Validity and reliability of GPS for measuring distance travelled in field-based team sports

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First published on: 20 September 2010

To cite this Article

To link to this Article: DOI: 10.1080/02640414.2010.504783
URL: http://dx.doi.org/10.1080/02640414.2010.504783
Validity and reliability of GPS for measuring distance travelled in field-based team sports

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(Accepted 24 June 2010)

Abstract
The aim of the present study was to examine the effects of movement intensity and path linearity on global positioning system (GPS) distance validity and reliability. One participant wore eight 1-Hz GPS receivers while walking, jogging, running, and sprinting over linear and non-linear 200-m courses. Five trials were performed at each intensity of movement on each 200-m course. One receiver was excluded from analysis due to errors during data collection. The results from seven GPS receivers showed the mean (+s) and percent bias of the GPS distance values on the 200-m linear course were 205.8 ± 2.4 m (2.8%), 201.8 ± 2.8 m (0.8%), 203.1 ± 2.2 m (1.5%), and 205.2 ± 4 m (2.5%) for the walk, jog, run, and sprint trial respectively. Walk and sprint distances were significantly different from jogging and running distances (P < 0.05).

The GPS distance values on the 200-m non-linear course were 198.9 ± 3.5 m (7.0%), 188.3 ± 2 m (7.5%), 184.6 ± 2.9 m (7.7%), and 180.4 ± 5.7 m (9.8%) for the walk, jog, run, and sprint trial respectively; these were significantly lower than those for the corresponding values on the linear course (P < 0.05). Differences between all non-linear movement intensities were significant (P < 0.05). The overall coefficient of variation within and between receivers was 2.6% and 2.8% respectively. Path linearity and movement intensity appear to affect GPS distance accuracy via inherent positioning errors, update rate, and conditions of use; reliability decreases with movement intensity.

Keywords: Accuracy, displacement, position

Introduction
Despite relatively few independent studies of the validity and reliability of global positioning system (GPS) technology in sport-related conditions (Barbero-Alvarez, Coutts, Granda, Barbero-Alvarez, & Castagna, 2010; Coutts & Duffield, 2010; Macleod, Morris, Nevill, & Sunderland, 2009), GPS receivers are gaining popularity in a number of sports as a means for coaches to assess specific movement demands of their athletes in both training and competition (Cunniffe, Proctor, Baker, & Davies, 2009; Petersen, Pyne, Dawson, Portus, & Kellett, 2010; Wisbey, Montgomery, Pyne, & Rattray, 2009). Few studies have reported the reliability and validity of distance data provided by non-differential GPS receivers (Coutts & Duffield, 2010; Edgecomb & Norton, 2006; Macleod et al., 2009; Portas, Rush, Barnes, & Batterham, 2007; Townshend, Worringham, & Stewart, 2008); others have investigated speed measurement using both non-differential (Schutz & Chambaz, 1997; Witte & Wilson, 2004) and differential GPS (dGPS) (Larsson & Henriksson-Larsen, 2001; Schutz & Herren, 2000). Non-differential, 1-Hz GPS receivers are reported to be accurate and reliable for measuring linear distance walked (Townshend et al., 2008) and distance moved over relatively linear paths (various unreported movement speeds) (Edgecomb & Norton, 2006). Indeed, Portas et al. (2007) have shown that GPS distance error (mean percent error) was highest during running at ~6 m · s⁻¹ (5.6%) and lowest during walking at 1.8 m · s⁻¹ (0.7%) on straight paths. These findings suggest that GPS is a valid method of measuring linear distance travelled at low movement speeds (<3 m · s⁻¹) and that movement velocity may influence measurement validity. However, given that many athletes train and compete at movement velocities greater than 3 m · s⁻¹ and often over curved or non-linear paths, further investigation is required.
Two studies have examined the validity of GPS under conditions relative to field sport athletes (Coutts & Duffield, 2010; Macleod et al., 2009). Each had participants complete multiple laps of a circuit while wearing one or multiple GPS receivers. Laps consisted of varied movement intensities (e.g. walking, running, standing) interspersed with agility-based movements such as a zigzag shuttle. The protocols simulated the movement patterns of field-based team sports, but neither included movement over curved paths. Distance error varied between receiver models; however, mean total distance errors were less than ±5% for all receivers evaluated. The methods used in these studies produced results that suggest that GPS is able to provide valid data for such conditions. However, these methods potentially mask any interactions between movement intensity, movement path, and GPS distance accuracy. This has implications when distance measurements are grouped according to movement intensity, for example speed zones (Wisbey et al., 2009). Given there is evidence to suggest that movement intensity influences GPS distance accuracy (Portas et al., 2007), it is reasonable to assume movement path (e.g. curve-linear, straight, circular) may also have an effect (considering distance is derived from changes in position). The validity and reliability of distance data provided by 1-Hz non-differential GPS receivers across such a range of dynamic conditions is yet to be evaluated. The aim of the present study, therefore, was to determine the effects of movement intensity and path linearity on GPS distance accuracy and reliability.

Methods

Participant

A 25-year-old male triathlete volunteered to participate in the study. Given that the accuracy of GPS measures are not affected by the physiological characteristics (gender, height, weight, fitness level, etc.) of participants, it has been common practice for past studies to use few (Townshend et al., 2008) or single participants (Witte & Wilson, 2004) for multiple trials, rather than the reverse. The number of samples or trials is of more value than the number of participants. Informed consent of the athlete was gained prior to participation and the study was approved by an ethics committee of the University of Queensland.

Apparatus

Eight identical single-frequency, non-differential, commercially available GPS receivers with an update rate of 1 Hz (WI SPI elite, GPSports, Canberra, ACT, Australia) were evaluated in this study. Developed for use in sport and exercise settings, the receivers provide coordinated universal time (UTC), position (longitude, latitude, altitude), Doppler shift velocity, the number of satellites used in the fix, and cumulative distance travelled. Distance was calculated from changes in position and subject to the manufacturer’s proprietary algorithm integrated to reduce measurement error (personal communication with GPSports). For all trials, the eight receivers were firmly attached to a custom-made harness secured to the participant’s upper back (level of the scapula). The receivers were arranged equi-distant (~3 cm) from each other, in two rows; the lower row of the harness was padded and allowed the receivers to protrude. This ensured that all receivers had a consistent, unobstructed “view” of the sky during upright locomotion. Pilot testing revealed that receiver positioning in the harness (e.g. medial/lateral or upper/lower row) did not influence distance or velocity measurement. The participant reported only minor discomfort due to some vertical and lateral oscillation of the receivers at higher movement speeds. Following the trials, data were downloaded using Team AMS software (V1.2.1.12, GPSports, Canberra) and exported for analysis.

A custom-built GPS receiver (EB-85A, ETEK Navigation Inc., Taiwan) and software application were used to time-code the trials. This receiver was fixed to a stationary tripod adjacent to the marked courses. At the start of a trial (participant on the start line), the investigator manually clicked a button in the application “stamping” GPS data streaming at 5 Hz. This was repeated again when the participant crossed the finish line before saving the data to file. Time provided in GPS data (UTC) is very accurate (in the order of 25 ns rms) (Misra & Enge, 2006) and is synchronized between all GPS receivers, thus these “stamped” times were subsequently used to identify trial start and finish times in the exported WI SPI elite data.

Procedures

The participant completed trials over two 200-m courses (linear and non-linear) on a flat grass field that was free of trees and buildings; both courses were measured using a total station EDM/theodolite (Set 5A, Sokkia Co. Ltd., Japan) and marked by a solid painted centre line 200 m from start to finish. Dashed lines were painted 0.25 m either side of the centre line to indicate the course “lane”. The non-linear course required the participant to complete movement paths common to field sports (see Figure 1), while the linear course was a straight path. The participant walked (~1.6 m · s⁻¹), jogged (~3.5 m · s⁻¹), ran (~5 m · s⁻¹) or sprinted
(7–8 m \cdot s^{-1}) each course. All movements throughout the course were in a forward direction, with the trial completed as the participant moved through (i.e. did not stop) the finish point. Five trials at each of the movement intensities on each course were completed; trials were performed sequentially where sprint trials were alternated with walk trials and run trials alternated with jog trials. In all trials, the participant was required to place his feet on the centre line and aim to maintain the required movement intensity throughout the trial. Where the movement intensity was unable to be maintained because of direction changes on the non-linear course, the participant was instructed to return to the required intensity as quickly as possible. The participant’s actual movement velocity was self-selected following familiarization of the movement descriptors during a warm-up. All trials were conducted on the same day between 09:00 and 15:00 h.

**Statistical analysis**

Data from one receiver were excluded from analysis due to what was later found to be a hardware fault that resulted in incomplete data being logged. For the remaining seven sets of data, GPS distance was compared with actual distance using the Bland-Altman method (Bland & Altman, 1986). Bias (mean error) and limits of agreement are presented for each movement intensity and course. The GPS distances were confirmed for normality using the Kolmogorov-Smirnov test. Descriptive statistics for GPS distances at each movement intensity on each course are presented, and one-way analysis of variance (ANOVA) with the Bonferroni post hoc procedure was used to examine the differences in GPS distance when moving at different intensities and on different paths. Pearson’s product-moment correlation coefficients were used to examine possible associations between total distance error and the mean number of satellites used during each trial. Mean velocity for each trial was determined by dividing the course distance (200 m) by the time taken to complete the trial, according to the time stamped GPS data. Peak velocity for each trial was determined from GPS data. The overall means (+s) for mean and peak velocities were determined for each movement intensity and course. All statistical analyses were performed using SPSS 15.0 (SPSS, Chicago, IL).

Intra-receiver reliability was reported as the 95% coefficient of variation between five repeated measures at the same movement intensity and course for each receiver. The average of the receivers was reported. Inter-receiver reliability was determined by the 95% coefficient of variation between the seven homogenous receivers for each movement intensity and course. The average of the five trials was calculated, with the 95% coefficient of variation defined as (1.96*σ)/mean (Atkinson & Nevill, 1998).

**Results**

The GPS conditions during data collection were considered good, as the weather and satellite conditions, which are known to affect GPS accuracy, were favourable (no cloud cover, horizontal dilution of precision recorded by the custom-built receiver was < 2, number of satellites = 7.7 ± 0.5 and 6.8 ± 0.8 for linear and non-linear trials, respectively) (Misra & Enge, 2006; Person, 2004). All mean and peak velocities were significantly different from each other within courses. Between courses, all mean velocities were significantly different for corresponding movement intensities, although only jogging, running, and sprinting differed in peak velocity (Table I).

The actual distance of both the linear and non-linear courses was 200 m. Table I presents the mean (+s) and range of GPS distances, while Figure 2 displays the bias ± limits of agreement for each movement velocity on both courses. On the linear course, the positive bias and limits of agreement suggest GPS distance was slightly overestimated (Figure 2) at all movement intensities, with the walk and sprint distances significantly greater than the jog and run distances ($P < 0.05$). The percentage bias across all movement intensities on the linear course was 2.0%, with upper and lower limits of agreement...
Table I. Movement velocity and GPS distance for each course and intensity.

<table>
<thead>
<tr>
<th>Movement dynamics</th>
<th>Mean velocity</th>
<th>Peak velocity</th>
<th>GPS distance measurement</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>mean ± s (m·s⁻¹)</td>
<td>mean ± s (m·s⁻¹)</td>
<td>mean ± s (m) range (m)</td>
</tr>
<tr>
<td>Linear</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td>1.6 ± 0.1*†</td>
<td>1.9 ± 0.1†</td>
<td>205.8 ± 2.4*</td>
</tr>
<tr>
<td>Jog</td>
<td>3.5 ± 0.1*†</td>
<td>4.2 ± 0.2*†</td>
<td>201.8 ± 2.8*</td>
</tr>
<tr>
<td>Run</td>
<td>5.0 ± 0.2*†</td>
<td>5.6 ± 0.3*†</td>
<td>203.1 ± 2.2*</td>
</tr>
<tr>
<td>Sprint</td>
<td>6.7 ± 0.4*†</td>
<td>7.7 ± 0.9*†</td>
<td>205.2 ± 4.0*†</td>
</tr>
<tr>
<td>Non-linear</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Walk</td>
<td>1.7 ± 0.0*†</td>
<td>1.9 ± 0.1†</td>
<td>198.9 ± 3.5*</td>
</tr>
<tr>
<td>Jog</td>
<td>3.2 ± 0.1*†</td>
<td>4.0 ± 0.2*†</td>
<td>188.3 ± 2.0*</td>
</tr>
<tr>
<td>Run</td>
<td>4.1 ± 0.1*†</td>
<td>5.3 ± 0.3†</td>
<td>184.6 ± 2.9†</td>
</tr>
<tr>
<td>Sprint</td>
<td>4.8 ± 0.2*†</td>
<td>6.9 ± 0.5†</td>
<td>180.4 ± 5.7†</td>
</tr>
</tbody>
</table>

*P < 0.05, significantly different from equivalent non-linear movement intensity. †P < 0.05, significantly different from linear jogging and running. ‡P < 0.05, significantly different from all other movement intensities (within course). Actual distance was 200 m. n = 35 for each intensity.

Table II presents the 95% coefficient of variation for each receiver, movement velocity, and course. The intra-receiver coefficient of variation was less than 5% across all movement conditions. Inter-receiver coefficients of variation were similar, except during non-linear sprinting, where greater variation between receivers was observed resulting in a coefficient of variation of 6.04%. The overall intra- and inter-receiver coefficients of variation were 2.66% and 2.88% respectively.

Discussion

The aim of the study was to determine the effects of movement intensity and path linearity on GPS distance accuracy and reliability. The participant’s effort varied between movement intensities, evidenced by the differences found in mean and peak velocities within each course. In addition, mean and peak velocities varied for almost all movement intensities between courses. The numerous decelerations caused by direction changes are likely to have caused the significantly lower velocities on the non-linear course than on the linear course, despite the participant’s consistent effort (e.g. maximal for sprinting trials) on both courses. The GPS was found to marginally overestimate distance travelled in a straight line (~4 m) across all movement intensities, although walking and sprinting were found to result in significantly greater total distance error compared with jogging and running. In comparison, over a non-linear path (curved paths of varying radii), GPS underestimated distance travelled and it was evident that this underestimation increased with increasing movement intensity (from ~1.1 m to ~19.6 m for walking to sprinting). The validity of GPS distance appears to be affected by path linearity and movement intensity. This is consistent with previous...
research investigating GPS velocity measurement (Witte & Wilson, 2004). The overall reliability of the GPS data across all trials was good, although decreased reliability was observed at higher intensity movements, especially sprinting.

The distance errors found in this study are best described as a function of several factors within the GPS itself rather than just the receiver (although receiver design is one contributing error source). Distance measurements are derived from position and time logged by the receiver, thus error in these variables will influence measurement accuracy. Position error permeates from user satellite geometry and pseudorange measurement errors. Pseudorange is the estimated distance from the receiver to each satellite used in the fix at a given instant in time. Pseudorange measurements are imperfect due to errors in satellite ephemeris and clock parameters (despite multiple corrective uploads each day), ionospheric and tropospheric delays (changes to signal speed and direction when passing through the Earth’s atmosphere), receiver noise (affecting signal strength), and multipath (reflected and delayed signals) (Misra & Enge, 2006). Partition of the relative contributions of these sources to the reported positional error is unknown for these units and will depend on the receivers’ hardware (e.g. antenna type and error mitigation algorithms for ionospheric delays) (Conley et al., 2006; US Department of Homeland Security, 2008). The number of satellites used in a position fix and their distribution in the sky relative to the user (user satellite geometry) also affects the accuracy of position estimation (Misra & Enge, 2006). A moderate, but significant negative correlation between the mean number of satellites (in a 200-m trial) and total distance error was found in the present study. Similarly, Witte and Wilson (2004) found that velocity error increased when the number of satellites decreased. These findings support the importance of satellite availability and geometry and it is recommended that GPS users familiarize themselves with positional dilution of precision, as it is one of the few variables a user has some control over. “Positional dilution of precision” is a description of satellite geometry, but it can be degraded (made larger) by signal obstruction due to terrain, foliage, building structure, and so on (Person, 2004). The GPS performance specifications report that a positional dilution of precision of ≤6 is available 98% of the time anywhere in the world assuming no localized obstruction (US Department of Homeland Security, 2008). A positional dilution of precision of 1 is considered optimal. Using our custom-made receiver, we have found this relatively easy to achieve on an open playing field with a receiver antenna (ceramic patch type) facing up, although this may vary inside stadiums due to signal obstruction (Williams & Morgan, 2009). These are inherent limitations of GPS and all contribute (in varying degrees) to errors in the distance measurements reported here.

In the present study, we found a mean total distance error of 5.8 m when walking over a straight 200-m path. Others have reported GPS distance estimates to be very accurate (mean distance error < 0.5 m) at low intensities (Portas et al., 2007; Townshend et al., 2008). Portas et al. (2007) reported mean distance error to have increased with increasing movement intensity; this was not confirmed in the present study. Total distance error at the highest movement intensity (sprinting, mean velocity ~ 6.7 m \( \cdot \) s\(^{-1}\)) was not found to differ from walking. Practically, the measurement errors found in the present study (~4 m or ~2%) for all intensities are acceptable for most sports where the movement is essentially linear (e.g. road running). Although the varying methods used and differing GPS hardware (chipset, antenna design, algorithms) tested may account for some of the inconsistencies, the present findings suggest GPS is a valid method of measuring distance under these conditions. However, these factors do not fully explain the consistent overestimation we and others (Portas et al., 2007; Townshend et al., 2008) have found.

Previous studies have found GPS to both overestimate (c. 1%) and underestimate (c. −3%) distance on non-linear courses (Coutts & Duffield, 2010; Macleod et al., 2009). While high-intensity efforts were included in their courses, the mean speeds reported by Macleod et al. are only comparable to fast walking or slow jogging (< 2.2 m \( \cdot \) s\(^{-1}\)). Similarly, Coutts and Duffield (2010) report that ~70% of the distance covered per exercise bout was performed at a speed of < 4 m \( \cdot \) s\(^{-1}\). Therefore, total distances/distance errors reported in these studies are

<p>| Table II. Intra- and inter-receiver 95% coefficients of variation. |
|--------------------|-------|-------|-------|-------|-------|-------|-------|-------|</p>
<table>
<thead>
<tr>
<th></th>
<th>Walk</th>
<th>Jog</th>
<th>Run</th>
<th>Sprint</th>
<th>Walk</th>
<th>Jog</th>
<th>Run</th>
<th>Sprint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Intra-receiver</td>
<td>1.85</td>
<td>2.54</td>
<td>2.02</td>
<td>2.71</td>
<td>2.79</td>
<td>1.98</td>
<td>2.60</td>
<td>4.80</td>
</tr>
<tr>
<td>Inter-receiver</td>
<td>2.02</td>
<td>2.33</td>
<td>1.46</td>
<td>3.38</td>
<td>3.43</td>
<td>1.63</td>
<td>2.75</td>
<td>6.04</td>
</tr>
<tr>
<td>Mean</td>
<td>2.66</td>
<td>2.88</td>
<td>2.66</td>
<td>4.80</td>
<td>6.04</td>
<td>2.66</td>
<td>2.88</td>
<td>4.80</td>
</tr>
</tbody>
</table>

Validity and reliability of GPS

Downloaded By: [Deakin University] At: 23:04 29 October 2010
largely considered to be a function of receiver performance during low- to moderate-intensity activities. Estimates of GPS distance during movement in the present study were consistently underestimated at similar speeds (walking and jogging) and quality decreased with increasing movement intensity. This was not observed in previous research. “Non-linear movement” in these studies could be described as a series of straight line efforts linked by a change in direction. In contrast, the present study used numerous circular bends of varying radii (0.9–10 m). Also, GPS receivers have been found to underestimate velocity measurements derived from distance/time in bend running (Townshend et al., 2008) and cycling (Witte & Wilson, 2004). Therefore, it is reasonable to assume that the inclusion of circular paths in the present study may account for some of the discrepancies with earlier work.

The GPS distance in curvilinear movement can be described as the sum of measured chords between position estimates inside the actual curved path. As the sampling rate increases, the path delineated by the chords approaches the actual curve. Theoretically, this implies an increased update rate may help reduce underestimation where movement demand includes running or sprinting curvilinear paths. The current findings suggest a 1-Hz update rate does not approximate the actual distance sufficiently at high movement intensities. Future research should investigate the benefits of an increased update rate (4–10 Hz are now available) under such conditions.

An additional implication of jogging, running or sprinting over circular paths is the need to lean to maintain balance. This introduces a discrepancy between the path followed by the GPS receiver and the measured or marked path. Lean angle increases with speed of movement during bend running (Townshend et al., 2008) and results in shorter paths travelled by the upper body (GPS receiver location) compared with the lower limbs. Townshend et al. (2008) reported lean angles of 3° and 10.5° for running and sprinting respectively around a bend of 10 m radius. By measuring along the inside dashed line deviating to the following inside side-line at the tangent point between the bends of the course used in the present study, a “lean-corrected” course length of 188.9 ± 0.173 m was determined. When GPS distances for running and sprinting are compared with this “lean-corrected” distance (which assumes a lean angle of 8.9° for all bends), bias reduces by more than half (−4.3 m and −8.5 m respectively), suggesting that lean angle may account for a significant proportion of the underestimate observed in the trials. Future research should aim to measure the path of the receiver rather than the path of the participant’s feet.

Intra- and inter-receiver reliability was acceptable (<3.5%) during all intensities of linear movement and non-linear walking, jogging, and running but deteriorated when sprinting (<6%). This is in agreement with Coutts and Duffield (2010), who also reported increased variation between receivers at higher speeds (>5.5 m · s⁻¹). Constantly changing satellite geometry is a probable cause of variation between repeated measurements. However, variation between receivers during simultaneous sampling cannot be explained by changing satellite geometry and we believe that this can be attributed primarily to differences in signal strength and the satellites used to get a position fix. This is a consequence not only of receiver hardware design (e.g. antenna type) but also the conditions of use (e.g. local obstruction, oscillation, and how the receiver is worn). The overall intra- and inter-receiver coefficients of variation (2.66% and 2.88% respectively) were determined to reflect the variation between repeated measurements or another receiver when used across all movement intensities and paths moved (e.g. week to week use by coaches in field sport training and competition). The receivers demonstrated a good level of reliability for most dynamic conditions, thus it is acceptable for users to make comparisons within and between receivers. However, previous research suggests questionable reliability (coefficient of variation of ~7%) of the same model receiver during field sport-related activities (Coutts & Duffield, 2010), thus users should be mindful of the reduced reliability during high-intensity non-linear movement.

The present findings suggest that 1-Hz non-differential GPS receivers are suitable under most conditions for the measurement of distance in field-based team sports. Currently, one of the most popular uses of GPS distance is as a measure of playing and training demand in field sports (Cunniffe et al., 2009; Petersen et al., 2010; Wisbey et al., 2009). Much of the distance travelled during field sport training and games is at low intensities (walking and jogging in linear and non-linear paths), interspersed with brief high-intensity efforts (Dawson, Hopkinson, Appleby, Stewart, & Roberts, 2004; Di Salvo et al., 2007; Rudkin & O’Donoghue, 2008). Indeed, 70–85% (Di Salvo et al., 2007), 80–88% (Dawson et al., 2004), and even 91% (Rudkin & O’Donoghue, 2008) of the total distance travelled in competitive soccer, Australian football, and cricket (fielding), respectively, can be spent in low-intensity activities. Given that such a large proportion of the total distance is travelled in movement patterns where GPS is capable of providing sound distance estimates (linear walking/jogging/running and non-linear walking/jogging) compared with the relatively short distances travelled where GPS is not as effective (non-linear running/sprintning), total
distance estimates are likely to be fair when monitoring players in field sports. However, the interaction of underestimated non-linear movement (c. 1–10%) and the overestimation of linear movement (c. 1–3%) leads us to question whether total distance is a valid representation of the movement demands experienced in field sport. The degree to which these errors cancel each other out is unknown.

Conclusions

The present study has shown that movement path and intensity significantly influence the validity and reliability of distance estimation by 1-Hz non-differential GPS Receivers. The GPS receivers evaluated are a valid method of measuring linear distance travelled at intensities ranging from walking through to sprinting. Measurement of GPS distance demonstrates reduced validity in non-linear movement patterns, including curved or circular paths, as movement intensity increases. Thus, during periods of high-intensity non-linear movement in field sports, 1-Hz GPS technology is likely to underestimate distance and may not meet an acceptable level of accuracy for some users. These significant underestimations are thought to be a consequence of an insufficient update rate and lean angle. Although 1-Hz GPS receivers should be considered a reliable tool for measuring distance travelled by athletes in field-based team sports, multiple changes in direction at high speed may reduce both reliability and validity. Acknowledging this, 1-Hz GPS technology has many applications in field sports environments provided users consider movement pattern (e.g. low intensity, high intensity, straight, circular, zig zag) and receiver capability when interpreting their data.

References


