Comparison of global positioning and computer-based tracking systems for measuring player movement distance during Australian Football

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Summary  Sports scientists require a thorough understanding of the energy demands of sports and physical activities so that optimal training strategies and game simulations can be constructed. A range of techniques has been used to both directly assess and estimate the physiological and biochemical changes during competition. A fundamental approach to understanding the contribution of the energy systems in physical activity has involved the use of time–motion studies. A number of tools have been used from simple pen and paper methods, the use of video recordings, to sophisticated electronic tracking devices. Depending on the sport, there may be difficulties in using electronic tracking devices because of concerns of player safety. This paper assesses two methods currently used to measure player movement patterns during competition: (1) global positioning technology (GPS) and (2) a computer-based tracking (CBT) system that relies on a calibrated miniautised playing field and mechanical movements of the tracker. A range of ways was used to determine the validity and reliability of these methods for tracking Australian footballers for distance covered during games. Comparisons were also made between these methods. The results indicate distances measured using CBT overestimated the actual values (measured with a calibrated trundle wheel) by an average of about 5.8%. The GPS system overestimated the actual values by about 4.8%. Distances measured using CBT in experienced hands were as accurate as the GPS technology. Both systems showed relatively small errors in true distances.

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Introduction

Understanding the energy demands of sports and specific positions within sports is important so that optimal training drills and game simulations can be constructed. A number of techniques have been
used to assess player movement patterns such as their speed profiles and work:rest ratios during competition. Available technologies for automated human-form tracking include mechanical, ultrasound, magnetic sensor, infrared, video, radio-frequency (RF) and global positioning systems (GPS).

Elite level Australian Football (AF) is a collision sport where very few players wear protective padding or other equipment. This limits the use of tracking technologies that must be worn by the players because the devices cannot be safely located on the body. Therefore, there is relatively little describing the time—motion patterns of elite AF players during competition.2

Electronic methods employing RF technology, while instantaneous in their data acquisition, have not been able to adapt to the specific requirements of AF. The constraints that must be considered include the size of the playing field (oval) which, at the professional level, may range from 151 up to 171 m in length and from 115 up to 143 m in centre breadth. This impacts on the necessary strength of the electronic signals from players and the energy source to accomplish this. Other factors include the movement resolution required, potential electronic interference and distances that signals have to be sent. Any worn instrumentation must be small, light, robust, padded and be low in power demands. There is also a need for the system to be safe for the players and spectators. The perfect system is yet to be built for use in the collision sport of AF.

Video tracking has until contemporary times generally been recognised as the most accurate method for estimating movement distances in time—motion studies.13 However, video systems are not able to function in real-time, may be subject to errors due to gait changes during game movements, and are extremely labour-intensive. Other techniques include notational systems which combine audio recordings of observations (for example, player gait, actions and game-related activities) with computer recreation of the movement patterns to determine distances and speeds.3,8 New developments for real-time data collection include GPS technologies. These have recently become available for use during competition even in collision sports such as AF (GPSports Pty. Ltd., 2003; http://www.gpsports.com.au). The GPS receivers worn by players during training and competition draw on signals sent from at least four of the earth orbiting satellites used in the GPS to locate their position.8 Using this information the receivers are able to calculate and store data on position, time and velocity.8 However, the current receiver size and the position where it is worn on the body (upper thoracic spine area) still presents some risk to players.

To overcome some of the constraints associated with tracking in AF, another system has also been developed. This tracking system is termed computer-based tracking (CBT) and has been developed to allow the user to follow the movement patterns of players visually and mechanically in real time during competition (SportsTec Pty. Ltd., 2004; http://www.sportstecinternational.com). This system relies on ground markings and cues as reference points that translate to markers on a miniatuised, calibrated version of each playing field. The latest CBT system is an adaptation of previous systems and techniques used to monitor player movements during sporting competitions.1,4,9,14 The system involves observation and visual judgements on the part of the tracker (operator). This technology is used to track the movement patterns of individual players for measures of distance covered, continuous mean speed and the breakdown of time spent in various speed categories. It has also been used to track the ball’s movement during games which has previously been used as a surrogate for game speed.10,11

GPS and CBT are the two main systems being used to monitor player movement during elite AF competition. The aim of this study was to compare the validity and reliability of the GPS and CBT systems for measuring player distances in AF.

Methods

Global positioning system

The GPS technology was originally designed for military use but has more recently found applications in aviation, marine and recreational outdoor activities. The system uses 27 earth-orbiting satellites that emit constant coded signals at the speed of light.6 GPS units must receive signals from at least three satellites to locate its position. Using this information a receiver is able to calculate and record data on position, time and velocity.6

The Sports Performance Indicator (SPI 10) was developed for tracking an individual’s movements during physical activity (GPSports Systems Pty. Ltd., 2003; http://www.gpsports.com.au). When worn by an individual, the GPS unit records data on time, speed, distance, position, altitude, direction and heart rate (requires a heart sensor strap). Following exercise, the data is downloaded to a PC where further information is provided in relation to speed breakdown.
The SPI 10 is carried by an individual in a padded back-pack just below the neck. For the SPI 10 to receive signals from satellites it is essential that it has a clear view of the sky. Therefore, the SPI 10 cannot be used indoors for tracking player movements.

Computer-based tracking system

The CBT system used was Trakperformance (Sportstec Pty. Ltd., 2004; http://www.sportstecinternational.com). The software allowed the player (or ball when analysing the game speed) to be mechanically followed on a scaled version of the specific playing field and was designed and programmed using the following basic algorithm:

\[ \text{linear distance} = \sqrt{(x_2 - x_1)^2 + (y_2 - y_1)^2} \]

where \( x_1 \) = horizontal \( x \) coordinate at time 1; \( x_2 \) = horizontal \( x \) coordinate at time 2; \( y_1 \) = vertical \( y \) coordinate at time 1; \( y_2 \) = vertical \( y \) coordinate at time 2. The \( x \) and \( y \) coordinates and distances are recorded in computer pixels.

The software program simply instructed the computer to take the current position, in \( x-y \) pixels on the screen at any time slice, and to calculate the linear distance travelled since the \( x-y \) position determined at the previous time slice. A calibration factor was used to convert pixels into metres. This varied depending on the playing field dimensions and the screen size where, in general, the larger the screen size and pixel dimensions the better the system resolution. The program allowed the derivation of the following variables in real-time: total distance travelled by the player and their mean speed which are displayed on the screen and updated second-by-second. This information was also recorded and saved to files that allowed the entire sequence of player movements and summary statistics of game events to be plotted (at the end of each quarter).

One recorder operating one dedicated computer was required for each player being tracked. The recorder tracked the player continuously from an elevated, midfield position in the stadium and recorded player movements with a conventional mouse or a mouse pen and a commercially available drawing tablet. Since the ground markings were important, reference points for tracking the players an elevated position was critical. The miniaturised playing field was calibrated so that a given movement of the mouse or mouse-pen corresponded to the linear distance travelled by the player.

Validity and reliability checks—distance

(1) GPS

(a) Validity checks were completed for 59 trials where a player being monitored via GPS was instructed to move around a pre-determined marked circuit. The actual distances (128—1386 m) were then determined with a calibrated trundle wheel pedometer.

(b) Intratester Reliability measures were assessed using the distances recorded during triplicate repeat trials while a player travelled around the same marked circuits wearing the GPS.

(2) CBT

(a) The validity analysis for player movement involved 176 trials of a player running over a range of marked courses set up on the football field (168 m × 133 m) while being tracked using CBT. The data were pooled from four trackers and used to calculate differences between measured and actual distances. The actual distances (18.1—1386 m) were unknown to either the player or tracker until after the tracking. The actual distances were determined with a calibrated trundle wheel pedometer.

(b) Triplicate repeat trials by three recorders over a range of courses \( (n=33) \), distances were 66—654.4 m were each used to check intratester reliability for player movement distances during live tracking.

(c) Duplicate trials of the distance the ball moved in eight separate quarters of two football games were also used as a means of assessing intratester reliability of the system. This was done by watching and recording the movements from the video analysis.

(d) Two trackers followed the same player during nine quarters within three football games (approx. 9 min × 30 min duration and an average of 2844 m). The two trackers also tracked a player during a series \( (n=37) \) of movements around a marked course of unknown distance (mean estimated distance 127—1386 m). The results for all the trials between trackers were compared as a measure of intertester reliability.

(3) Comparison of tracking technologies

A comparison of the two methods for measuring movement distances was performed when data were collected simultaneously. In this analysis the players wore the GPS system on their back as they travelled at various speeds
around circuits of different lengths and geographic layout. The data were collected over 28 trials with a range of distances (measured with the trundle wheel pedometer) between 125 and 1386 m (mean 283 m). At the same time two experienced trackers were seated in an elevated position in the grandstand recording the subject’s movement pattern using CBT. A calibrated trundle wheel pedometer verified the actual track distance following the completion of the circuit. The trundle wheel was calibrated so that it measured 1 m per full revolution. Overall, the movement pattern for each circuit was recorded by the (1) GPS system, (2) two recorders using the computer-based tracking system and (3) trundle wheel pedometer.

Statistical analysis
Paired t-tests were used to determine differences between the GPS distances and those recorded using the trundle wheel pedometer. The same methods were also used for assessing differences between CBT and true distances and for the evaluation of inconsistencies between different trackers when using CBT to track the same player.

Regression analysis was used to show the relationship between actual and measured distance (validity of both systems) and the relationship between the distances measured by two recorders (intertester reliability). Relative technical error of measurement (TEM%) was used to calculate intrater reliability for both systems. This was calculated using the technique described by Pederson and Gore. Relative error in panel (B) was calculated as ((GPS distance – trundle wheel distance)/trundle wheel distance) × 100.

Results
Validity and reliability checks—distance

(1) GPS
(a) Validity checks showed the GPS and actual distances were highly correlated (r = 0.998; Fig. 1A). However, there was a significant difference between the distances measured by the GPS system and the actual distances measured by the trundle wheel pedometer (t = 5.27; df = 58; p < 0.001). Over the 59 trials the average error of the GPS system was ±4.8 ± 7.2% with an absolute error of ±6.3 ± 6.0%.

(b) Triplicate repeat measures of the distance a player travelled for a range of circuits demonstrated a TEM of 5.5% (intrater reliability). The correlation between the triplicate measures was highly significant (r = 0.989; Fig. 2).

(2) CBT
(a) Validity checks showed that the CBT and actual distances were highly correlated (r = 0.999; Fig. 3A). However, there was a significant difference between the distances measured by the CBT system and the actual distances measured by the trundle wheel pedometer (t = 4.87; df = 175; p < 0.001). Over the 176 trials, the aver-
Figure 2. GPS reliability checks for a player moving around an oval. The GPS tracking patterns for a player moving around a pre-determined running circuit multiple times (football oval) is shown in (A) above. The oval shape and relative size is shown in (B) above. The observation that the GPS-based tracking plot was not superimposed on another with each circuit confirms that part of the error source in distance recorded (validity check) comes from errors associated with the GPS technology. Furthermore, the difference in distance with each circuit is a measure of reliability.

| Figure 3 | CBT vs. trundle wheel distances. Tracking distances for CBT vs. actual distances are shown. In panel (A) there was a significant correlation between distances measured using both systems. Panel (B) illustrates that there was a systematic error as a function of actual distance (slope is different from zero, p < 0.0001). That is, the mean relative error decreased across actual distances. Also, the absolute error is greater over shorter distances when compared to those over longer distances. The relative error in panel (B) was calculated as ((CBT distance – trundle wheel distance)/trundle wheel distance) × 100.

(a) Average error of the CBT system was +5.8 ± 7.4% with an absolute error of 7.3 ± 6.0%. There was a reduction in the relative error of CBT as a function of increasing distance as shown in Fig. 3B.

(b) Triplicate repeat trials by three experienced recorders over a range of courses (n = 8–17) produced intrater tester TEMs of 3.3, 2.6 and 2.4%, respectively.

(c) Reliability checks using duplicate trials of video analysis of eight quarters of tracking the football movements produced an intrater tester TEM of 4.7% for distance travelled.

(d) When the same player was tracked live by two trackers (over nine quarters of three games) the distances recorded differed with a TEM of 6.1%. When all game and non-game data were combined (n = 46 data points), the error averaged 5.3%. The

| Figure 4 | Intertester comparisons for distances are shown in Fig. 4.

(3) Comparison of tracking technologies

The ANOVA analysis between the different tracking methods revealed significant differences in total distances (F = 9.3; df = 2 and 52; p = 0.0001). Post hoc analysis showed significant differences between the distances measured by the CBT system and the trundle wheel (p = 0.04), the GPS system and the trundle wheel (p = 0.0001), and between the CBT and GPS systems (p = 0.02). The correlation between the two methods over a range of distances was r = 0.997 with a mean difference of 1.2 ± 10.6% and a mean absolute difference of 8.7 ± 6.1%. These are illustrated in Fig. 5 below:
Figure 4  Intertester regression for distances measured using CBT. Two experienced trackers measured the same person moving (at different speeds) around a marked track of unknown distance and over nine quarters within three games. The correlation was 0.99 with a TEM of 9.3%.

Discussion

There is no perfect system for measuring how far players travel during sports performance. Video analysis methods have generally been considered the most valid systems but other technologies, including GPS methods and computer-based tracking systems, are now entering the market. Other than manufacturers’ statements, very little scientific evidence exists to verify validity claims. In order to measure the validity of two new tracking systems, players were required to travel around marked running paths while being “tracked”. These paths were then measured for actual distance using a calibrated trundle wheel. The trundle wheel measurements were therefore the ‘gold standards’ for true distances.

This paper analysed two systems used to track players around an Australian Football field: (1) global positioning and (2) computer-based tracking systems.

GPS

The results of the validity checks on the GPS tracking system revealed that there was a significant difference between the distances measured by this system and the distances measured by the calibrated trundle wheel pedometer. Both the average and absolute differences between these two methods were found to be relatively small (4.8 and 6.3% error, respectively). However, together these results indicate that there are systematic errors associated with the GPS tracking system. While it is common perception that GPS technology should be the ‘gold standard’, the inherent errors of this methodology are less appreciated. For example, in the validity and reliability testing a subject was made to run multiple loops of a football oval on the boundary while wearing a GPS unit (Fig. 2). These tests were designed to show any imperfections in tracking the subject using the GPS system. The GPS tracking plot should have shown the running pattern as a (near) single line superimposed on the boundary line of the oval. The actual plot illustrates that the GPS technology has a small source of error for location, and therefore distance travelled, which needs to be considered. This is most likely related to the resolution capabilities of the satellite tracking technology.
Tracking systems for measuring player movement

The results of the reliability checks showed that the GPS system has a relative TEM of 5.5%. The validity and reliability checks suggest that the GPS system can be confidently used to measure the distance a player travels during AF competition or training with an understanding that, in general, it includes a small overestimation of true distances travelled.

CBT

The computer-based tracking system does not require any player instrumentation. This is a major advantage over the GPS system. However, there are also major assumptions and limitations of the computer-based system used in this study. We are not aware of validity and reliability reports for similar computer-based tracking devices so comparisons are not possible. The current system is a computerised version of the paper-and-chart system used by Nettleton and Sandstrom to describe movement patterns in AF. They did not report reliability or validity details. A similar computer-based version has also been used during television broadcasts of AF (http://www.pineapplehead.com.au) but no details of accuracy have been reported.

The results of the validity trials for the CBT revealed a significant difference between the distances measured by this system and distances measured by the calibrated trundle wheel pedometer. The average difference between these methods was 5.8–7.3% error for mean and absolute errors, respectively. Again, these results suggest that there are systematic errors associated with the CBT system whereby, in general, an overestimation of distances occurs.

One possible cause of this overestimation is related to the small ‘sideways’ movements of the mouse or mouse pen that occur as the distances travelled by the player are recorded, particularly at the lower movement speeds. Due to the way the CBT system was designed and programmed, when a player runs in a perfectly straight line any small ‘sideways movements’ of even 1 pixel on the screen are translated into increased distances. However, as the CBT system calculates distance based on the linear distance between two points, some of this overestimation is cancelled out if a player travels in a curved path because the corners are cut (depending also on the sampling rate). Since player movement paths in competition are rarely in straight lines the error due to cutting corners is important. The two types of errors are additive such that one overestimates and the other underestimates distance. In many instances these work to cancel one another out. Under the set of conditions outlined, and with some practice, the tracking system provides estimates of distance travelled with an absolute error of less than about 7%.

In the current study, experienced trackers were used to track the players’ movement patterns using the CBT system. Fig. 4 illustrates that when two experienced trackers measured the same player there was a significant correlation between the distances the trackers measured (r = 0.99; TEM 9.3%). However, one potential source of error that must be considered is the human error associated with the CBT system. A high correlation may still involve systematic errors that are introduced by different trackers who have slightly different techniques (for example, hand-eye coordination, visual acuity, hand steadiness and concentration patterns). The relatively small intertester TEM provides evidence that the overall error between experienced trackers is within acceptable limits for this technology.

Overall, the reliability checks showed the system is reliable for repeated measures of distance travelled. The low TEMs (both within and between trackers) are encouraging and, together with the results of the validity studies, indicate that the system can be confidently used in field games such as AF to track player movements, particularly when distances are recorded over quarters or halves.

Comparison of tracking technologies

Comparisons between the three methods of measuring player movement revealed small but significant differences. Both the GPS and CBT systems overestimated the true distances. Importantly, the comparisons between GPS and CBT showed that, although a strong correlation was found (r = 0.997), there was a significant difference between the distances measured by these two tracking systems (F = 9.3; p = 0.02). These differences, therefore, must have involved some systematic error. The GPS system was consistently overestimating both the true and CBT-measured distances, although these were functionally small.

Summary and recommendations

Following the results of the present series of tests, we recommend the following settings for those monitoring player tracking during AF competition:

- Both the GPS and the CBT systems overestimate the true distances travelled by players.
- The overestimations are relatively small for both systems and average less than about 7%. In experienced hands the CBT system is slightly more accurate than the GPS (by about 1%). Both sys-
tems have errors that are relatively large when small distances are involved (< about 200 m) but these become relatively less over longer movement patterns such as those measured across quarters (>2 km).

- The major benefit of the GPS is the fact that tracking is automated and avoids the need to have a single person tracking each player. Given enough GPS units a whole team of players could be tracked during the same game or conditioning drills. This would be very labour-intensive using the CBT system.

- When using the CBT system the playing field should be enlarged on the computer screen to the maximum possible size to increase tracking accuracy on the screen. The resolution of the screen should be adjusted to the greatest level of pixels per metre.

Practical implications

- Both global positioning technology and computer-based tracking systems involve systematic overestimation errors when tracking player movement during sports performance.

- The levels of error are relatively small and predictable and, therefore, should not prevent the use of either of these technologies to monitor player movements.

References


