THE ACCURACY AND RELIABILITY OF SPI ProX GLOBAL POSITIONING SYSTEM DEVICES FOR MEASURING MOVEMENT DEMANDS OF TEAM SPORTS

Running title: The Accuracy and Reliability of GPS Devices

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Aim: The aim of this study was to determine the accuracy and reliability of SPI ProX Global Positioning System (GPS) devices for measuring movement at various speeds and movement patterns as evident in team sport demands.

Methods: Eleven amateur soccer players performed a 40 m straight sprint test (with 10-20-30 m split times), a zigzag test, 30 m walking, jogging and moderate intensity runs.

Results: Results indicated that the SPI ProX GPS measurements showed acceptable accuracy for all movement patterns for distance (Coefficient of Variation [CV] = 0.14% to 3.73%; 95% Ratio Limits of Agreement [95% ratio LOA] = 0.97 x / ÷ 1.09 to 1.00 x / ÷ 1.05) and speed (CV= 4.22% to 9.52%; 95%LOA = -0.17 ± 1.70 km · h^{-1} to 2.30 ± 1.17 km · h^{-1}) compared with the measured distance and speed determined from timing gates, respectively. Furthermore, acceptable reliability of SPI ProX GPS measures for distance (CV= 0.34% to 3.81%; 95%LOA = -0.09 ± 0.23 m to -0.34 ± 2.31 m) and speed (CV= 3.19% to 6.95%; 95%LOA = -0.05 ± 3.90 km · h^{-1} to 0.42 ± 3.68 km · h^{-1}) were also evident.

Conclusion: Whilst SPI ProX GPS devices were within acceptable ranges of reliability, they remained significantly different to criterion measures of team sport movement demands.

Key Word: Team sport, Global Positioning System, Movement Analysis, Accuracy

Introduction

Training and competition demands for athletes in team sports include regular intermittent movements such as walking, jogging, moderate-intensity running and sprinting.[1] 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.[2] Recently, quantification of the movement profile of athletes during training and match-play has involved both video-based time-motion analysis systems[3,4] and Global Positioning System (GPS) devices. [5,6] However, given the cost and laborious nature of non-automated time-motion analysis, GPS technology is a popular tool for the measurement of player external loads.[7]

Increasing evidence reports the validity and reliability of GPS devices for measuring movement during high-intensity, intermittent exercise. For example, Coutts and Duffield [8] examined the validity and intra-model reliability of different GPS (1Hz) devices for quantifying high intensity, intermittent exercise performance. Findings from this study showed that the 1 Hz devices have an acceptable level of accuracy for total distance during intermittent exercise, though a reduced validity was observed during higher intensity activities. Similarly, Gray et al.[9] examined the effects of movement intensity and path linearity on 1 Hz GPS distance validity and reliability. In this study, one participant wore eight 1 Hz GPS receivers while walking, jogging, running, and sprinting over linear and non-linear 200-m courses. These results demonstrated that the coefficient of variation (CV) within and between receivers was 2.6% and 2.8% respectively. Further, Gray et al.[9] also reported that path linearity and movement intensity appear to affect accuracy of distance measures via inherent positioning errors, update rate, and that reliability decreased with increased movement speed. In another study, Waldron et al.[10] investigated the concurrent validity and reliability of 5 Hz GPS to assess sprinting speed and distance. They reported that speed and distance were reliable (CV = 1.62% to 2.3%), particularly peak speed (95%LOA= 0.00 ± 0.8 $km.h^{-1}$). Moreover, Castellano et al.[11] examined reliability and accuracy of 10 Hz GPS devices for short-distance exercise. They found that 10 Hz GPS devices were highly accurate and high intra- and inter-device reliability was observed. Duffield et al.[12] examined accuracy and reliability of GPS devices (1 Hz and 5 Hz) for measurement of movement patterns in confined spaces for court-based sports compared to a 100 Hz motion analysis system. The results of this study revealed 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 to 0.70) and the faster the speed and more repetitive the movement pattern (over a similar location), the greater the measurement error. Finally, Varley et al.[13] have examined the validity and reliability of 5 and 10 Hz GPS devices for measuring instantaneous velocity during acceleration, deceleration, and constant velocity while straight-line running. They reported that the 10 Hz GPS devices more accurately quantified the acceleration, deceleration, and constant velocity running phases than 5 Hz GPS devices.

Based on the aforementioned results it is plausible that the validity of GPS devices are improving with improved technology. Recent technological advances have proposed a 15 Hz GPS device to measure movement profiles of athletes. However, the SPI ProX devices actually have a 5 Hz sampling rate, which is then interpolated three times per second between sampling points to take the positional sampling rate to 15 Hz. However, the accuracy and reliability of this GPS technology for use in team sports or movement patterns in confined spaces is any better than standard 5 or 10 Hz models is unknown. Accordingly, the aim of the present study was to determine the accuracy and reliability of SPI ProX GPS devices for measuring movement demands encountered in team sports.

Materials and methods

Subjects

Eleven male, amateur soccer players (age 23.0 ± 1.4 y; height 177.0 ± 6.1 cm; body mass 72.9 ± 8.6 kg; training experience 10.6 ± 1.9 y) voluntarily participated in this study. Written informed consent was obtained from all of the participants after notification of the research procedures, requirements, benefits, and risks prior to the commencement of data collection. The study was approved by the local Ethics Committee, and was conducted in a manner consistent with the institutional ethical requirements for human experimentation in accordance with the Declaration of Helsinki

Procedures

The study included 3 testing sessions conducted over a 3-week period. One week before testing served as a familiarization for the players to the straight sprint, 30 m walking, 30 m jogging, 30 m moderate-intensity running and zigzag tests. Following the familiarization session, the aforementioned tests were repeated one week apart on two occasions. Prior to testing, participants performed a 20-min warm-up, consisting of moderate-intensity running, three maximal sprints, striding and static stretching. All testing took place across the centre of an open field, free from obstruction or adjacent building on a synthetic floor at a similar time of the day[14] with a clear view of an 'open' sky. All participants were instructed to abstain from arduous exercise and maintain a similar food and fluid intake for the 24 h prior to each test.

During testing, eleven portable GPS devices were used, with each player fitted with the same GPS device (SPI ProX; GPSports, Canberra, Australia) on each session. The SPI ProX device (size = 48 x 20 x 87mm; mass = 76g) was placed into a harness that positioned the device between the shoulder blades. The GPS units were turned on 10 min before the start of the test and turned off immediately after the test had ended. Movement tests (to be detailed later) commenced from a standing start, 20-cm behind the starting line. The players remained stationary for approximately 5 s at the start line before commencing each respective test. After completion of all the tests, GPS data were downloaded and analyzed via customized manufacturer's software (Team AMS R1; GPSports, Canberra, Australia) to establish the time, speed, and distance for each test. The start time of tests during the analysis was determined by the first increase above zero on the velocity trace.[15] Timing gates were used to record the time taken to complete each of the respective tests (Prosport TMR ESC 2100, Tumer Engineering, Ankara, Turkey). In order to reach or maintain true peak speed through all tests, an additional colored cone was placed at 5 m beyond the finish point, which players were instructed to consider as the finish point.

The players performed 2 maximal 40 m straight sprints (with 10, 20, 30 m split times also recorded). There was a recovery period of 3 minutes between the 40 m straight sprints. The fastest time to cover the 40 m distance in the sprint test was used in the ensuing data analysis. In addition, participants performed two trials of each self-selected speed of 30 m walking, 30 m jogging and 30 m moderate speed run test as per instructions, data collection and analysis above.

Lastly, participants twice performed a zigzag change of direction test without a ball on a rubber floor. Change of direction was tested using a zigzag course consisting of four 5-m sections set out at 100° angles (Figure 1). The zigzag test was chosen because it requires the acceleration, deceleration, and balance control at high speeds that are required for team sports and hence provide greater ecological validity for teams sport movements in a controlled environment.[16]

**** INSERT FIGURE 1 AROUND HERE****

The accuracy was determined by comparing mean speed (km · h^{-1}) at 10 m, 20 m, 30 m, 40 m, Zigzag test, 30 m walking, 30 m jogging and 30 m moderate-intensity running measured by the timing gates with values recorded using the GPS devices. The accuracy was also obtained by comparing distance at 10 m, 20 m, 30 m, 40 m, zigzag test, walk, jog and moderate-intensity running (quantified using a calibrated tape measure of actual distance) to that recorded by the GPS devices. Furthermore, between session test–re-test reliability of the GPS devices to measure distance at 10 m, 20 m, 30 m, 40 m, zigzag test, 30 m walking, 30 m jogging and 30 m moderate-intensity running were also assessed.[10]

Statistical analysis

All results are reported as mean (M) and standard deviation (Sd). The mean differences between two methods of measurement (the biases) were confirmed for normality using the Shapiro-Wilk test *($p>0.05$)*. The data were investigated for heteroscedasticity by plotting a figure of absolute difference against the mean and calculating the correlation coefficient.[17] Heteroscedastic errors were present for all measures of distance *($r= -1$; $p<0.05$)* in the accuracy phase of GPS devices. Due to the computed coefficients not being significantly different *($p>0.05$)*, it was assumed the data did not show any heteroscedasticity for the other variables. To assess accuracy and reliability, the 95% Limits of Agreement (95% LOA), the 95% Ratio Limits of Agreement (95% ratio LOA)[18, 19] and Coefficient of Variation (CV) [17] were employed. The Bland–Altman method calculates the bias, and 95% limits of agreement (Bias ± 1.96 x Sd). It is expected that the 95% limits include 95% of differences between the two measurement methods.[20] In the event that heteroscedasticity was present, for these variables only, the 95% ratio LOA were calculated by division and multiplication of the mean difference by the square of the geometric standard deviation. The strength of the CV (<10%) was quantified in accordance with Atkinson and Nevill.[17] Paired samples t-tests were used to examine differences between means of measurement methods and to compare measurements between test and re-test. Statistical significance was set at p<0.05 and statistical analyses were performed using SPSS 17.0 (SPSS, Chicago, IL, USA).

Results

Mean (± SD), CV (%) and 95% ratio LOA values for distance and speed measurements recorded by GPS devices, respectively, compared to actual distance and timing gates are presented in Table I. For the distance covered during 10 m, 20 m and 40 m sprint splits, as well as zig zag tests, the 95% ratio LOA suggest overestimation of the GPS devices against actual distance by 0.97 x / ÷ 1.09, 0.99 x / ÷ 1.04, 0.99 x / ÷ 1.03 and 1.09 x / ÷ 0.90, respectively *(p>0.05)*. For the 30 m sprint splits, walking and jogging movements the GPS devices underestimated the distance by 1.00 x / ÷ 1.05, 1.00 x / ÷ 1.02 and 1.00 x / ÷ 1.00, respectively *(p>0.05)*. Furthermore, CV's between GPS distance and measured distances were between 0.14 and 3.73%.

Except from moderate-intensity running *(p>0.05)*, there were significant differences *(p<0.05)* between timing gate and GPS measures for speed variables (Table I). Specifically, the 95% LOA showed an underestimation (i.e., 10 m, 20 m, 30 m, 40 m and zigzag test) and overestimation (i.e., walking, jogging and moderate-intensity running), respectively by the GPS devices compared to timing gates (Table 1). Biases ranged from -0.17 km $\cdot$ h^{-1} to 2.30 km $\cdot$ h^{1}, with errors of 0.50 km $\cdot$ h^{-1} to 2.33 km $\cdot$ h^{-1}.

**** INSERT TABLE 1 AROUND HERE****

Mean (± SD), CV (%) and 95% LOA values of both test and re-test distance measurements recorded by GPS devices, and speed measurements recorded by GPS devices and timing gates are presented in Table II. Both GPS devices and timing gate measurements of distance and speed demonstrated no significant differences *(p>0.05)* within measurement system for any of the measured variables between re-test sessions. Specifically, CV's ranged from 0.34% to 3.81% for distance measures of GPS devices. Of note, the CV results (CV_{GPS} = 3.19% to 6.95%; $CV_{Timing\ Gates}$= 1.09% to 6.10%) were consistently below 10% for speed measures of GPS devices and timing gates.

**** INSERT TABLE 2 AROUND HERE****

Discussion

The present study is the first to report the accuracy and reliability of SPI ProX GPS technology for measuring distance and speeds of movement demands as related to common team sport movements, albeit in their isolated movement patterns. The main findings showed that whilst SPI ProX GPS measures were within acceptable ranges of CV for all variables of distance (CV ≤ 3.73%; 95% ratio LOA = 0.97 x / ÷ 1.09 to 1.00 x / ÷ 1.05) and speed (CV≤ 9.52%; 95%LOA = -0.17 ± 1.70 $km \cdot h^{-1}$ to 2.30 ± 1.17 $km \cdot h^{-1}$), they remained significantly different to criterion timing gate measures of actual distance and speed, respectively.

Previous study results have reported that 1, 5, and 10 Hz GPS devices provide variable accuracy on measured distance and speed.[9-12, 21] For example, Waldron et al.[10] reported the CV of 5 Hz GPS devices as 8.06 %, 8.09% and 5.00% for distance and 9.81%, 8.54 % and 6.61% for speed in 10, 20, 30 m sprints, respectively. The current study results indicate that the SPI ProX GPS devices show an improved level of accuracy (<4 %) for measured distances, even at higher speeds *(Table I)*. Previous studies suggest that the higher the sampling rate, the higher accuracy of GPS devices.[22, 23] Accordingly, GPS devices exhibit lower CV's for distance, although based on the 95% ratio LOA data, seem to overestimate the distances for 10, 20, 40 m sprints and zig zag test; whilst underestimating distance for 30 m sprint, as well as walking, jogging and moderate intensity running movements. In agreement with other recent studies.[10, 22] Why distance was underreported at 30-m compared to other distance in the maxilla sprint remain unknown; however as this would represent peak speeds, it may result from sampling rate issues alluded to in previous literature.[7, 12] Regardless, overall inspection of the results would suggest distance measures from SPI ProX GPS devices are of acceptable accuracy.

Whilst the accuracy of GPS devices to measure distance seems to be regularly reported[9, 13], measures of speed tend to show lowered accuracy compared to timing gates[10, 24, 25] or motion analysis systems[12]. In the present study, the CV's of the SPI ProX GPS system ranged between 5 – 10%, which are greater than those observed for distance measures. Previous research reports the CV of speed measures for 5 and 10 Hz GPS devices as 5 – 20%[10, 12, 22]. Again, it has been inferred that with higher sampling rates and improved software algorithms the accuracy of speed measures has improved[12, 22]. Whilst no comparison to other sampling rates were made in the present study, the CV's < 10% here seem to be within accepted levels of agreement[17]. Specifically, the 95% LOA suggest an underestimation for high intensity movements (10 m, 20 m, 30 m, 40 m and zigzag test) and overestimation for low and moderate intensity movements (walking, jogging and moderate-intensity running) of the GPS compared to timing gates for the speed measurements. Regardless, these findings provide evidence to support the accuracy of using distance, thought the greater error range observed with measures of speed remain of concern when using GPS devices for team sports.

Furthermore, acceptable measures of reliability were also evident for GPS measures of distance (CV≤ 3.81%; 95% LOA = -0.09 ± 0.23 m to -0.34 ± 2.31 m; $p>0.05$) and speed (CV≤ 6.95 %; 95%LOA = -0.05 ± 3.90 km · h^{-1} to 0.42 ± 3.68 km · h^{-1}; $p>0.05$)

commensurate with the test-rest reliability of timing gates (CV≤ 6.01%; 95%LOA = -0.17 ± 0.87 km · h^{-1} to 0.43 ± 1.07 km · h^{-1}; p>0.05). Such findings suggest SPI ProX GPS distance and speed measures to be of an acceptable level of reliability for use in monitoring of movement demands of team sports[17].

Previously, Jennings et al.[22] have reported the reliability of 1 Hz and 5 Hz GPS devices to be improved as distance traveled increased, but conversely reliability was decreased as speed increased. In addition, Duffield et al.[12] revealed that 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). However, Waldron et al.[10] showed that the reliability of the 5 Hz GPS 10, 20, 30 m and moving 10 m sprint ranged from 0.78% to 2.3% (CV), with peak speed over 30 m providing the most reliable measure (CV = 0.78%; 95% LOA= 0.00 ±0.8). Whilst no other studies have reported the reliability of SPI ProX GPS devices, the test–re-test reliability values in the present study suggested that SPI ProX GPS devices can provide a reliable measure of distance and speed variables. Furthermore, the comparable CV and LOA of GPS data to those observed in timing gate measures of speed also suggest that SPI ProX GPS devices may be as effective in the measurement of speed over a set distance as is often measured with timing gates. That said, it is acknowledged that the two respective systems will provide different data sets, and given the reported CV's, may not be interchangeable.

Conclusion

In conclusion**,** the present study results showed that SPI ProX GPS devices offer a reliable tool for measuring movement demands of team sports. Moreover, the use of GPS technology to measure distance and speed of field-based team sport may be improved with the present devices given the acceptable CV's reported here. However, significant differences between GPS devices and criterion timing gate measures, particularly for speed measurements should be noted by practitioners. Although these findings suggest some improvement in GPS technology advances the continual development and upgrade of software and hardware are required to improve the accuracy and reliability of such technology for use in team sports.

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Table I. Accuracy of distance and speed measurements of SPI ProX GPS devices against tape measure and timing gate measurements.

Table II. Reliability of distance and speed measurements recorded by SPI ProX GPS devices and timing gate.

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Figure 1: Zigzag Test