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**Abstract**

This study assessed the interchangeability between 10-Hz multi-GNSS GPS devices (Vector®) and two optical tracking systems (TRACAB® and Second Spectrum®). The study also investigated the agreement between data from the optical tracking systems when processed with manufacturer software and GPS-filtered software. Thirty players competing in the English Premier League were monitored using three different tracking systems across five matches. To determine the interchangeability between tracking systems, player movement variables including, total distance, high-speed running distance (19.8–25.2 km‧h-1), sprinting distance (>25.2 km‧h-1), efforts >19.8 km‧h-1 and maximal speed were compared. Equations were formed with samples ranging from 16-36 using linear regression and linear mixed-effects models to allow interchangeability of player movement variables between tracking systems. More than half of the variance of most interchangeability equations were explained and associated with very strong positive correlations (r>0.72). Small to huge differences were found between tracking systems for most player movement variables. Data of optical tracking systems had decreased values in all speed variables >19.8 km‧h-1 when processed through GPS software. This study provides equations for practitioners to interchange player movement variables between TRACAB, Second Spectrum and Vector GPS tracking systems with reduced error. This will enable practitioners to combine and share data captured with different tracking systems to analyse and improve their training.

**Keywords:** interchangeability, GPS, tracking systems, soccer, optical tracking, player movement

**Introduction**

The monitoring of players’ locomotor movements during both training and matches is now common place in professional soccer (Murray & Varley, 2019). Elite soccer clubs typically use a combination of optical tracking systems and wearable-based tracking systems to quantify locomotive movement. These systems provide locomotive data, such as total distance and distance covered at different speeds, that can be incorporated into the athlete monitoring system process to help practitioners assess load completed by their players and inform subsequent training and recovery prescription (Buchheit & Simpson, 2017). Historically, clubs adopted optical tracking systems during match play and wearable-based systems (e.g. global positioning system devices; GPS) during training due to players’ being prohibited from using wearable technology during official matches. However, since 2015 FIFA (﻿Fédération Internationale de Football Association) has granted permission for use of wearable technology during official matches. Despite this rule change, there has been a slow adoption rate of clubs using wearable technology during matches due to practical issues such as player compliance and coach acceptance.

Each high-level soccer league typically signs a commercial deal with an optical tracking system company to act as the main supplier of optical tracking data during match play for all teams within the league. In the English Premier League (EPL), during the early 2000s, physical and technical data was provided by ProZone and Amisco to soccer clubs which were utilised to conduct initial research on the external locomotor movements of elite level soccer players (Carling, Bloomfield, Nelsen, & Reilly, 2008). From 2013, the EPL adopted the use of the TRACAB system as the main data provider for all the teams within the league. However, for the 2019-20 season this was replaced with the Second Spectrum system, with some individual clubs retaining the provision of TRACAB data through their own individual agreements. This change in data provider, alongside teams also using wearable GPS devices during official matches, has led to a mixed use of data from different tracking systems within a club. Clubs now not only have data from different optical tracking systems (e.g. TRACAB and Second Spectrum), but also data from different types of tracking systems (e.g. Optical tracking system and GPS devices) within their longitudinal databases across training and matches.

The level of agreement between tracking systems is an important point for practitioners in order to establish whether they can use data across different systems interchangeably with confidence. Practitioners need to account for any potential differences between systems when they are using more than one data system source as part of their player assessment strategies. Previous research investigating this interchangeability have found that multiple optical tracking systems tend to report greater overall total distances and also distances covered at higher speeds (i.e. >14.4 km/h) compared to GPS technology (Buchheit et al., 2014; Harley, Lovell, Barnes, Portas, & Weston, 2011; Randers et al., 2010; Taberner et al., 2019). However, the majority of the previous research utilised legacy GPS devices sampling at lower rates (e.g. 1-Hz and 5-Hz) which have been found to demonstrate reduced levels of reliability and validity compared to newer devices (Scott, Scott, & Kelly, 2016). Newer devices may also have access to multiple Global Network Satellite Systems (GNSS) as opposed to previous models with only single GNSS access which may also improve optional accuracy (Scott, Scott & Kelly, 2016). Indeed, closer agreement has been found between data from 10-Hz multi-GNSS GPS devices and TRACAB data compared with data from 10-Hz single-GNSS GPS devices (Taberner et al., 2019). Many GPS companies now also provide users with the option to import data from optical tracking systems into their software, which is then filtered in order to ‘match up’ the data from GPS devices and optical tracking systems. However, to the authors knowledge, there is no published data establishing the agreement between the data directly from the optical tracking systems and the filtered data through such software.

The purpose of the present study was to assess the interchangeability between a 10-Hz multi-GNSS GPS device and two optical tracking systems (TRACAB and Second Spectrum). Furthermore, the study aimed to establish the agreement between the optical tracking systems data and that derived from filtered data via GPS Openfield software.

**Methods**

*Participants*

Thirty professional male soccer players (excluding goalkeepers) competing in the EPL participated in the present study (age: 28 ± 3 years; height: 181 ± 5 cm; weight: 79 ± 5 kg). Data were collected across five matches at the team’s home stadium during the 2019-20 season. Of these matches, two were pre-season friendly matches (matches 1 and 2) and the other three were competitive cup competition matches (matches 3, 4 and 5). Second Spectrum data were collected across all five matches involving 30 individual players. TRACAB data were collected across three matches (matches 1, 2 and 3) involving 26 individual players. GPS data were collected over four matches (matches 1, 2, 4 and 5) involving 25 individual players. The range of individual data observations across player locomotor movement variables were 16 – 36.

Approval for the study was provided from the club and all data collection procedures were a condition of the players’ condition of employment. Nevertheless, the study followed the Code of Ethics ﻿of the World Medical Association (Declaration of Helsinki) and was approved by the local university research ethics committee. All data were anonymised prior to analysis in order to ensure player confidentiality.

*Data collection procedures*

Player locomotor movement data were collected simultaneously using two optical tracking systems (TRACAB®, ﻿Chyronhego, New York, USA and Second Spectrum®, Los Angeles, USA). Briefly, data is collected via semi-automated HD cameras that are positioned around the stadium sampling at a frequency of 25-Hz. The TRACAB system has been recently approved by FIFA as a validated player tracking method through the Quality Programme for Electronic Performance and Tracking Systems (EPTS) (<https://football-technology.fifa.com/media/172171/chyronhegoopt-fifa-epts-report-nov2018.pdf>). Linke et al. (2020) recently found the TRACAB system to demonstrate acceptable levels of validity for both instantaneous speed (Gen4: 0.09 m.s-1 root mean square deviation (RMSE); Gen5: 0.08 m.s-1 RMSE) compared to the VICON motion capture system. To the author’s knowledge, there is no peer-reviewed published data on the reliability of the TRACAB system. To the author’s knowledge, there is no publicly available data on the reliability and validity of the Second Spectrum system, most likely due to the system only being adopted in the current season. It must be noted that the purpose of the present study is to compare current data sets used by soccer practitioners, rather than establish the accuracy of such systems.

GPS data were collected using a commercially available 10-Hz multi-GNSS device (Vector®, Catapult Sports, Melbourne, Australia). The device was positioned between the player’s scapula using the manufacturers garment, with a tight fit ensured to avoid unnecessary device movement. Data collection procedures were in accordance to the guidelines of Malone et al. (2017), with each player having their own specific device. The number of satellites and horizontal dilution of position (HDOP) across all data collection were: number of satellites 16 ± 3; horizontal dilution of position 0.53 ± 0.06, respectively. The Vector GPS device has also been approved by FIFA as a validated system through the EPTS testing process (<https://football-technology.fifa.com/media/172128/oct-2019-catapult-vectorgps-fifa-epts-report.pdf>). To the author’s knowledge, there is no peer-reviewed published data on the reliability and validity of the Catapult Vector GPS system. Data were downloaded using the manufacturer’s software (Openfield®, version 1.14, Catapult Sports, Melbourne, Australia). The GPS velocity data was calculated using the Doppler-shift method. The data sets from both TRACAB and Second Spectrum were subsequently imported and filtered through the Openfield® software using the manufacturers algorithm which is commonly used by practitioners to convert both data sets onto a single platform. This filtered data will be referred to as TRACAB\_OF and Second Spectrum\_OF. The specific details around the conversion algorithm is currently unavailable due to intellectual property rights from the manufacturer.

For all matches, data were analysed across the full match duration including any stoppage time. Player locomotor movement variables analysed included total distance, high speed running distance (19.8 – 25.2 km‧h-1), sprinting distance (>25.2 km‧h-1), efforts >19.8 km‧h-1 and maximal speed reached. These variables are commonly used by soccer practitioners to longitudinally track the external load undertaken by players (Akenhead & Nassis, 2016).

*Statistical analysis*

To examine the interchangeability between the tracking systems, descriptive statistics (mean and standard deviation) were calculated for the player locomotor movement variables derived from the TRACAB, Second Spectrum(both processed by own manufacturer software and Openfield® software) and GPS tracking systems. The distribution of the variables was checked against the assumption of normality by visual inspection of a Quantile-Quantile plot and use of a Shapiro-Wilk test. The mean difference in variable values between the tracking systems was analysed using a paired t-test. In situations where the assumption of normality was violated, a Wilcoxon t-test has been used. Assumption of normality has been violated between Second Spectrum and Second Spectrum\_OF for the variables efforts > 19.8 km/h and maximal speed. Violation of normality is due to the number of efforts being based on counts and maximal speed based on a single recorded value, which makes these variables randomly distributed. The Second Spectrum dataset also consists of the most datapoints (5 matches) which inflated the randomly distributed datapoint to be not normally distributed. Statistical significance was accepted at p ≤ 0.05. The effect magnitude (i.e., the mean difference in variable values between the positional tracking devices) was expressed in both raw and standardised units using the following qualitative descriptors: trivial (<0.20), small (0.2-0.6), moderate (0.6-1.2), large (1.2-2.0), very large (2.0-4.0), huge (>4.0) (Hopkins, Marshall, Batterham, & Hanin, 2009).

A simple linear regression analysis was then conducted on datasets with only independent measures (TRACAB with GPS and TRACAB\_OF with GPS) to determine the relationship between the used variables of the tracking systems. A linear mixed-effects model was fit on the remaining datasets with recurring measures (TRACAB with Second Spectrum, Second Spectrum with GPS and Second Spectrum\_OF with GPS). The model was fit with a variable of one tracking system as the dependent variable and the same variable of another tracking system as the fixed effect. A random intercept for player ID was included to account for players with recurring measures in the dataset. Statistical significance was accepted at p ≤ 0.05. Prior to analysis, data were tested for equality of variances which revealed the populations were equal. A Pearson’s product moment correlation coefficient (r) was calculated to describe the magnitude of the linear relationship between the variables of two tracking systems in standardised units. The magnitude of the Pearson’s correlation coefficient was interpreted using the following qualitative descriptors; trivial = 0, small (0.10-0.30), moderate (0.30-0.50), large (0.50-0.70), very large (0.70-0.90), near perfect (0.90-0.99), perfect (1.00) (Hopkins, Marshall, Batterham, & Hanin, 2009). The raw standard error of estimate (SEE) was calculated to examine the standard error in the estimate of the variables true output. The R2 metric quantifies the variance in the variable of one tracking system explained by the variable of the other tracking system. The R2 statistic for linear mixed-effects models has been calculated with a method created for linear mixed-effects models named marginal R2 (Nakagawa, & Schielzeth, 2013). Marginal R2 is the variance explained by the fixed effects over the total variance of the dependent variable. All statistical analyses were conducted in MATLAB R2019b (The MathWorks, Massachusetts, USA).

**Results**

All variables demonstrated very strong positive correlations (r > 0.72) between tracking devices where over half of the variance is explained (R2 > 52%), except for maximal speed variables between Second Spectrum and GPS, and between Second Spectrum\_OF and GPS (r: 0.63-0.68, R2: 40-46%). Figure 1 shows the differences in variables between tracking systems, with small to huge differences found between most variables. TRACAB\_OF and Second Spectrum\_OF had a small to large decrease in all variables compared to when data was processed by their own manufacturer software, except for total distance which had a very large to huge increase. Table 1 shows the linear regression and linear mixed-effects model results with interchangeability equations that can be used to convert variables from each tracking system to estimate the value that would be expected if another tracking system was used. The standard error of estimate reported were between 11.4 - 166.3 for all distance measures in meters, < 1.66 for maximal speed and < 8.11 for efforts.

**\*\*\*Insert Figure 1 here\*\*\***

**\*\*\*Insert Table 1 here\*\*\***

**Discussion**

This study aimed to assess the interchangeability between a 10-Hz multi-GNSS GPS device and two optical tracking systems (TRACAB and Second Spectrum). A secondary aim was to establish the agreement between the optical tracking systems data and that derived from filtered data via GPS Openfield software. Differences were observed between all three tracking devices in all variables (Figure 1). Specifically, TRACAB demonstrated the highest values for all variables followed by Second Spectrum and then GPS, except for total distance and maximal speed. More than half of the variance of most interchangeability equations were explained and associated with very strong positive correlations. Furthermore, lower values were reported by optical tracking systems after processing by Openfield software.

Total distance was greater by a large to very large magnitude for TRACAB and GPS compared to Second Spectrum, despite the distance >19.8 km‧h-1 being lower by a moderate to very large magnitude for GPS compared to both optical tracking systems. Similar results have been observed in research that has compared interchangeability of optical tacking systems and GPS devices (Buchheit et al., 2014; Randers et al., 2010; Harley, Lovell, Barnes, Portas, & Weston, 2011; Taberner et al., 2019). This supports the notion that the greater total distance and lower high-speed distance observed for GPS is due to a greater distance observed at lower speeds compared to optical tracking systems (Randers et al., 2010; Harley, Lovell, Barnes, Portas, & Weston, 2011).

The greater maximal speed observed for both optical tracking systems compared to GPS agrees with the findings of similar studies (Buchheit et al., 2014). These differences in maximal speed are likely due to the different data filtering techniques applied in the manufacturer software. For example, data filters such as a moving average can smooth the speed data causing a reduction in peaks (maximal speed). Maximal speed being affected by data filtering of manufacturer software is supported by the Second Spectrum\_OF and TRACAB\_OF data not reporting any difference compared to GPS. The differences in distance covered between Optical tracking systems and GPS is also likely to be due to specific manufacturer software data filtering. This is supported by the finding that the difference between the Optical tracking system data and GPS data for distances covered was similar to the difference between Optical tracking system data and GPS Openfield filtered Optical tracking system data (Figure 1).

The number of high-speed efforts detected were greatest for TRACAB while there was no difference between Second Spectrum and GPS. To our knowledge this is the first study to compare the interchangeability of optical tracking systems and GPS for measuring the number of high-speed efforts (>19.8 km‧hr-1). The detection of efforts from tracking system data can involve multiple considerations which can differ between and within each tracking system. The detection of efforts often requires a minimum duration above a fixed velocity threshold for the effort to be identified as real. For example, the number of high-speed efforts detected with 10-Hz GPS devices during a soccer match when different minimum effort durations were applied showed moderate to large differences in the number of efforts detected with ~150 efforts detected for 0.1 s duration compared to ~90 efforts detected for 1 s duration (Varley, Jaspers, Helsen, & Malone, 2017). As these differences were observed even when using the same device, it is not surprising that differences were observed in the current study when comparing efforts between different systems. This demonstrates the importance for practitioners to understand how their data is filtered and processed with each tracking system they are using.

The equations in Table 1 are a practical tool for practitioners and researchers who may need to convert variables collected with TRACAB, Second Spectrum or Vector GPS (processed with the manufacturer software or Openfield) to be used interchangeably. For example, if a user wants to convert the variable of distance covered between 19.8-25.2 km‧hr-1 measured with TRACAB to GPS they can use the equation: GPS = -0.97 + 0.82(TB). A player who is reported to have covered 1093 m in this variable when measured with TRACAB may have been estimated to have covered 1314 m (24.0 + 1.18(1093) = 1314) if GPS was used. It is important to note the standard error of estimate (SEE) when using an equation and its impact on individual and group data. If the same equation as previously described for distance covered between 19.8-25.2 km‧hr-1 measured with TRACAB converted to GPS is used for a group of players who have been reported to have covered 5000 m, the converted calculated distance can be estimated to have an error of ±38.9 m or ±0.78 % (38.9/5000\*100=0.78) of the true distance value. However, if the same formula is being used on a single player who is reported to have covered 320 m, the estimated error of ±38.9 m has a bigger impact on the converted calculated distance which can be ±12.2% (38.9/320\*100=12.2) of the true distance value. It is important for a practitioner to consider this standard error of estimate and its impact on individual and group data when using an equation.

The SEE in this study are smaller than those reported in previous research providing interchangeability equations (Buchheit et al., 2014; Taberner et al., 2019). This could be due to increased accuracy of tracking systems over the years. However, it should be noted that distance covered >25 km‧hr-1 between TRACAB and Second Spectrum have a larger error (+50%) compared to the other equations. The source of the error in these variables is unknown but may be due to the high speed the player is moving. This could cause several errors within each system. Upper body sway when moving at a high-speed may affect each tracking system differently. The GPS unit may move around more in the vest when moving at high-speed. Finally, optical tracking systems may find it harder to identify players accurately due to the high-speed. A limitation of the study is the small sample size for some of the variables, with a larger sample size potentially reducing the error of the equations. However, the practical issues of collecting both optical and GPS systems during match-play, such as player compliance, coach buy-in and restrictions to available data for researchers, limit the opportunity to generate larger sample sizes from a match number perspective. Nevertheless, interchanging the variable measures between tracking devices with the use of the equation, even equations with the largest estimated errors, result in a smaller error than interchanging variable measure between tracking devices without the use of the equations.

Future studies should investigate the sources of error within each system so that they can be accounted for when interchanging player locomotor movement variables between different tracking devices.

**Conclusion**

Interchangeability between locomotor movement variables collected with different tracking systems is important to help practitioners to convert and compare variables. This study provided equations that practitioners can use to interchange player locomotor movement variables between TRACAB, Second Spectrum and Vector GPS tracking systems (processed with the manufacturer software or Openfield) with reduced error. This will enable practitioners to combine and share data captured with different tracking systems to analyse and improve their training.

**Disclosure Statement**

The authors report no conflict of interest involved with the present study, nor received any funding in support of the conducted research.

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