Validation of a laser device for assessing high-speed running in an outdoor team sport setting

Sports Engineering (2025) 28:25
https://doi.org/10.1007/s12283-025-00509-4

TECHNICAL NOTE

Validation of a laser device for assessing high-speed running in an outdoor team sport setting

Grant M. Duthie[1,2,3] · Sam Robertson[3] · Kevin Ball[3] · Jade Haycraft[3] · Lizi Bright[3] · Tom Parkinson[4] · Johsan Billingham[4] · Robert J. Aughey[3]

Accepted: 15 May 2025

Abstract
Laser-based systems are commonly used to measure running speed in many sports. The resulting output can be used to assess performance, profile athletes and measure the effect of coaching interventions. This study aimed to compare the running speed output from a commercially available laser (Laser Speed, MuscleLAB) with a three-dimensional motion capture system (Vicon, Oxford Metrics Group), a commonly recognized "gold standard" method of measuring human movement. Conducted on a professional football stadium pitch during daylight, 29 participants completed between one and six straight line, high-speed runs (> 6.9 $m \cdot s^{-1}$) over a distance of about 20 m. Instantaneous velocity was obtained from each system and compared across a total of 25,082 samples. Results showed high agreement between the two systems, with a mean root mean square error of 0.06 $m \cdot s^{-1}$ recorded and an association between the systems of $r = 0.99$. When considered across the 29 participants, minor differences were noted, with a mean error of 0.03 $m \cdot s^{-1}$. Higher error tended to be observed as running speed increased, with low variation in results across different participants. Laser-based speed assessment technology presents as an easy to use, relatively low-cost option for the assessment of linear running speed in outdoor team sport settings.

Keywords Validation · Electronic and performance tracking · Sprint running

1 Introduction

Laser and radar-based tracking systems are commonly used to measure running speed in athletes [1–4]. These systems have the advantage of being relatively low cost, easy to set up and are non-invasive to the athlete. Before using any equipment to measure human performance, an understanding of its measurement properties, such as reliability, should be obtained [5]. This provides confidence in the data provided for various use cases, such as research or applied athlete interventions. Of these measurement properties, concurrent validity, the extent to which the system output relates to a previously validated measure collected at the same time [6, 7], is one of the most important and commonly assessed variables. This establishes the extent to which the system measures what it intends to measure.

To date, validation of laser and radar devices for the measurement of linear running speed has been undertaken against a variety of systems measuring concurrently [8, 9]. In a first example, times measured at 20 m and 50 m during a 100 m sprint using a laser sampling at 2 Hz were not substantially different from photocells, with a 0.99 correlation between systems recorded [8]. In another study, output from a laser sampling at 2000 Hz displayed a 0.92 correlation with output from photocells, but was slightly lower associated ($r = 0.86$) with a two-dimensional photogrammetry system incorporating high-speed video [9]. High-speed video has also been used to assess bias and random error in a 100 Hz laser at sprint distances of 1, 10, 30 and 50 m [10]. Differences were greatest at 1 m (+0.41 $m \cdot s^{-1}$) with random error relatively stable across all the distances tested

✉ Grant M. Duthie
grant.duthie@acu.edu.au

1 School of Exercise Science, Australian Catholic University, Sydney, Australia

2 Sports Performance, Recovery, Injury and New Technologies (SPRINT) Research Centre, Australian Catholic University, Melbourne, Australia

3 Institute for Health and Sport, Victoria University, Melbourne, VIC, Australia

4 Football Technology Innovation Subdivision, Fédération Internationale de Football Association (FIFA), Zurich, Switzerland

Published online: 16 June 2025

(+0.11 $m \cdot s^{-1}$) [10]. Laser and radar devices have also been compared against more contemporary measures of sprinting performance, such as the 1080 sprint device [11], which is a linear encoder-based unit that attaches to the running and samples at 333 Hz. A radar sampling at 46.875 Hz was compared to the 1080 sprint for measurement of force–velocity parameters. The 1080 sprint consistently had higher velocity recorded than the radar with a bias of 6.3% [11].

Despite this body of work, comparison of laser-derived instantaneous speed to that of a criterion, or "gold standard" reference system has not yet been reported. Instantaneous speed forms the basis of most derived measures used in sport and thus should typically constitute the first level of validation. Laser devices can sample at anywhere between 2 and 2000 Hz [12, 13], with common data outputs of 100 Hz. Consequently, reference systems capable of similar sample rates should be used to protect the integrity of data captured for comparison, without the need for re-sampling or extrapolation.

Three-dimensional (3D) motion capture systems are often regarded as a criterion measure against which laser devices can be compared [14]. Vicon (Oxford Metrics Group Plc [OMG], Oxford, UK) has both a high sample rate [15], sub-millimetre precision of location of reflective markers placed on the body [14, 16] and has been used extensively in the validation of electronic and performance tracking systems in sport [16, 17]. Further, as many athletic performances take place outdoors, it is important to establish the performance of laser in a stadium environment where performance occurs. A stadium may be a challenging location for the use of laser, with possible signal bounce from reflective elements in the stadium and difficulty maintaining the beam on the torso of the runner [9]. The aim of this study was therefore to establish the criterion validity of a laser for the measurement of sprint performance against a 3D motion capture system in a stadium environment.

2 Materials and methods

2.1 Test procedure

This study was conducted as part of electronic and performance tracking system validation commissioned by The Fédération Internationale de Football Association (FIFA) for the FIFA Quality Programme [17]. Ethical approval to conduct the study was granted by the relevant institutional ethics committee (HRE16-278). As such, the motion capture test volume described in the next section was used for a variety of activities not included for analysis here. Briefly, those activities were a movement circuit, 2v2 small-sided football game and a 5v5 small-sided football game [15]. Briefly, the circuit consisted of walking, jogging and striding efforts in a linear or zigzag pattern, while the small-sided games involved players attempting to maintain possession of the ball within a 30 × 30 m space. The specific data included was obtained from a straight-line sprint, commencing about 20 m outside the test space to allow participants to reach a high speed. At the end of the sprint, participants decelerated and continued to run through the outer edge of the capture space. Data were collected on 29 players to ensure a sufficient number of trials to facilitate system comparison. Each player performed between one and three sprints, the number of which was self-selected based on their perceived fatigue levels at the time of the test.

2.2 Three-dimensional motion capture system

Participant position and movement speed were determined by a large-scale three-dimensional motion capture system. To track participants, five 38-mm retro-reflective spherical markers were placed on specific landmarks: one on each shoulder and three on the pelvis. The mid-position of the three pelvis markers was determined for each data frame to approximate the centre of mass of the player [16]. Shoulder markers aided in the identification of individual participants. The test volume was reconstructed into three-dimensional space from 42 Vicon Vantage cameras (Oxford Metrics Group Plc [OMG], Oxford, UK) with a sampling frequency of 100 Hz. The cameras were positioned around the 30 × 30 m test area. The Vicon system was used, as marker-based systems are considered the gold standard for 3D motion capture with sub-millimetre accuracy reported in large outdoor space test environments [18]. Calibration was performed as per standard biomechanical testing [19] with a passive wand (using reflective markers) that was moved through the testing space until all cameras collected sufficient data for this calibration to be achieved. Data for each marker were manually labelled in Vicon Nexus motion capture processing software and then transferred to Visual3D biomechanics analysis software (C-Motion Inc., Germantown, MD, USA). Data were interpolated where necessary using the interpolation function in Visual3D with a maximum window of ten frames. This duration (0.1 s) was deemed to be the longest acceptable gap to interpolate the data. Data were then smoothed using a dual-pass Butterworth digital filter. The cutoff frequency of 2.5 Hz was chosen based on the results of wavelet analysis, residual analysis and visual inspection of the effects of different cutoffs on the data (particularly around the maxima and minima). The lower end of these analyses was chosen (between 2.5 and 5.0 Hz was indicated) as it served to reduce the effects of the intra-step velocity fluctuation, thereby providing a better estimate of overall velocity. This approach of overall velocity estimation is directly relevant to the method used by practitioners to quantify running velocities in which they use

bands (e.g. distance run within a certain velocity band). Data (speed) were cropped to the start and finish of the sprint to allow for aligning temporally with those from the laser system.

2.3 Laser

The laser speed (MuscleLAB, Stathelle, Norway) was selected for use in the study. Studies have compared output (velocity, contact time, flight time, step length and step frequency) from this device with that of an infrared contact mat [20] as well as a force plate and three-dimensional inertial measurement unit system [21]. The device was positioned about 5 m directly behind the starting line at a height of 1 m to approximate the athlete's centre of mass location on a tripod. The laser manufacturer's proprietary software (MuscleLab, Stathelle, Norway) was programmed so that the trial would 'self-terminate' collection once the participant had reached 40 m. Using the laser's optic-reflective red dot sight, one member of the research team experienced in using the laser system tracked the participant, positioning the site between the scapulae. A clearly marked sprint lane was displayed through the Vicon capture space, to encourage participants to run in as straight a line as possible and for the laser beam to remain focussed on the participant for the duration of each run. Following completion of the sprint effort the 100 Hz speed time data was exported for analysis.

2.4 Statistical analysis

3D motion capture raw position data were differentiated to obtain horizontal plane speed using a three-point finite central difference formula [22]. 3D motion capture and laser data were time synchronized using cross correlation of speed data [23]. Once synchronized, data were trimmed and extracted into individual data files, which typically constituted between 200 and 300 data points per trial. Speed data were compared through calculating the mean differences between the two datasets and the root mean square error (RMSE): the sample standard deviation of the differences between 3D motion capture and laser. For each individual file, the RMSE was calculated as the root of the mean of the squared difference between the speed from the 3D motion analysis and laser data. Descriptive statistics (mean, standard deviation [SD], median and range) were obtained across all data points for both the laser and 3D motion analysis systems. Pearson's correlation coefficient was used to identify the strength of the relationship between the two datasets. Differences between the laser and Vicon for each participant trial were displayed using Bland–Altman plots, with the mean bias and 95% confidence interval also shown. The datasets generated during the current study are available from the corresponding author on reasonable request.

3 Results

A total of 82 individual files were assessed for 29 individuals (between 1 and 3 per participant). A total of 25,082 samples were compared between Vicon and laser data, all at a speed greater than 6.9 $m \cdot s^{-1}$. Overall, the RMSE between laser and the Vicon criterion was 0.06 $m \cdot s^{-1}$. A scatterplot displaying all samples is shown in Fig. 1. Mean speed ± SD for all data points was 8.58 ± 0.02 $m \cdot s^{-1}$ for Vicon and 8.62 ± 0.02 $m \cdot s^{-1}$ for the laser. The median speed and range were 8.56 (7.08–9.51) $m \cdot s^{-1}$ for Vicon and 8.60 (6.92–9.57) $m \cdot s^{-1}$ for the laser. Pearson's correlation coefficient between the data points collected from the two systems was $r = 0.99$ with a 95% confidence interval of $r = 0.9947–0.995$.

Individual participants' mean differences between the two systems are reported in Fig. 2 (mean ± 95% confidence limits). Differences between the laser and Vicon for each participant trial were displayed using Bland–Altman plots, with the mean bias and 95% confidence interval also shown (Fig. 3).

4 Discussion

This study validates the accuracy of a commercially available laser against a criterion measure in a stadium environment. The laser tested showed acceptable accuracy for the measurement of linear running speed greater than 6.9 $m \cdot s^{-1}$, with values recorded similar or lower to those reported in the literature for many electronic player tracking systems (EPTS) currently used in team sports. These results were further affirmed through examination of the association between the two systems, with an extremely strong positive relationship noted in both the correlational and regression analyses. This indicates for many applied purposes, the laser may be used interchangeably with the Vicon system, when used under the same circumstances outlined in this paper.

Of the few studies that have attempted to validate the accuracy of lasers for sprint running performance, all have utilized correlational analysis [8, 9]. For example, laser was nearly perfectly correlated ($r = 0.99$) with photocells for time to 20 and 50 m [8]. Further, there were strong to nearly perfect correlations between laser and video for mean ($r = 0.96$) and maximal velocity ($r = 0.87$) and mean velocity at 0–10 ($r = 0.93$), 10–20 ($r = 0.97$) and 20–30 m (0.99) [9]. Interestingly, the strength of the correlation here increased with greater distance covered, which is associated with a more constant running speed being achieved [9].

There is limited value for practitioners in the use of a correlation for validation, as the magnitude of error

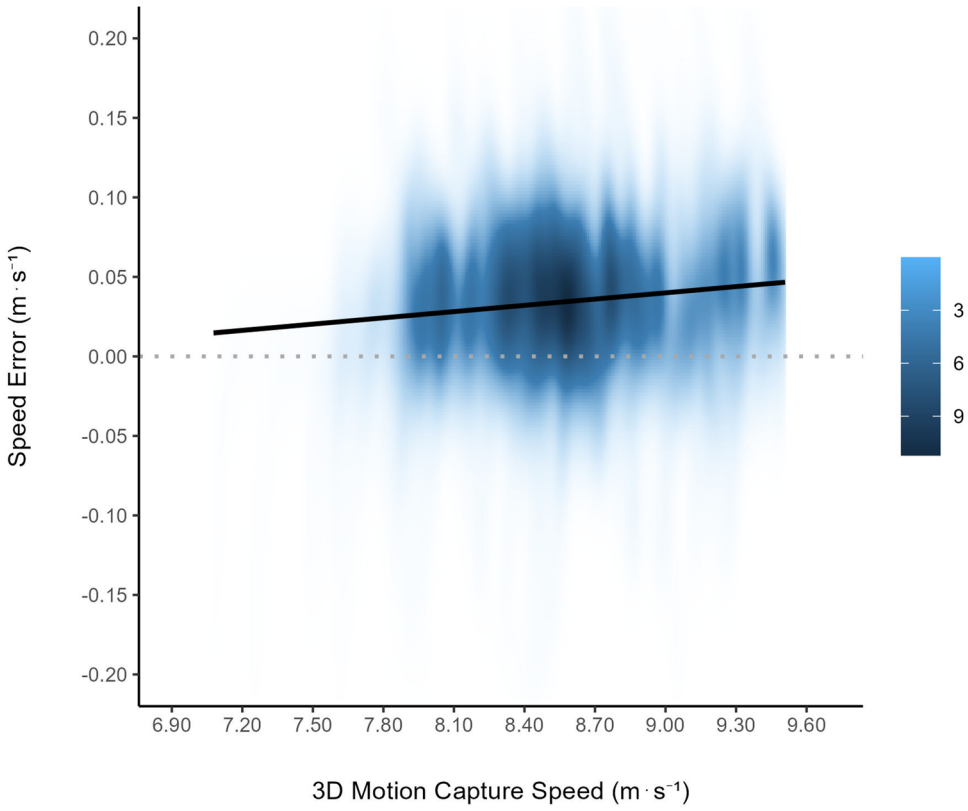

Fig. 1 The distribution of speed error versus speed measured by laser against the criterion three-dimensional motion capture system. Density is used rather than individual data points to account for the high number of samples collected

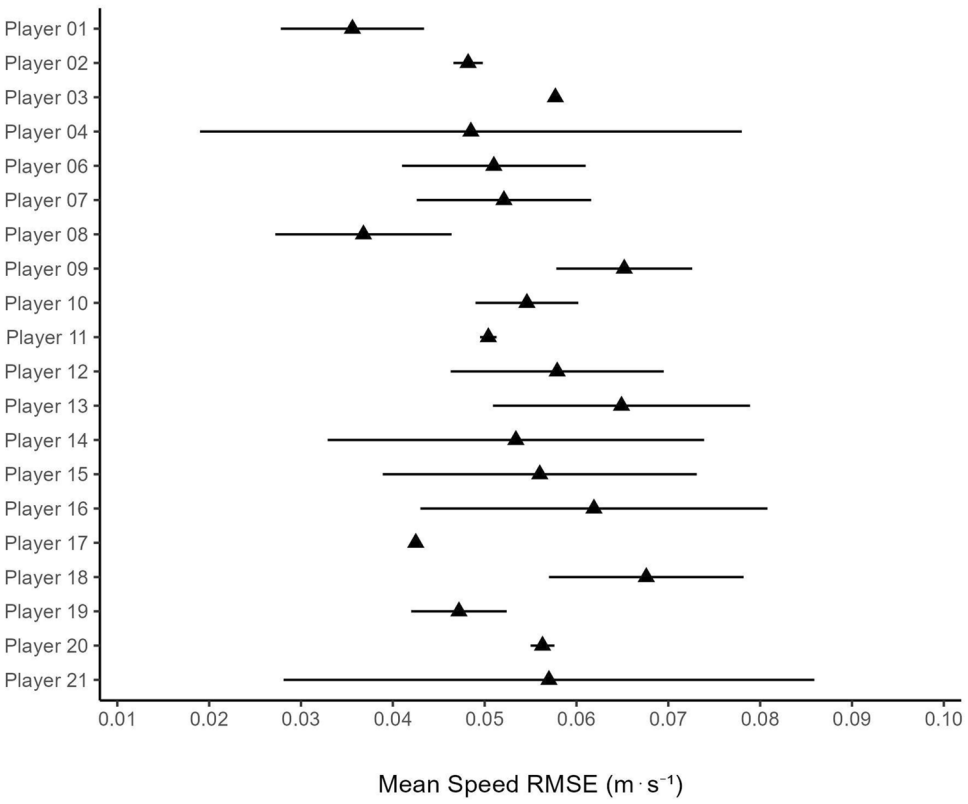

Fig. 2 Mean error comparison of laser against the three-dimensional motion capture system by participant. Data are mean error ± 95% confidence intervals. Note that participants completing only one trial have not been visualized

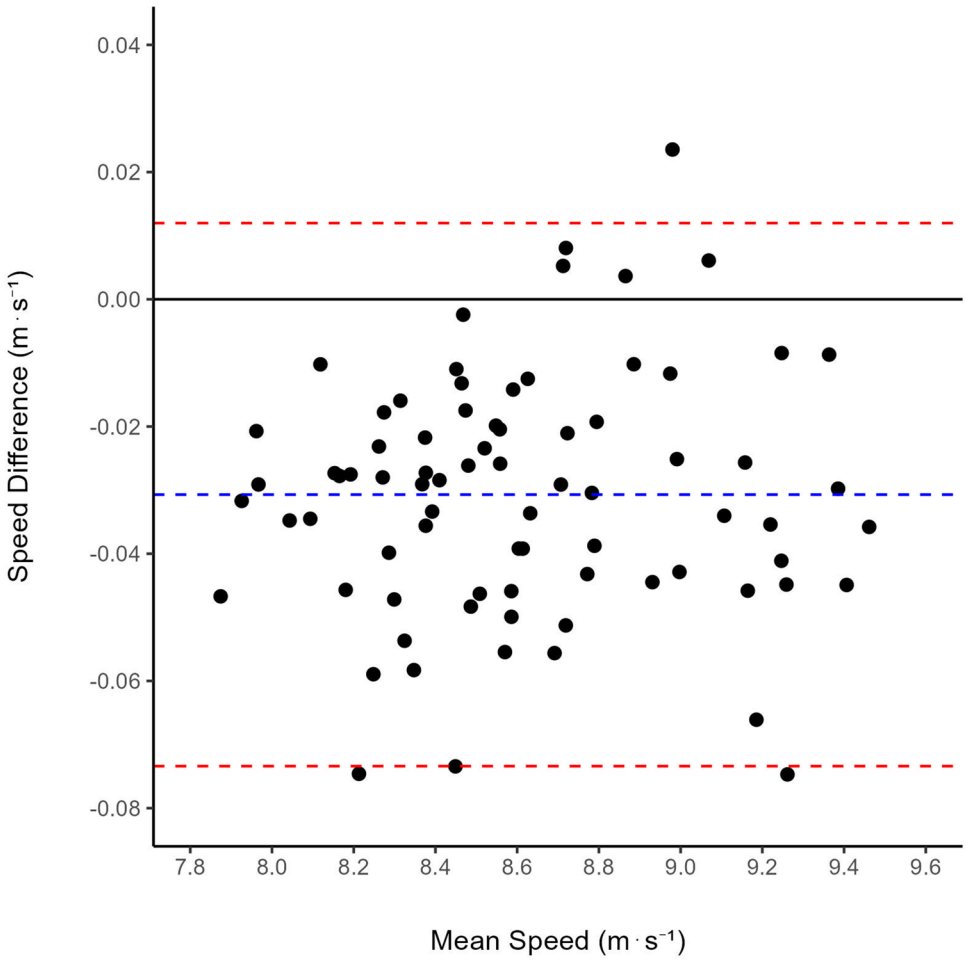

Fig. 3 Bland–Altman plot representing mean differences by trial between the Vicon and laser systems relative to the observed mean value from Vicon and laser systems. Mean bias is represented by the blue-dashed line, with 95% confidence intervals shown as red-dashed lines

between the two systems cannot be determined. To that end, the difference between photocell and laser measures of average speed of 0–10, 10–20 and 20–30 m was also calculated by Ferro et al. [9]. Average speed was higher measured by laser between 0 and 10 m despite a high correlation, but not substantially different between 10–20 and 20–30 m [9].

It is also difficult to position the results of the laser from this study to the broader EPTS industry. Published data from commercial EPTS contains a broader array of activities than the simple straight line, with relatively constant speed running used here. Notwithstanding this, the accuracy of speed measurement can be described against the state of the art in EPTS. Compared to EPTS, we found the laser speed to be more accurate than the Gen4 (RMSE: 0.09 $m{\cdot}s^{-1}$) or Gen 5 (RMSE: 0.08 $m{\cdot}s^{-1}$) Chyron Hego TRACAB system [24] and also STATS Optical SportVU (RMSE: 0.41 $m{\cdot}s^{-1}$), Inmotio LPS (RMSE: 0.25 $m{\cdot}s^{-1}$) and GPSportsSPI Pro X (RMSE: 0.28 $m{\cdot}s^{-1}$) [13].

The performance of the laser tested in our study endorses its use for the measurement of sprint running performance, but also the derivatives from instantaneous speed measurement. For example, instantaneous velocity can be used to determine the mean speed for a given distance [9, 10], horizontal force–velocity profiles [4] or potentially acceleration [25], including counts [26], distance [26, 27] or acceleration load [28]. The minor variation in error between and within participants is also likely due less to system issues and more so those participants not running in a direct straight line for each trial. It is plausible that the experience of the operator of the laser device could influence the quality of data recorded during a sprint event. To improve the quality of data, it is suggested that operators become familiar with the collection of linear speed data prior to a scheduled testing event.

Unlike some EPTS systems, the laser is relatively cost-effective, but also portable and quick and easy to setup and utilize. In the applied setting, each of these features is important, where training and testing schedules and venues can change with little notice.

5 Conclusions

The laser provides acceptable accuracy compared to a criterion motion capture system for the measurement of linear sprint movement. The accuracy of the laser exceeds that of commercial EPTS for linear speed assessment; consequently, the laser could be used to establish the concurrent validity of EPTS for the measurement of sprint speed and for other purposes such as training and testing in the field.

Acknowledgements This research was funded by the Fédération Internationale de Football Association (FIFA) as part of an electronic and performance tracking system validation for the FIFA quality programme. The authors acknowledge the support of Cádiz Club de Fútbol, and especially Mr Manuel Anguita Núñez. The authors also acknowledge technical support from Vicon, Gabriele Paolini and his team at GPEM and Alex Muir from Logemas.

Funding Open Access funding enabled and organized by CAUL and its Member Institutions.

Data availability Datasets generated during the current study are available from the corresponding author on request.

Declarations

Conflict of interest The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

References

1. Morin JB, Bourdin M, Edouard P, Peyrot N, Samozino P, Lacour JR (2012) Mechanical determinants of 100 m sprint running performance. Eur J Appl Physiol 112(11):3921–3930. https://doi.org/10.1007/s00421-012-2379-8
2. Cross MR, Brughelli M, Brown SR, Samozino P, Gill ND, Cronin JB et al (2015) Mechanical properties of sprinting in elite rugby union and rugby league. Int J Sports Physiol Perform 10(6):695–702. https://doi.org/10.1123/ijspp.2014-0151
3. Macadam P, Simperingham KD (2017) Acute kinematic and kinetic adaptations to wearable resistance during sprint acceleration. J Strength Cond Res 31(5):1297–1304. https://doi.org/10.1519/jsc.0000000000001596
4. Samozino P, Rabita G, Dorel S, Slawinski J, Peyrot N, Saez de Villarreal E et al (2016) A simple method for measuring power, force, velocity properties, and mechanical effectiveness in sprint running. Scand J Med Sci Sports 26(6):648–658. https://doi.org/10.1111/sms.12490
5. Sullivan GM (2011) A primer on the validity of assessment instruments. J Grad Med Educ 3(2):119–120. https://doi.org/10.4300/jgme-d-11-00075.1
6. Robertson S, Kremer P, Aisbett B, Tran J, Cerin E (2017) Consensus on measurement properties and feasibility of performance tests for the exercise and sport sciences: a Delphi study. Sports Med 3:1–10. https://doi.org/10.1186/s40798-016-0071-y
7. Streiner DL, Norman GR, Cairney J (2015) Health measurement scales: a practical guide to their development and use (5th edition). Oxford University Press, USA. https://psycnet.apa.org/doi/https://doi.org/10.1093/med/9780199685219.001.0001
8. Berthoin S, Dupont G, Mary P, Gerbeaux M (2001) Predicting sprint kinematic parameters from anaerobic field tests in physical education students. J Strength Cond Res 15(1):75–80
9. Ferro A, Floría P, Villacieros J, Aguado-Gómez R (2012) Validity and reliability of the laser sensor of Biolasersport® System for the analysis of the running velocity. Rev Int Cienc Deporte 8(30):357–370. https://doi.org/10.5232/RICYDE2012.03005
10. Bezodis NE, Salo AIT, Trewartha G (2012) Measurement error in estimates of sprint velocity from a laser displacement measurement device. Int J Sports Med 33(6):439–444. https://doi.org/10.1055/s-0031-1301313
11. Feser E, Lindley K, Clark K, Bezodis N, Korfist C, Cronin J (2022) Comparison of two measurement devices for obtaining horizontal force-velocity profile variables during sprint running. Int J Sports Sci Coach 17(6):1455–1461. https://doi.org/10.1177/17479541211067211
12. Morin JB, Sève P (2011) Sprint running performance: comparison between treadmill and field conditions. Eur J Appl Physiol 111(8):1695–1703. https://doi.org/10.1007/s00421-010-1804-0
13. Di Prampero PE, Fusi S, Sepulcri L, Morin JB, Belli A, Antonutto G (2005) Sprint running: a new energetic approach. J Exp Biol 208(14):2809–2816. https://doi.org/10.1242/jeb.01700
14. Merriaux P, Dupuis Y, Boutteau R, Vasseur P, Savatier X (2017) A study of Vicon system positioning performance. Sensors 17(7):1591. https://doi.org/10.3390/s17071591
15. Aughey RJ, Ball K, Robertson SJ, Duthie GM, Serpiello FR, Evans N et al (2022) Comparison of a computer vision system against three-dimensional motion capture for tracking football movements in a stadium environment. Sports Eng. https://doi.org/10.1007/s12283-021-00365-y
16. Linke D, Link D, Lames M (2018) Validation of electronic performance and tracking systems EPTS under field conditions. PLoS ONE 13(7):e0199519. https://doi.org/10.1371/journal.pone.0199519
17. Association FIFA (2019) Resource hub: certified product database Zurich, Switzerland: Fédération Internationale de Football Association [cited 12/12/2024]. https://football-technology.fifa.com/en/resource-hub/certified-product-database/football-technologies/epts/certified-systems/.
18. Ogris G, Leser R, Horsak B, Kornfeind P, Heller M, Baca A (2012) Accuracy of the LPM tracking system considering dynamic position changes. J Sports Sci 30(14):1503–1511. https://doi.org/10.1080/02640414.2012.712712
19. Blair S, Duthie G, Robertson S, Hopkins W, Ball K (2018) Concurrent validation of an inertial measurement system to quantify kicking biomechanics in four football codes. J Biomech 73:24–32. https://doi.org/10.1016/j.jbiomech.2018.03.031
20. Van den Tillaar R (2021) Comparison of step-by-step kinematics of elite sprinters' unresisted and resisted 10-m sprints measured with Optojump or Musclelab. J Strength Condition Res 35(5):1419–1424. https://doi.org/10.1519/jsc.0000000000002898

21. Van den Tillaar R, Nagahara R, Gleadhill S, Jiménez-Reyes P (2021) Step-to-step kinematic validation between an Inertial Measurement Unit (IMU) 3D system, a combined Laser+ IMU system and force plates during a 50 m sprint in a cohort of sprinters. Sensors 21(19):6560. https://doi.org/10.3390/s21196560
22. Gilat A, Subramaniam V (2011) Numerical methods for engineers and scientists: an introduction with applications using Matlab. Wiley
23. Buck JR, Daniel MM, Singer A (2002) Computer explorations in signals and systems using Matlab. Prentice Hall
24. Linke D, Link D, Lames M (2020) Football-specific validity of Tracab's optical video tracking systems. PLoS ONE 15(3):e0230179. https://doi.org/10.1371/journal.pone.0230179
25 Delves RIM, Aughey RJ, Ball K, Duthie GM (2021) The quantification of acceleration events in elite team sport: a systematic review. Sports Med Open. https://doi.org/10.1186/s40798-021-00332-8
26. Delaney JA, Cummins CJ, Thornton HR, Duthie GM (2018) Importance, reliability, and usefulness of acceleration measures in team sports. J Strength Cond Res 32(12):3485–3493. https://doi.org/10.1519/jsc.0000000000001849
27. Akenhead R, Hayes PR, Thompson KG, French D (2013) Diminutions of acceleration and deceleration output during professional football match play. J Sci Med Sport 16(6):556–561. https://doi.org/10.1016/j.jsams.2012.12.005
28. Brooks ER, Benson AC, Fox AS, Bruce LM (2020) Physical movement demands of elite-level netball match-play as measured by an indoor positioning system. J Sports Sci 38(13):1488–1495. https://doi.org/10.1080/02640414.2020.1745504