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Technical note

Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports

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Abstract

The aim of this study was to assess the accuracy and reliability of global positioning system (GPS) measures of distance and speed, compared to a high-resolution motion analysis system, for confined movement patterns used in many court-based sports. A single male participant performed 10 repetitions of four respective drills replicating court-based movement patterns and six repetitions of a random movement drill that replicated tennis match-play movement patterns. Two 1 Hz and two 5 Hz GPS devices concurrently measured distance covered and speed of all court-based drills. A 22 camera VICON motion analysis system, operating at 100 Hz, tracked the position of an 18 mm reflective marker affixed to one of the GPS devices to provide the criterion movement data. Results indicated that both 1 and 5 Hz GPS devices under reported distance covered as well as both mean and peak speed compared to the VICON system ($P < 0.05$). The coefficient of variation for both GPS devices for distance and speed measures ranged between 4 and 25%. Further, the faster the speed and more repetitive the movement pattern (over a similar location), the greater the measurement error. The inter-unit reliability for distance and speed measures of both 1 and 5 Hz systems for movements in confined spaces was generally low to moderate ($r = 0.10$–0.70). In conclusion, for court-based sports or movements in confined spaces, GPS technology under reports distance covered and both mean and peak speed of movement.

Keywords: Movement analysis; Team sports; Validity

1. Introduction

Accurate assessment of the movement profile of athletes during training and match-play can assist in the development of specific conditioning activities and recovery strategies. Accordingly, the use of global positioning system (GPS) technology has been used to measure movement patterns, specifically distance covered and speed of movement, in many intermittent-sprint sports.[1] Recent studies have reported the reliability of GPS measures of distance and speed, and have also attempted to establish the criterion validity of speed measures.[2,3] However, to date, speed has been assessed via the comparison of GPS data (collected at either 1 or 5 Hz) to infra-red timing systems that report a mean speed, but not a peak or a continuous measure of the fluctuation in speed. Further, while previous literature has highlighted the potential use of GPS technology for intermittent-sprint sports in open spaces and over prolonged continuous movements (i.e. football codes and hockey)[2–5]; as yet the accuracy and reliability of GPS technology for use in court-based sports or movement patterns in confined spaces is unknown. Additionally, no research has reported a true validation of GPS measures of speed against high resolution motion analysis devices (i.e. VICON motion analysis system). Therefore the aim of this study was to assess the accuracy and reliability of GPS measures of distance and speed for confined movement patterns as used in court-based sports such as tennis.

2. Methods

One moderately trained male (age: 30 years, height: 176 cm, mass: 70 kg) completed 10 repetitions of four

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respective drills replicating court-based movement patterns and six repetitions of a random movement drill that replicated tennis match-play movement patterns. The four court-based movement drills consisted of (1) a slow jog in a rectangle pattern around the lines of the baseline, singles sideline and service line of a standard tennis court (26 m in total distance); (2) a fast run in a rectangle pattern as reported for the previous drill; (3) a side-to-side movement pattern approximately 2 m either side of the centre line of a tennis court baseline and (4) a side-to-side movement pattern approximately 4 m either side of the centre line of a tennis court baseline. The random movement drill consisted of 6 s of random movement around the baseline of a tennis court replicating movements commonly observed in tennis match-play. Each drill was timed with a stopwatch and the subject maintained a stationary pose at the start and end of each respective drill to assist determination of different drills for later analysis.

During each drill, GPS data were collected concurrently by four devices housed in individual, customised harnesses worn simultaneously between the scapulae in line with the lower cervical spine. Two 5 Hz (MinimaxX, Team Sport Model, Catapult, Australia) and two 1 Hz (SPI elite, GPSports, Australia) GPS units were used in concert, with all devices activated 15-min prior to data collection to allow acquisition of satellite signals. Further, at all times, an 'open' sky was present and there were no obstructions, ensuring clear space for satellite acquisition. Speed was calculated post hoc by customised software specific to each brand of GPS unit (GPSports; Team AMS v2.1, MinimaxX; v28.5 Logan Software). Additionally, to determine criterion movement distance and speed data during the respective drills, the three-dimensional (3D) position of a reflective marker, attached to a harness of one of the participant's GPS devices, was recorded by a 22 camera VICON motion analysis system (Oxford Metrics, UK) operating at 100 Hz. All testing was performed at night, outdoors on a plexicushion court at the Australian Institute of Sport. Relevant static and dynamic calibration was undertaken to accurately determine the 3D space in which the movement drills were completed. The VICON system was calibrated to an accuracy of less than 1 pixel for each camera, with camera resolutions of 12 MP, representing an error of 0.0008%.[6]

Prior to statistical analyses, all VICON data was time aligned with the GPS units to match movement duration. A one-way analysis of variance (ANOVA) with Tukeys' post hoc tests was used to analyse the difference between respective measurement devices for both distance and speed within each court-based drill. The inter-unit reliability was assessed by intra-class correlation (ICC) analysis, while the typical error was expressed as a coefficient of variation (CV).

3. Results

Seven satellites were acquired during the testing session, ensuring adequate satellite acquisition for data collection. Table 1 shows the distance covered and mean and peak speeds of each court-based movement drill for each device. Both 1 and 5 Hz devices showed significant differences ($P < 0.05$) to the VICON measures of distance and speed. In particular, these differences were greater during the faster speed movements, particularly when movement patterns involved repeated movements over a similar location in space (2-m and 4-m drills). Table 2 shows the ICC and CV for each GPS device for all movement drills. ICC values for both 1 and 5 Hz devices were low to moderate for most drills (0.10–0.70), while CV's for respective devices were between 4 and 25%.

4. Discussion

Estimation of the physical load associated with training and matchplay is a source of interest for many court-based sports. However, questions pertaining to the validity of the calculated measures may limit the integration of this technology. Previous research on the accuracy and reliability of GPS devices for measuring athlete movement patterns indicates that for slow to moderate speeds over moderate to longer distances, GPS technology has acceptable inter-unit reliability and accuracy for distance measured.[2–5] However, as the speed of movement increases, the reliability of 1 Hz GPS technology has been reported as somewhat lower.[2] Further, previous research has outlined the error measurement of GPS devices to range between 2 and 25%, depending on movement distance and speed.[2–5] The present research generally agrees with this previously published data, with inter-unit CV for distance covered ranging from 4% for slower movement speed, up to 30% for faster movement speed. Moreover, compared to the VICON system, GPS devices underestimate the distance covered, particularly at higher speed and during repeated movement patterns in confined spaces.

The current study is the first to have a true criterion measure of speed through the use of a VICON motion analysis system capturing data at 100 Hz. Results indicated that both 1 and 5 Hz systems underestimated both peak and mean speed (by 10–30%) during court-based movement drills. Again, the faster movement speeds result in an increased CV, suggesting that as compared to VICON, the lower resolution of GPS devices fails to capture all relevant data. Accordingly, during movements performed at high velocity and/or that include frequent changes of direction, this manifests to under-represent mean and peak velocity measures.

While differences between respective 1 and 5 Hz GPS devices are expected due to the resolution of the units, a 5 Hz device seemed more accurate when measuring distance and velocity for movement patterns at higher velocities in confined spaces. However, there was still some discrepancy between 5 Hz models and VICON measures. Further, the inter-unit reliability for the 5 Hz system seemed to be lower than that of the 1 Hz model. Given many of the movement

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Table 1
Mean ± SD for VICON system, 1 and 5 Hz GPS devices for distance covered, mean speed and peak speed of slow and fast rectangle drills and 2-m, 4-m and random movement tennis drills.

	VICON	5 Hz #1	5 Hz #2	1 Hz #1	1 Hz #2
Distance (m)					
Slow	25.8 ± 1.5	23.9 ± 2.0	23.6 ± 1.8[a,d]	25.5 ± 1.1	25.9 ± 0.7
Fast	25.6 ± 0.3	21.3 ± 3.6[a]	18.0 ± 2.6[a,c,d]	20.9 ± 2.6[a]	21.8 ± 1.1[a]
2-m tennis	37.0 ± 0.7	34.2 ± 1.2[a,c,d]	30.7 ± 1.0[a,c,d]	23.1 ± 0.7[a]	23.7 ± 0.7[a]
4-m tennis	33.7 ± 0.5	34.6 ± 6.3[a,c,d]	28.5 ± 2.7[a,c,d]	24.0 ± 1.3[a]	22.8 ± 1.5[a]
Random	12.0 ± 2.4	8.3 ± 1.7[a]	8.3 ± 1.9[a]	8.0 ± 1.2[a]	7.9 ± 1.7[a]
Mean speed ($m\,s^{-1}$)					
Slow	1.7 ± 0.1	1.6 ± 0.2	1.6 ± 0.1	1.5 ± 0.1[a]	1.6 ± 0.1
Fast	2.9 ± 0.2	2.4 ± 0.4[a,c,d]	2.1 ± 0.3[a,d]	2.0 ± 0.2[a,b,c]	2.6 ± 0.2[a,b]
2-m tennis	1.1 ± 0.1	1.0 ± 0.1[a,c,d]	0.9 ± 0.1[a]	0.8 ± 0.1[a,d]	0.9 ± 0.1[a,d]
4-m tennis	1.7 ± 0.1	1.8 ± 0.3[c,d]	1.5 ± 0.1[a,c,d]	1.4 ± 0.1[a,b,c]	1.1 ± 0.1[a,b,c]
Random	2.0 ± 0.4	1.4 ± 0.3	1.4 ± 0.3	1.3 ± 0.2[a]	1.4 ± 0.6
Peak speed ($m\,s^{-1}$)					
Slow	2.6 ± 0.1	3.1 ± 0.7[a,d]	3.0 ± 0.3[d]	2.3 ± 0.1[d]	2.4 ± 0.1[d]
Fast	4.9 ± 0.2	4.7 ± 1.6	3.9 ± 0.8[a]	3.7 ± 0.6[a]	4.2 ± 0.3
2-m tennis	2.6 ± 0.2	2.7 ± 0.4[d]	2.5 ± 0.4[d]	1.9 ± 0.1[a,d]	1.9 ± 0.1[a,d]
4-m tennis	3.9 ± 0.2	4.9 ± 1.2[a,d]	4.1 ± 0.8[d]	2.7 ± 0.2[a,d]	2.3 ± 0.4[a,d]
Random	3.9 ± 0.8	3.3 ± 1.5	3.2 ± 0.9	2.4 ± 1.1[a]	2.5 ± 1.2[a]

[a] Within each respective drill type: significantly different to VICON.
[b] Within each respective drill type: significantly different between 1 Hz models.
[c] Within each respective drill type: significantly different between 5 Hz models.
[d] Within each respective drill type: significantly different between 1 and 5 Hz models.

patterns in small areas or for court-based sports involve repetition of movement in the same location in space, the greater frequency of measurement in the 5 Hz system may account for the generally more accurate measures of speed noted in the 5 Hz devices. Despite greater accuracy, and while speculative, the observed reduction in inter-unit reliability in the 5 Hz model may relate to the increased volume of collected data in the 5 Hz model, or differences in treatment of acquired data by the respective systems. Regardless, in sports where measures of mean and peak speed are of interest, it appears advisable to use higher resolution devices.

Table 2
Intra-class correlations (ICC) and co-efficient of variation (CV) within GPS device (between respective 1 Hz and 5 Hz models) for respective slow rectangle, fast rectangle, 2-m and 4-m and random movement tennis drills.

	5 Hz ICC	1 Hz ICC	5 Hz CV	1 Hz CV
Distance (m)				
Slow	0.38	0.17	9.8	3.6
Fast	−0.06	0.20	17.8	9.5
2-m tennis	0.01	0.24	3.5	3.6
4-m tennis	0.15	0.15	11.0	5.8
Random	0.43	0.87	16.8	7.6
Mean speed ($m\,s^{-1}$)				
Slow	−0.09	0.45	9.1	2.1
Fast	0.05	0.25	17.1	11.1
2-m tennis	0.41	0.70	3.4	3.9
4-m tennis	0.03	0.55	15.6	5.6
Random	0.43	0.69	16.9	19.3
Peak speed ($m\,s^{-1}$)				
Slow	0.06	0.70	17.6	2.3
Fast	−0.12	−0.08	31.7	15.3
2-m tennis	0.69	0.22	20.3	5.8
4-m tennis	0.08	0.11	24.5	12.6
Random	−0.08	0.93	35.3	26.7

In conclusion, the use of the current GPS technology to measure distance and speed of court-based or confined space movements likely leads to an underestimation of movement distance and speed. Consequently, practitioners using this technology to monitor athlete activity should account for this underestimation when monitoring movement patterns. Further, due to lower inter-unit reliability, it is advisable that participants and athletes wear the same device within any research design or while training in the field. Finally, it should be noted that these results apply to current versions of GPS software and hardware, which continue to undergo development.

Practical implications

- GPS devices underestimate the distance covered and speeds recorded during court-based, confined movement patterns.
- Where possible, the same GPS device should be used for the same player or subject in order to avoid inter-unit error.

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