters

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ABSTRACT

The use of inertial devices in sport have become increasingly common. The aim of this study was to examine the within-day validity and reliability of a relatively new inertial measurement unit at measuring basketball movement parameters. Eighteen well-trained basketball players completed several individual performance tests including linear running and change of directions, acceleration, and decelerations, jumping and impacts to measure the validity and reliability of the microtechnology. The players also completed a specific test called the Basketball Exercise Simulation Test (BEST) to investigate whether the microtechnology could accurately detect more dynamic movements. Pearsons's correlations were determined linking assessments of the practical measures taken from the inertial measurement unit to criterion measures. Testing revealed good validity between the microtechnology and criterion measures with the 20 m run test at various velocities (6 km.h^{-1}, 12 km.h^{-1}, 18 km.h^{-1}, 24 km.h^{-1}, maximal speed km.h^{-1} (mean bias <5%). However, total distance, body collisions, accelerations and decelerations showed lower validity (mean bias >10%). Total distance, number of sprints, number of sprints >15 km.h^{-1}, number of decelerations >3m.s^{-2}, number of accelerations and decelerations showed very large to nearly perfect reliability (ICC = 0.88 – 0.99). Whereas, relative distance (m.min^{-1}), maximal speed (km.h^{-1}), total number of accelerations (>3 m.s^{-2}), total number of jumps, average heart rate showed high reliability (ICC 0.77 – 0.87). These results demonstrate the units were able to accurately detect most basketball movement patterns correctly with good repeatability.
Keywords: Performance analysis, Inertial measurement units, Sports technology, Sensors.

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INTRODUCTION

Monitoring of movement patterns in basketball can be employed to quantify a range of variables including training and competition loads (Fox, Stanton, & Scanlan, 2018), recovery levels, and individual performance parameters (Edwards et al., 2018). These parameters are important as they are closely aligned with performance-related outcomes such as fitness (Fox, Scanlan, & Stanton, 2017), fatigue (Edwards et al., 2018), and injury risk (Weiss, Allen, McGuigan, & Whatman, 2017). Such monitoring can provide large datasets to inform player management strategies, however, monitoring external load presents unique challenges due to the accessibility and cost of commonly used methods. For example, global positioning systems (GPS) are typically used to quantify external load variables such as speed and distance in field-based team sports, but GPS units are not able to be used indoors. Movement metrics such as distance, speed, acceleration, and jumps for indoor team sport players have historically been determined using video-based time-motion analysis (TMA) which takes considerable time and resources to process. To alleviate the poor GPS signal indoors, local positioning systems (LPS), which are a GPS-type system that works by using three or more short-range signalling nodes inside a training or game facility, have been developed to provide GPS variables for indoor environments. However, LPS are often expensive and while the indoor nodes are removable, it is not feasible to relocate these when training and playing at alternate venues due to the time and complexity of transporting and setting up these systems in a new facility.

Given the limitations of current movement tracking systems, there is increasing interest in the use of microsensor technologies such as inertial measurement units to measure external loads in sport (Fox et al., 2017). These inertial measurement units are the most common microsensors for monitoring external load in basketball (Fox et al., 2018; Montgomery, Pyne, & Minahan, 2010; A. T. Scanlan, Wen, Tucker, & Dalbo, 2014; Schelling & Torres, 2016) and suit basketball games as they require no satellite-based signal transfer, no indoor node set-up and produce data that can be quickly analysed. Many inertial measurement units can also be integrated with heart rate monitors to record external and internal loads simultaneously, thereby minimising the burden of coordinating multiple systems (Fox et al., 2017). A relatively new inertial measurement unit on the local market called VXSport Omni (VXSport, Wellington, New Zealand) provides an option for coaches and teams to monitor external load in their players. However, little information exists on the validity and reliability of VXSport devices on movement patterns particularly in basketball players.

The validity of an instrument is its ability to measure what it is intended to measure with accuracy and precision (Sullivan, 2011). This is typically quantified by comparing the output of the respective instrument to a ‘gold-standard’ or criterion measure. Typical measures of validity include bias (relative and absolute), standard error of the estimate (SEE), standard error of measurement (SEM), and typical error (TE) expressed as a coefficient of variation (CV) (Hopkins, 2015). On the other hand, the reliability of an instrument denotes its ability to reproduce measures on separate occasions when it is known that the measure of interest should not fluctuate (Hopkins, 2015). Otherwise, termed ‘intra-device’ or ‘test–retest’ reliability, this is important when tracking and identifying ‘meaningful’ changes over a specified period. Typical measures of reliability include typical error expressed as a CV and intra-class correlation (ICC) (Sullivan, 2011). Intra-class correlations quantify the association between two variables that have a permanent degree of relatedness while CV describes the variability between multiple data sets (Sullivan, 2011). The aim of this study was therefore to measure the validity and reliability of the VXSport Omni at recording important movement characteristics of basketball athletes.

METHODS

Subjects

Using G*Power (G*Power 3.1.9.7) analysis we calculated a priori sample size of 12 would be required using a large effect size (ES = 4.0) equivalent to the high intraclass correlation coefficient (r = 0.94) found with 20 m sprinting (McMahon et al., 2017) and an alpha level of 0.05, and power (1-beta) of 0.80 with repeated measures analysis. We decided to recruit 20 subjects to account for any dropouts. In the end, eighteen well-trained basketball players were recruited into the study and had at least 10.0 ± 2.4 (mean ± SD) years playing experience and had played for senior competitive teams in New Zealand. Approximately 75% of the players were also contracted to semi-professional basketball teams in New Zealand. All subjects gave their written informed consent in accordance with the Declaration of Helsinki. The protocol was approved by the Lincoln University Human Ethics Committee (HEC2022-25).

Design

During the pre-season training phase, players were required to attend 3 testing sessions. The first was a familiarisation session where the players were introduced to the testing procedures and equipment used. Additionally, during this session, anthropometric measurements were taken. Two days later, the first testing session took place to assess the within-day validity of the IMU device. On this day, players were asked to perform a series of simple movements that were measured using the IMU device which was compared to a criterion measure. Seven days after the validity testing session, the players returned for the second test day to investigate the within-day reliability of the IMU devices. The players completed a standard basketball movement test twice with a 10-minute rest between the tests (Figure 1).

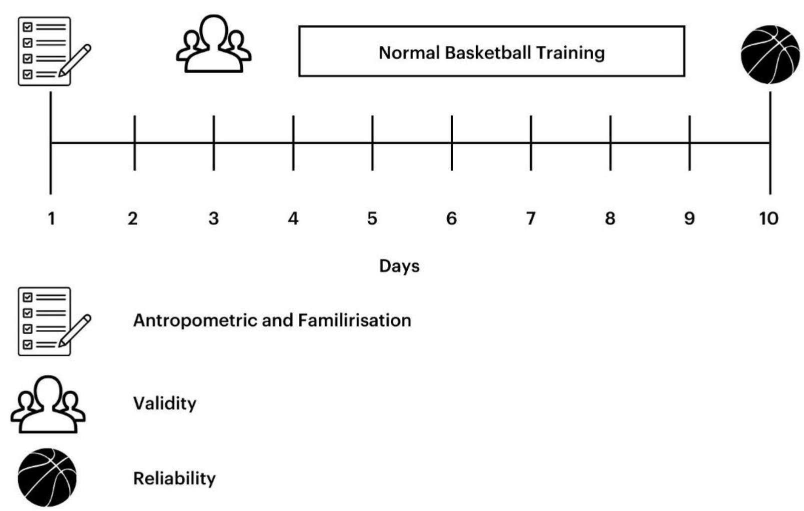

Figure 1. Weekly schedule for players familiarisation and testing for within-day validity and reliability.

Procedures

Players were instructed to maintain consistent dietary and sleeping patterns for 48 h prior to each session. Players were instructed to refrain from strenuous activity, abstain from alcohol for 24-h, and to avoid eating a heavy meal and caffeine containing beverages or food for 4-h prior to all experimental testing. All testing occasions were conducted on an International Basketball Federation (FIBA) regulation hardwood indoor basketball court at 1pm with an air temperature of 19.9°C ± 1.04, and 37.9 ± 0.62% humidity on all sessions (mean ± SD, climate controlled through air conditioning). All testing was conducted in the presence of the research team, with standardised verbal encouragement given across each test to control participant arousal levels. Prior to the first testing, anthropometric measures such as height (portable stadiometer, Seca 213, Seca GMBH, Hamburg, Germany), body mass (electronic scales, BWB-600, Tanita Corporation, Tokyo, Japan), and sum of 8 skinfolds i.e., triceps, subscapular, biceps, iliac crest, supraspinale, abdominal, front thigh and medial calf (Harpenden Skinfold Callipers, Baty International) were taken. The player's body composition was measured wearing light clothing and after emptying their bladders. Body mass was measured to the nearest 0.1 kg and height was measured without shoes and socks to the nearest 0.1 cm with the head in the Frankfort plane. During all testing, continuous measures of heart rate (HR in b·min^{-1}) were recorded using the VXSport Sunnto heart rate device (VXSport, New Zealand). Players underwent a 10-min standardised warm-up consisting of low-intensity jogging, whole-body dynamic stretches and brief bouts of high-intensity running and jumping prior to the movement performance tests.

Inertial measurement unit and calibration test

An inertial measurement unit (VXSport Omni, Wellington, New Zealand) with a sampling rate of 100 Hz was placed between the scapulae in the manufacturer's purpose-designed vest fitted to each player prior to movement testing. The unit contains gyroscopes and accelerometers to detect movement in all directions. To make sure the inertial measurement unit recorded accurate data, players were required to undertake a one-time individual unit calibration to relate their unique gait to the inertial measurement unit. This calibration occurred 7 days prior to any fitness testing sessions. This involved players' going outside on a rugby field with a GPS signal, away from sources of interference (i.e., tall buildings and dense foliage). Researchers selected the "*indoor calibration*" sport setting in the VX Sport software, and the devices were activated and placed inside a vest. After all three lights turned green, indicating a GPS lock, the participants were instructed to perform various activities, which included walking, jogging, striding, and sprinting at maximum speed for 125 meters, followed by a complete halt. Each distance was marked by a cone and players instantly changed their speed once they hit each cone. Testers were present at each speed band cone to ensure a proper change was met. Subsequently, the players took a 5-minute rest, sitting upright in a chair. Once this rest period concluded, the participants repeated the entire process once more. After completing this session, data was downloaded and saved to the player's profile. This data was then used in the VX sport software to determine the movement characteristics of the athlete while they were indoors. Each device was assigned to a specific player for the entire duration of the study.

Validity testing

Distance test

One the first testing day after a warm-up, players walked (at their own speed) around the diameter of a full FIBA regulation hardwood indoor basketball court to get a measure of total distance. This was performed twice, separated by 2 mins of inactive rest sitting in an upright position at the start/finish line. Participants were directed to remain strictly on the marked outline of the court and avoid deviating from the lined path. Two observers monitored every participant closely, making sure that no shortcuts were taken. Verbal reminders were consistently given to reinforce adherence to the guidelines.

20 m straight line speed and distance test

Two minutes after the distance test, each player completed two 20-m running displacements at various speeds separated by 2 mins of active recovery. Four sets of timing gates (Smartspeed, Fusion Sports, Australia) were placed at the starting position, and at 5, 10, and 20 m distances to calculate the time taken through each section. A pacer light system (Indico Technologies, Italy) was used to assist the submaximal pace of each participant to ensure speed band zones were achieved, which included walking (6.0 km.h^{-1}), jogging (12.0 km.h^{-1}), striding (16.0 km.h^{-1}), and maximal sprinting (>24 km.h^{-1}) over the 20-m distance. Prior to each test, players paused in a stationary position at the start line for 10 s with their front foot placed 1 meter back from the starting line. This was to allow for a clear distinction to start the test and to assist with the coordination of the microtechnology data to the specific movements post data collection. Players were asked to stop as soon as possible at the end of each 20-m test. The players completed the 4 different paced movements starting with the walk and finishing with the maximal sprint with a 20 sec rest period between movements to allow the players to walk back to the starting line. Players were then given a passive rest for 2 mins before completing a second set of runs through the timing lights (Figure 1A). During analysis, we adjusted the total distance by subtracting 1 meter to compensate for the initial difference in starting distance. Further to this, we placed a measuring tape beyond the timing lights to measure any distance overrun which was then corrected during analysis. This method ensured the accuracy of the total distance measured when a participant completed the test.

Zig Zag

After 3 mins of inactive rest (sitting), players performed two maximum effort zig zag runs over a total distance of 27 m (5.4 m per measured zig zag line, Figure 1B). Each player was asked to start on the line and sprint as fast as they could up to the cone then decelerate and change direction before maximally accelerating to the next cone (5 in total). Prior to, and at the end of the zig zag, each player performed a 10 s stationary pause and then a rest period of 2 minutes to allow for adequate recovery and a clear distinction of a starting and end point for the microtechnology analysis. Once again, distance run past the final marker was calculated using a calibrated measurement device. For this test researchers were only interested in the total number of accelerations and decelerations, not total distance achieved.

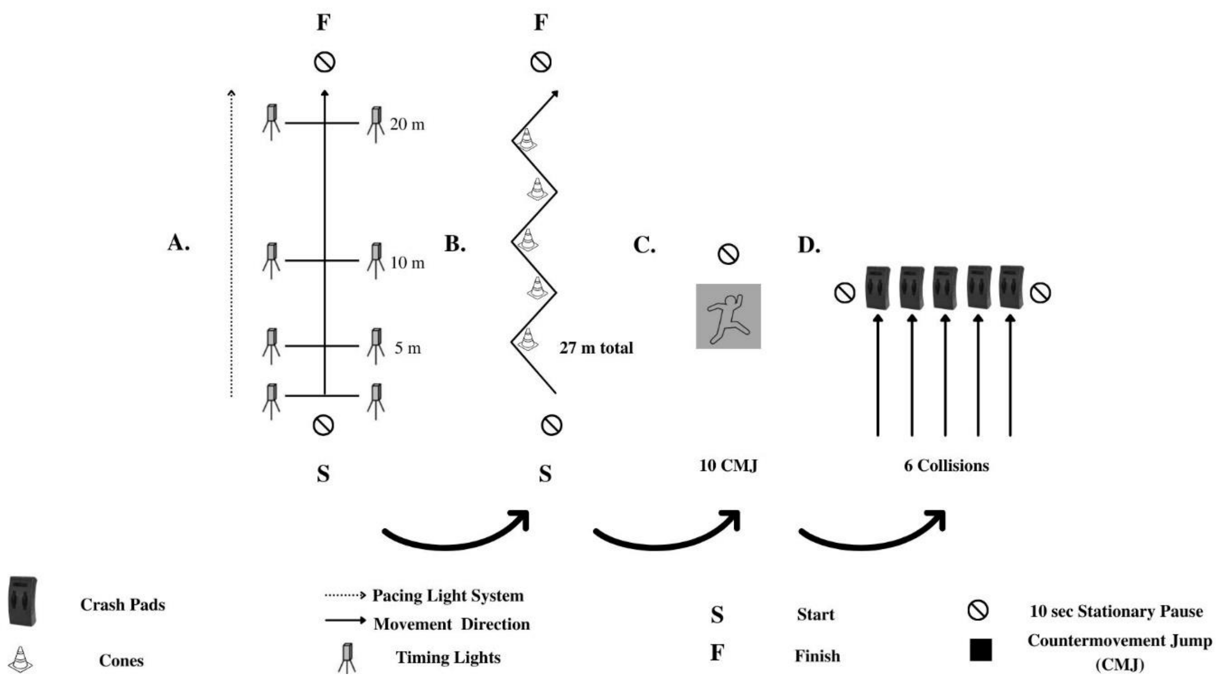

Figure 1. Representation of the activities performed during each bout of the (A) 20 m straight line speed and distance (B) 27 m zig zag (C) countermovement jump and (D) crash pad collisions.

Countermovement jump

After another 3 minutes rest, players performed 10 maximal countermovement jumps. Each jump was separated by a 3 s pause to allow for a maximal effort. Once completed, a passive seated 2-min recovery was given to allow for adequate recovery before performing another 10-jump set. A jumping mat (Fusion Sport Jump Mat, Australia) was used as a criterion measure for both total counts as well as jump height.

Collisions

Following a further 3 min passive rest, players performed 6 collisions with a 3-step run-in as hard as they could against a crash pad held by a researcher. Each collision was followed by a 3 s pause to allow for a maximal effort as this was mimicking a blocking movement in basketball. A 2-min rest was administered for adequate recovery prior to performing a further set of blocks. Each collision was measured by the inertial measurement unit as *g*-force.

Reliability testing

Basketball exercise simulation test

After 7 days rest players were asked to return and complete the BEST test (Aaron T. Scanlan, Dascombe, & Reaburn, 2014). The BEST test is a simulated basketball movement test which we used to investigate the reliability of the inertial measurement unit in a more sport-specific manner. The BEST test was developed using a circuit design based on notational distance data calculated for various movement types across multiple adult male basketball matches (Aaron T. Scanlan et al., 2014). For ease of testing preparation, court line-markings were used as indicators for activity and directional changes. Approximately 1725 m is travelled during a full 12-min BEST test, including: 727 m of low-intensity activity (standing, walking, and jogging), 826 m of high intensity activity (running and sprinting), and 172 m of shuffling activity. These distances are comparable to those reported during Australian adult male basketball competitions (Aaron T. Scanlan et al., 2014). Each BEST circuit consisted of 30 s of activity. Participant's heart rate was also measured during the BEST test using the VXSport Sunnto heart rate device (VXSport, New Zealand). To ensure adherence to test protocols, a video camera (Panasonic HC-WX970M, 50 Hz, Tokyo, Japan) was strategically positioned at the baseline of the basketball court, 14 meters away from the half-court line, providing a comprehensive view of the test. The footage captured was utilised to cross-reference microsensor data with actual movement patterns, ensuring reliability in the test.

Data acquisition

Data that was collected included the heart rate during all tests and criterion measures of speed (timing lights), distance (calibrated tape measures), and a visual notification of number of jumps (20 in total) and crash pad hit ups (12 in total). This criterion information was compared to the observed data from the VXSport Omni unit (e.g., speed, distance, accelerations, decelerations, jump number and jump height and collisions). Furthermore, data collected during the BEST test was (used to indicate reliability of the device) included total distance (m), relative distance ($m.min^{-1}$), maximum speed ($km.h^{-1}$), total no. of sprints, total no. of sprints >15 $km.h^{-1}$, total no. of accelerations >3 $m.s^{-2}$, total no. of decelerations >3 $m.s^{-2}$, total no. of jumps, average HR ($b\cdot min^{-1}$), total no. of accel and total no. of decelerations.

Statistical analyses

All data are presented as mean ± standard deviation (SD). Validity of the inertial measurement unit was determined by comparative analysis between the device recordings (mean of the 2 movement tests) and the criterion measures taken (e.g., distance, speed, number of accelerations decelerations, number of jumps, height of jumps, number of crash pad hits) using specifically designed spreadsheets (Hopkins 2015). Within-day mean bias and mean bias as a % between the observed and criterion measures were recorded. Measures collected on the BEST Test on the second day of testing were analysed for reliability by calculating the absolute difference, typical (standard) error of estimate in raw units (TE), percent typical error or coefficient of variation CV (TE%), and the intraclass correlation coefficient (ICC). The following descriptors were used for the ICC measures: "*trivial*" 0.0 - 0.1, "*small*" 0.1 – 0.3, "*moderate*" 0.3 – 0.5, "large" 0.5 – 0.7, "*very large*" 0.7 – 0.9, "*nearly perfect*", 0.9 – 0.1 (Hopkins, 2015). Based on previous recommendations, reliability of the movement tests were rated as good (<5%), moderate (5-10%), or poor (>10%) (Hopkins, 2015).

RESULTS

Validity

The 20 m running test (at 6 km.h^{-1}, 12 km.h^{-1}, 18 km.h^{-1}, 24 km.h^{-1}, and maximum speed km.h^{-1}) showed good validity (mean bias <5%), whereas total distance around the basketball perimeter showed poor validity (mean bias >10%) (Table 1).

Table 1. Validity of the VXSport device to detect selected movement patterns in male and female basketball players.

	Criterion Measure (n=18)	VX Sport Omni (n=18)	Absolute Difference	Mean Bias (m)	Mean Bias (%)
Total dist. (m)	86	96.4 ± 2.2	10.39 ± 2.22	10.39 ± 0.73	12.7 ± 0.9
20m Speed Test 1 (6 km.h^{-1})	6	6.1 ± 0.4	0.11 ± 0.37	0.01 ± 0.30	1.7 ± 7.1
20m Speed Test 2 (12 km.h^{-1})	12	12.3 ± 04	0.26 ± 0.40	0.13 ± 0.32	2.1 ± 3.4
20m Speed test 3 (18 km.h^{-1})	18	18.5 ± 0.4	0.54 ± 0.40	0.41 ± 0.32	3.0 ± 2.2
20m Speed Test 4 (24 km.h^{-1})	24	25.1 ± 0.5	1.05 ± 0.46	0.87 ± 0.36	4.5 ± 1.8
20m Speed Test 5 Max Speed (km.h^{-1})	27.5 ± 1.7	27.8 ± 1.7	0.27 ± 0.36	0.10 ± 0.27	0.17 ± 1.4
Total no. of jumps	10	9.8 ± 0.5	- 0.21 ± 0.53	- 0.38 ± 0.43	- 2.0 ± 1.06
Body Impacts	6	0.9 ± 0.9	- 5.11 ± 0.92	- 5.41 ± 0.75	
Total no. of accel.	5	4.6 ± 0.7	- 0.37 ± 0.67	- 0.59 ± 0.55	- 8.6 ± 1.16
Total no. of decel.	5	5.0 ± 0.4	- 0.03 ± 0.37	- 0.15 ± 0.30	- 0.8 ± 1.08

Note. Data are mean ± SD. Dist, distance; no, number; accel, accelerations; decel, decelerations.

Table 2 shows the validity between the criterion (Jump Mat) and practical (VXSport Omni) jump measures is poor (mean bias %: >10%).

Table 2. Validity of the VXSport Omni device to detect jump parameters.

	Max Jump Height (CMJ Mat)	Max Jump Height (VX Sport)	Absolute Difference	Mean Bias (cm)	Mean Bias (%)
Test 1	46.6 ± 5.5	53.0 ± 6.5	6.42 ± 3.4	4.76 ± 2.6	14.2 ± 7.4
Test 2	48.5 ± 5.7	54.9 ± 5.7	6.37 ± 2.3	5.25 ± 1.7	14.0 ± 5.2

Note. Data are mean ± SD.

Reliability

Total distance, total number of sprints, total number of sprints >15 km.h^{-1}, and total number of accelerations and decelerations during the Best Test showed very high to nearly perfect reliability with the ICC ranging from 0.88 – 0.99 (Table 3). Whereas, relative distance (m.min^{-1}), maximal speed (km.h^{-1}), total number of fast accelerations (>3 m.s^{-2}), total number of jumps, and average HR (b·min^{-1}) showed very high reliability with the ICC ranging from 0.77 – 0.87 (Table 3).

Table 3. Reliability of the VXSport device during selected movement patterns in male and female basketball players.

	Trial 1 (n=18) mean ± SD	Trial2 (n=18) mean ± SD	Absolute Difference mean ± SD	TE mean	TE% mean (95% CL)	ICC
Total dist. (m)	1545 ± 215	1568 ± 195	23.1 ± 19.3	27.5	1.9 (1.4-2.8)	0.98
Relative dist. ($m.min^{-1}$)	128.8 ± 18.0	126.8 ± 20.2	-1.9 ± 8.3	5.9	5.8 (4.3-8.8)	0.87
Max Speed ($km.h^{-1}$)	22.0 ± 3.1	21.5 ± 3.5	-0.5 ± 2.1	1.5	7.0 (5.2-10.6)	0.82
Total no. of sprints	78.1 ± 17.7	78.0 ± 17.9	-0.1 ± 4.3	3.0	4.2 (3.1-6.3)	0.97
Total no. of sprints (>15 $km.h^{-1}$)	52.0 ± 19.8	53.8 ± 21.0	1.8 ± 3.9	2.8	7.2 (5.4-11.0)	0.99
Total no. of accel. (>3 $m.s^{-2}$)	60.9 ± 23.3	60.2 ± 22.0	-0.7 ± 15.0	10.6	17.8 (13.1-27.8)	0.88
Total no. of decel. (>3 $m.s^{-2}$)	49.9 ± 19.5	48.2 ± 19.8	-1.7 ± 11.3	8.0	15.6 (11.5-24.3)	0.94
Total no. of jumps	18.9 ± 2.0	18.8 ± 1.7	-0.1 ± 1.4	1.0	5.0 (3.8-7.9)	0.77
Average HR ($b \cdot min^{-1}$)	177.1 ± 11.0	177.3 ± 11.0	0.2 ± 7.0	4.9	2.8 (1.9-5.2)	0.85
Total no. of accel.	100 ± 18.5	99.9 ± 15.8	-0.1 ± 7.0	4.9	4.5 (3.4-6.9)	0.95
Total no. of decel.	78.1 ± 14.3	76.5 ± 15.1	-1.6 ± 5.1	3.6	4.4 (3.3-6.8)	0.96

Note. Data in first 3 columns are mean ± SD. Dist, distance; no, number; accel, accelerations; decel, decelerations; HR, heart rate; TE, typical (standard) error of estimate in raw units; TE%, percent typical error (or coefficient of variation CV); ICC, Intraclass correlation coefficient.

DISCUSSION

In this investigation, our objective was to assess the reliability and validity of an inertial measurement unit for monitoring athlete movement in basketball players, particularly by comparing their performance against established criterion measures. We found that the inertial measurement unit used in this study was highly reliable at capturing within-day player movements during dynamic activities and providing a credible method for tracking sprint zones. Further to this, the device showed good validity when it came to the 20 m running test (mean bias <5% at all speeds), however the devices validity was lower for total jump count, maximum jump height, body impacts, and the overall number of accelerations and decelerations (mean bias >10%).

One of the main findings of the present study showed that the inertial measurement unit was reliable with most parameters intra-class correlations ranging from 0.77 – 0.99. Total distance, total number of sprints and total number of decelerations showed near perfect reliability while relative distance ($m.min^{-1}$), maximum speed ($km.h^{-1}$), total number of accelerations and average HR showed very high reliability. This near perfect and very high reliability likely stems from the players' ability to replicate the movements correctly as instructed. Each player possessed a high proficiency in basketball and was familiar with the movements involved in the test. Furthermore, all players received a familiarisation session before the testing commenced. Importantly, the consistency of the device in picking up the same measurements with high precision across multiple trials underlines its reliability, confirming that it is a dependable tool for accurately capturing and replicating the specific athletic movements and efforts in a controlled setting. This characteristic is crucial for ensuring the integrity of the data collected, providing confidence in the device's utility for sports science research and athlete performance analysis.

The difference in measurements between tests include both biological (i.e. the players movements are different) and technological (i.e. the device has some error) variation, and the true intra-device reliability cannot be determined. To understand the true test-retest reliability of an inertial measurement unit, the biological variation must be eliminated from the movement, by performing identical movements on repeated occasions (Crang et al., 2021). However, for the purpose of this study, the researchers aimed to mimic the movement patterns involving players to illustrate potential measurement errors. This approach is more practical and can help coaches and practitioners in understanding potential differences between training sessions and games, and in considering these variations when designing training programmes based on data.

The IMU demonstrated good validity across most variables. A likely explanation for this might stem from the ability to use a pacing light system to guide the submaximal speeds of the players. Interestingly, maximum speed showed the highest validity out of all tests. We suspect the slightly lower validity of the submaximal running velocities was due to a delay in the players ability to maintain pace with the timing light, especially at the beginning when the players had to accelerate from a standing start to the required velocity. The findings of the current study do not support previous research where the authors found no significant relationship between 20 m straight sprint times measured by the timing gates and a global positioning system unit ($r = 0.118$, $p > .05$) (Javier et al., 2016). A possible explanation for this is that a low measuring frequency was used (10 Hz vs 100 Hz in the current study) and the study had low testing numbers (12 vs. 18 players) which may increase the errors in the testing. Additionally, the separate GPS and IMU units use different accelerometers, gyroscopes and software algorithms, thereby leading to unique measurements of movement. This disparity may account for the observed variations in our findings. While straight line sprints seemed to have high validity, other measures such as body impacts, total distance, vertical jumps showed lower validity.

In the current study, body impacts were underreported by the IMU. Typically, body impacts are detected by the accelerometer inside wearable devices, using software-based algorithms Cummins, Orr, O'Connor, and West (2013). The accelerometer works by comparing real-time movement against a threshold that distinguishes whether an impact has occurred Cummins et al. (2013). During the study, players hit a crash pad with maximal force, but we suspect the pads may have absorbed much of the force generated, resulting in lower IMU readings. While there is a lack of knowledge in validating collisions in basketball, there is plenty of research that investigated at other sports such as rugby league and rugby union match-play with devices containing 100 Hz accelerometers. The authors found that when compared to a criterion measure (video notational analysis) significant correlations were found between video and automatically detected collisions of the IMU for mild ($r = 0.89$), moderate ($r = 0.97$) and heavy ($r = 0.99$) collisions in games (MacLeod, Hagan, Egaña, Davis, & Drake, 2018) (Kelly, Coughlan, Green, & Caulfield, 2012) (Gabbett, Jenkins, & Abernethy, 2010) (Hulin, Gabbett, Johnston, & Jenkins, 2017). In basketball, adapting the same collision detection algorithm requires careful adjustment. The sport's frequent yet lesser physical interactions mean collisions are less forceful than in rugby. Thus, the basketball algorithm may need refining to accurately identify these subtler contacts without mistaking non-contact movements—like sudden stops or jumps—for collisions. Ensuring the algorithm's sensitivity can differentiate between actual contacts and non-contact events is crucial to avoid misinterpretations. Therefore, further research is needed to investigate whether the IMU picks up realistic collisions in basketball. Understanding the true intensity and nature of impacts in basketball could lead to better injury prevention strategies. Accurately measuring the forces players are subjected to, can help develop more effective training and conditioning programs to prepare athletes for these stresses, thus potentially reducing the risk of injury.

Total distance showed poor validity (mean bias >10%) by overestimating distance by 10.4 ± 2.2 m. The overestimation of distance could be attributed to biological errors, such as variability in human stride length and inconsistency in motion patterns. It could also be explained by IMU errors including drift, calibration issues, and integration inaccuracies, which together may have failed to capture the nuances of directional changes and minor speed variations, leading to accumulated inaccuracies in distance measurements. Despite these inaccuracies, the distance was consistently overestimated across two tests for all players, suggesting that, while not perfect, this method still provides a useful and consistent means of calculating distance for both training sessions and games. The findings of the current study support previous research (Sandmæl, Van Den Tillaar, & Dalen, 2023). In the study by Sandmæl et al. (2023), the authors observed that an IMU tended to underestimate total indoor distances compared to a criterion measure (−8.7 ± 6.5m). The authors reported that this underestimation was attributed to the IMU's lack of calibration for individual gait and stride length variability, leading to inaccuracies in distance tracking. Although the current study observed an overestimation of total distance, the margin of error remains similar, highlighting a consistent level of inaccuracy across different contexts. This insight is valuable as it suggests that, despite the direction of bias (over or underestimation), the magnitude of error is consistent, allowing for adjustments to be made to improve accuracy or to account for this bias in data analysis, thereby still offering a useful tool for monitoring and enhancing athletic performance through reliable, if corrected, distance measurements.

Vertical jump height measured using an IMU compared to the jump mat, was found to be 6.4 ± 3.4 cm lower on the first test and 6.4 ± 2.3 cm lower on the second test on the same day. A potential reason for these differences is the methodology underpinning jump height calculation of the VX Omni unit compared to the jump mat. The jump mat bases the calculation on flight time ($h = ft^2g/8$, where h, height = ft, flight time * gravity/8) whereas the IMU unit uses the accelerometer embedded in the unit. Previous research has identified that the descending phase is longer than the ascending phase, as participants land in a slightly crouched manner (Aragón, 2000). It has been calculated that this difference in landing position during a countermovement jump with hands on hips may equate to an overestimation of vertical jump height of 2.3 cm (Kibele, 1998) or 2.8 cm (Enoksen, Tønnessen, & Shalfawi, 2009), which could explain the discrepancy between the jump mat vertical jump heights and those measured using the IMU.

When comparing accelerations and decelerations to a criterion measure, both were underestimated by the IMU device, despite instructions for players to deliberately adjust their speed at specific markers on a basketball court (mean bias - 8.6 ± 1.2 for acceleration - 0.8 ± 1.2 for deceleration). It is possible that the players did not put in enough effort. The task of slowing down and speeding up can be tiring, so the players may have minimised this by moving through the change of direction at a steady pace, leading to an underestimation of these movements. When compared to previous research, Wundersitz et al. (2015) found the application of different filters and frequencies in IMU devices significantly impacts the accuracy of acceleration measurements. IMU devices sampling between 10 to 16 Hz, particularly a 12 Hz filter, were optimal for achieving suitable accuracy (CV < 10%) in measuring accelerations during team sport activities (Wundersitz, Gastin, Robertson, Davey, & Netto, 2015). However, newer devices with higher sampling rates, such as those sampling at 100 Hz, may introduce complexities in the movement signal, potentially compromising the device's ability to accurately distinguish between accelerations and decelerations. Further investigation is needed to determine whether the lower validity stems from limitations in the technology or from factors related to human performance.

Practical applications

Tracking performance metrics such as total distance, accelerations, decelerations, sprint zones, jump counts, and collisions can significantly enhance basketball performance strategies, player development, and reduce injury risk. Analysing sprint zones, understanding the effect of fatigue on performance, and tracking long-term sprint patterns can offer insights into training effectiveness, while monitoring collisions can reduce injury risks. Incorporating these metrics into basketball performance analysis can assist in tailoring training and recovery programs, strategic decisions during games, and contribute to the overall success of the team.

CONCLUSION

These findings demonstrate that inertial measurement based wearable tracking devices can successfully be applied for athlete monitoring in indoor team sports such as basketball and provide potential to accurately quantify movement demands for individual players. Since we have found that the IMU devices used in this study show good reliability and acceptable validity in most basketball movements (except for total jump count, maximum jump height, body impacts, and the overall number of accelerations and decelerations), players and coaches should be confident in the data produced by such devices.

AUTHOR CONTRIBUTIONS

The study was designed by HS and MH. HS and PO collected the data. HS analysed the data and MH and HS then interpreted the data. HS composed the manuscript while MH, SB, PO, and TK added important intellectual content. All authors have read and agreed to the published version of the manuscript.

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