Validity and Reliability of a 15 Hz GPS Device for Court-Based Sports Movements

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GPS | Validation | Court-based sport

Headline

The validity and reliability of global positioning technology (GPS) for measuring the physical demands of various sports have been questioned (1,2,3). Court-based sports are characterized by rapid changes in direction within a confined space (4,5,6,7). Thus, one would expect lower quality of GPS data compared to field sports (8,9,10).

Aim

The purpose of this study was to determine the criterion validity and reliability of a 15Hz GPS unit during court-based movements that simulate activities encountered during a tennis match.

Methods

Twenty GPS units were used (SPI HPU, GPSports, 15 Hz GPS, 100Hz/16g accelerometer, 50Hz magnetometer). A calibrated trundle wheel was used as the criterion device (MeterMan MK45M, Komelon, 363cm diameter, 1.141m circumference, 0.1m resolution). Before and after each day, the wheel was calibrated against a 100m steel tape. Wheel calibration did not change during the day's session and nor between days.

Two HPU SPI units (paired units) were attached to the wheel, 8 and 15 cm directly above the axis of the wheel and 2.5 cm lateral to the pivot point of the wheel. This allowed comparisons between individual GPS units and the wheel (criterion validity) as well as between paired units (inter-unit reliability). Four trials were conducted to test the validity and reliability of the units (see Figure 1). Standard course paths were followed as closely as possible. Care was taken to ensure that the wheel did not move backwards or sideways and that the wheel stayed in contact with the ground. The start and stop times of each trial were recorded using a GPS-linked digital watch.

The distance trial (DIST) consisted of four laps of a regulation 400m running track. The GPS units and wheel travelled along an imaginary line 0.3m from the inside of lane one. The wheel and units travelled through 100m intervals with alternating speeds similar to a jog, run and sprint. At the end of the final lap, the units were slowed and the wheel brought to a stop on the start/finish line. Wheel distance was then recorded.

The three court-based trials were performed on a regulation tennis court. For the shuttle run trial (SHUT), the wheel followed a path along the singles baseline (8.2m), pivoted 180°, and then returned to the starting point. Five sets of three laps were performed with a 20 sec pause between sets (246 m total distance). During the change of direction trial (COD), the wheel followed a course that consisted of five segments and four turns. For the first segment, the wheel was moved along the doubles baseline (10.8m). A 180° turn was executed and the wheel returned along the baseline. A 90° turn was executed and wheel moved along the doubles sideline to the service line (5.5m). The wheel was rotated 90° and followed the service line to the other doubles sideline (10.8m). Lastly, a 153° turn was executed and the wheel moved along a straight line towards the intersection of the opposite doubles sideline and the baseline (12.1m total distance). The second lap began with a 153° turn before moving the wheel along the baseline. Each lap was separated by a 20sec pause (250m total distance, 24 turns). The random movement trial (RAND) consisted of five, 10 sec sets of random movements within the singles court, designed to replicate movements common to a tennis match. At the beginning of each set, the wheel was placed directly on the middle of the baseline. The wheel was them moved randomly between the singles sidelines and between the baseline and net. Each set was separated by 20s during which time wheel distance was recorded. No standard distance was established but total distance was 135m.

Cohen's d was used to calculate effect sizes between unit and wheel distances and categorized as trivial (<0.2) and small (0.2-0.5). Bland-Altman plots determined the agreement between the GPS- and wheel-measured distances (14,15,16). Bias and limits of agreement (LOA) were calculated, along with root mean square (RMS) errors. Intraclass correlation coefficients (ICC) were also computed to further evaluate agreement between devices and the wheel.

Results

Typical GPS position recordings for the four trials are shown in Figure 1. There are noticeable differences between the standard paths and the GPS determinations (±0.5m). This is expected as high-speed movements and rapid directional changes made it difficult for the wheel to precisely track the specific path. In fact, the wheel and GPS units over-estimated the standard distances by 1.0-2.5% (Table 1). However, Cohen's d classified differences between the wheel in units as trivial and small. The mean RMS error values between the two devices were < 2% for three of the four trials. Table 2 shows the level of agreement between the two devices. Intraclass coefficient (ICC) were quite high (>0.95). Bland-Altman plots of the total distances for the four trials are in Figure 2. For all trials, mean bias values are negative, indicating an over estimation of wheel distance by the GPS units. Nevertheless, bias values are small, less than 2.5m and less than 2%. The LOA range for the DIST trail is 46.20m, less than 20m for the others and less than 9% for all trials. For the four trials combined, 96.25% of the difference measurements fall within the LOA. Considering measurements for each lap or set for all four trials (n=320), more than 60% of the RMS error values and more than 80% of the bias values are within ±2%. The mean RMS error for the entire data set is 1.79±0.07%, mean bias is -1.00±0.11% and the LOA is -4.82 to 2.82%. The ICC for all 320 points is 0.998. Inter-unit reliability for paired units (upper and lower mounted) was good as well. For all sets and laps executed (n=160), mean RMS error between units is 1.84±0.21%, mean bias is 0.63±0.36% and the LOA ranged from -1.62 to 2.89%. The mean ICC coefficient for the paired units is 0.995.

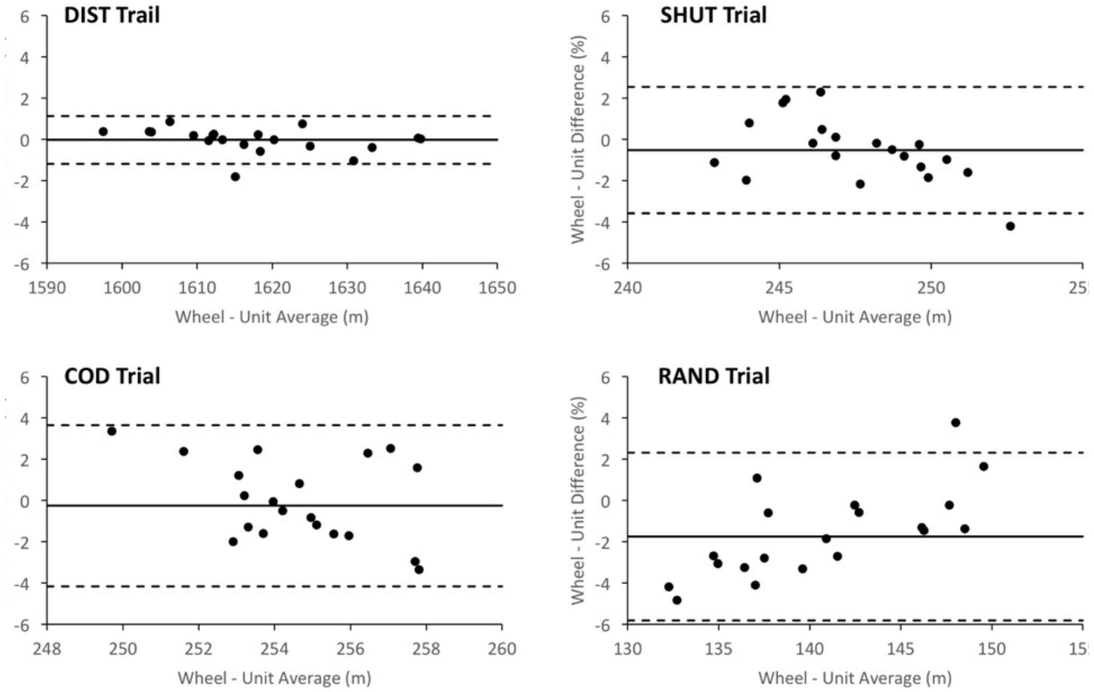

Fig. 1. Bland-Altman plots of the differences between distances recorded by the trundle wheel and GPS units. In this figure, differences are expressed as percent difference. Bias values are indicated by the solid lines and LOA by the dashed lines.

Discussion

The use of GPS to estimate physical efforts during court-based sports such as tennis has aroused considerable interest. A key concern is the accuracy and reliability of GPS technology for rapid change of direction movements with a confined space. For GPS systems and other technical devices used during exercise, measures of validity (i.e. error values) less than 5% are considered good (2,4). In this study, the GPSports SPI HPU units were found to have very good criterion validity and inter-unit reliability as RMS error and bias values were typically within ±2%. While both the GPS units and wheel overestimated standard path distances, the differences between the device estimates were small. Given this, the SPI HPU GPS units can be used with a high degree of confidence to determine distances covered during court-based sports such as tennis.

In previous studies (8,9), investigators compared distances recorded by the GPS units during confined movements with video determination using VICON. In these studies, a reflective marker was placed on the unit so that the distances recorded by the video system mirrored that of the unit. Accuracy in these studies was found to be in between 4 to 10%, somewhat larger than shown here. This may reflect difference in the GPS units used (GPSports SPI Elite, SPI HPU, Catapult MinnimaX). Typically, accelerometer data supplements GPS data to compute speed then distance. The results is higher sampling frequencies and the ability to “bridge the gap” between periods of GPS signal loss (15,16). This involves the use data smoothing techniques, application of a Kalman filter and proprietary algorithms (15,16,17,18). Others (15,18) point out that the choice of algorithm used to combine GPS and accelerometer data can impact the calculated distances. Thus, it is possible that differences in algorithms used to calculate speed and distance could affect validity scores.

Other studies utilized running path distance or distance along a course as a criterion. This assumes that the individual wearing the GPS unit is capable of following the criterion path. Any deviation from the path affects validity determination. For example, Rawstorn et al. (19) performed measurements on subjects running while wearing a 15Hz GPS device (GPSports, SPI Pro X). They found a statistically significant overestimation of the path distance by the GPS units (2.6%). The reported error includes intrinsic error of the units and differences in the actual distance traveled by the subject. Figure 1 shows noticeable deviations between the GPS signals and the criterion path during the DIST trial. We hoped to follow the standard path as closely as possible. However, this did not occur as the wheel and units recorded distances greater than 1600m. Since the GPS units were secured to the wheel, any path deviations would be reflected in both the wheel and

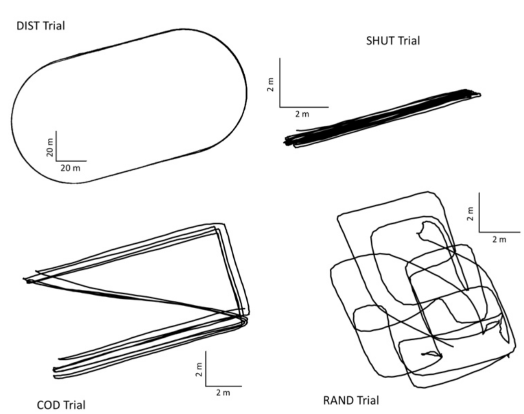

Fig. 2. Standard courses and typical GPS position recordings during each of the four trials.

Table 1. Standard course distances and distances traveled by the trundle wheel and GPS units.

	DIST	SHUT	COD	RAND
Standard (m)	1600	246	249	n/a
Wheel (m)	1617.30 ± 2.49	246.89 ± 0.50	254.28 ± 0.51	139.49 ± 1.49
GPS (m)	1617.70 ± 3.13	248.18 ± 0.90	254.94 ± 0.91	141.89 ± 1.01
Cohen's d	0.032^{t}	0.396^{s}	0.200^{t}	0.422^{s}
RMS Error (m)	6.61 ± 1.56	3.13 ± 0.56	4.31 ± 0.55	3.19 ± 0.42
RMS Error (%)	0.41 ± 0.10	1.26 ± 0.22	1.69 ± 0.22	2.29 ± 0.31

Values are x ± SEM. Cohen's d and RMS errors were calculated for wheel vs GPS distances. ^{t} trivial effect size, ^{s} small effect size.

Table 2. Agreement variables for the four trials between wheel and GPS distances.

	DIST	SHUT	COD	RAND
ICC (R2)	0.997	0.999	0.998	0.954
Bias (m)	-0.40 ± 2.61	-1.29 ± 0.86	-0.66 ± 1.12	-2.38 ± 0.64b
LOA (m)	-23.50, 22.70	-8.91, 6.33	-10.60, 9.28	-8.04, 3.28
Bias (%)	-0.02 ± 0.13	-0.51 ± 0.35	-0.25 ± 0.44	-1.75 ± 0.46b
LOA (%)	-1.17, 1.13	-3.58, 2.55	-4.15, 3.65	-5.81, 2.31

Values are x ± SEM. LOA values are expressed as upper and lower values.

GPS measurements. Thus, the use of a calibrated wheel as the criterion is preferable to using path or course distances.

Limitations

- During backwards movement of the wheel, distance is subtracted by the mechanical counter such that the actual distance traveled would be underestimated. If the wheel lost contact with the ground or slipped sideways, the distance recorded by the wheel could be affected. To reduce these possibilities, care was taken to maintain constant contact with the ground and to avoid reversing the wheel, especially during abrupt changes in direction.
- Positioning of the units away from the wheel's point of contact with the ground could introduce error. As the handle of the wheel rotates forward, backward and sideways, in the absence of wheel movement, the units would record these as distance travelled (≈4 and 7cm for 30° of rotation). While care was taken to maintain constant handle position during each trial, it is possible that movement error occurred.
- An important issue not addressed in this study is what constitutes "distance traveled" during activity and how this may influence the reported distances. GPS units record distances traveled by the unit, not necessarily by the player. During play, tennis athletes routinely lean, reach and sway while the feet remain stationary on the ground. With a trunk mounted GPS unit, several centimeters of movement would be recorded as distance traveled despite the feet remaining stationary. Over the course of a tennis match, these small movements may accumulate. This raises several questions. Is distance travelled by the GPS unit considered reflective of true distance travelled by the player? Does "body lean" introduce noticeable error when using GPS units? Further, is such error greater that the intrinsic error of the unit?

Practical Applications

- For court-based sports where activity is confined to a small area, the present data suggest that coaches and trainers can confidently use trunk-mounted GPS devices to monitor distances in sports such as tennis.
- However, it should be pointed out that when considering the suitability of these devices for estimation of training loads, one must consider the error within the context of their intended use.
- In addition, one should consider non-playing movements such as ball retrieval and change overs when calculating training loads.

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