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1 **Interchangeability of position tracking technologies; can we merge data?**

2 *Matt .Taberner [1,2], Jason .O'keefe [1], David .Flower[1,2], Jack .Phillips[1], Graeme .Close[2],*

3 *Daniel D. Cohen[3], Chris .Richter[4,5], Christopher .Carling[6]*

4   1. Performance Department, Everton Football Club, Liverpool, UK

5   2. Liverpool John Moore's University, Liverpool, UK

6   3. University of Santander (UDES), Bucaramanga, Colombia

7   4. Sports Surgery Clinic, Dublin, Republic of Ireland

8   5. University of Roehampton, UK

9   6. University of Central Lancashire, Preston, UK

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12 **Contact Details:**

13 Matt Taberner, Everton FC Performance Department, USM Finch Farm, Finch Lane,

14 Halewood, Liverpool, L26 3UE

15 Telephone: +447989952415

16 Email: matt.taberner@evertonfc.com

21   **Abstract**

22   Purpose: The purpose of this study was to assess the interchangeability of position tracking

23   metrics obtained using global positioning systems (GPS) versus those obtained by a semi-

24   automatic high definition (HD) optical camera system. Methods: Data was collected from a

25   cohort of 29 elite soccer players (age: 23.1 ± 5.1 years, height: 180.4 ± 5.8 cm, mass: $74.6 \pm$

26   6.7 kg) in four matches played in four different stadiums. In two matches 10Hz GPS (GPS-1,

27   StatSports, Belfast, UK) were used, while in the other two matches augmented 10Hz GPS

28   (GPS-2, StatSports, Belfast, UK) were used. All four matches were analysed concomitantly

29   using six semi-automated HD motion cameras sampling at 25Hz (TRACAB, Chyronhego,

30   New York, USA). Results: Mean bias was between 6-10% for GPS-1 and 1-4% for GPS-2

31   respectively. No proportional bias was found ($p > 0.184$). The SEE within calibration

32   functions (expressed in % to mean) was between 5-22% for GPS-1 and 4-14% for GPS-2.

33   While some significant differences existed between GPS-1 and TRACAB (total distance and

34   high-speed), positional tracking variables were highly correlated between GPS-1, GPS-2 and

35   TRACAB ($r^2 > 0.92$) with GPS-2 displaying stronger correlations ($> r^2 = 0.96$). Conclusion:

36   In the present study augmented GPS technology (GPS-2) and the TRACAB camera system

37   provided interchangeable measures of positional tracking metrics to allow concurrent

38   assessment and monitoring of training and competition in soccer players. However, we

39   recommend practitioners evaluate their own systems to identify where errors exist and re-

40   calibrate accordingly to confidently interchange data.

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Introduction

Until recently, the use of global positioning systems (GPS) was prohibited in official competition conditions by FIFA. Despite a law change in 2015, GPS remains under-utilised due to practical reasons such as comfort and player compliance. As such, commercial optical semi-automatic camera systems are still commonly used to track the locomotive patterns of professional players during official match-play. Recently a semi-automated HD optical tracking system known as TRACAB has been installed in every English Premier League stadium and numerous soccer stadiums around the world. Six HD cameras track both the movement of players and the ball, allowing the calculation of the same variables derived from GPS systems, including total distance and distances travelled within specific velocity bands (Cummins et al. 2013).

External load metrics such as total distance, high-speed and sprint distance are frequently monitored in high-level professional clubs across many leagues around the world including the English Premier League, La Liga, Serie A, Major League Soccer and Australian A-league (Akenhead and Nassis, 2016). Monitoring changes in these external load metrics that are commonly related to varying demands in training and match-play is used by practitioners to mitigate potential injury risk (Bowen et al. 2019). The application of evidence-based periodised football specific loading strategies (Walker et al. 2018) serves to enhance performance, build chronic load, improve physical qualities and potentially reduces injury risk (Malone et al. 2017; Duhig et al. 2016). A player's retrospective external load data also provides an important benchmark to consider in both the planning and delivery of outdoor physical preparation sessions during rehabilitation and return to play (RTP) (Taberner et al. 2018; Blanch and Gabbett, 2016).

66 Surprisingly, limited information currently exists regarding the interchangeability of data

67 derived from contemporary GPS and optical tracking technologies (Buchheit et al. 2014)

68 especially considering how widely used GPS is in professional clubs alongside TRACAB

69 data (Beato et al. 2018a). Without such information practitioners are unable to confidently

70 combine training and match data in order to monitor weekly total volumes, intensities and

71 frequencies of various components of external load. It is important for practitioners to be able

72 to do so to support; 1) training monitoring and prescription to enhance performance, 2)

73 management of load to minimise cumulative fatigue, 3) mitigation of injury risk, and 4)

74 rehabilitation and RTP of injured players (Gabbett, 2016; Gabbett et al. 2017; Bowen et al.

75 2016; Taberner and Cohen 2018).

76 The purpose of this study was to assess the interchangeability between position tracking

77 variables derived from GPS and those of a semi-automatic HD camera system in elite

78 football players.

79 **Methods**

80 *Participants*

81 A cohort of twenty-nine elite football players from the first team (n = 9 players) and under-23

82 (n = 20 players) squads belonging to an English Premier League soccer club participated (age:

83 23.1 ± 5.1 years, height: 180.4 ± 5.8 cm, mass: 74.6 ± 6.7 kg), with data collected over four

84 matches. For GPS-1 and TRACAB comparison, data was collected from two competitive

85 under-23 matches in the 2016/2017 season. In match one, data was collected from 12 players

86 (age: 21.8 ± 4.6 years, height: 180.4 ± 5.1 cm, mass 73.0 ± 4.5 kg) and in match two from 11

87 players (age: 20.5 ± 0.9 years, height: 181.1 ± 6.1 cm, mass: 71.5 ± 5.3 kg). For the GPS-2 and

88 TRACAB comparison, data was collected from 9 players during one pre-season first team

89 friendly match (age: 27.9 ± 4.4 years, height: 180.4 ± 6.4 cm, mass: 77.4 ± 9.1 kg) and from

90   10 players (age: 20.2 ± 1.4 years, height: 181.3 ± 5.1 cm, mass: 74.3 ± 4.7 kg) during one

91   competitive under-23 match in the 2017/2018 season.

92   All data arose as a condition of employment in which players were routinely monitored over

93   the course of the competitive season. Nevertheless, approval for the study from the club was

94   obtained (Winter and Maughan, 2009) and ethics approval was granted by the University of

95   Santander ethics committee. To ensure confidentiality, all data were anonymised before

96   analysis.

97   *Experimental overview*

98   Positional information was recorded by two commercially available GPS units; GPS-1 (10Hz

99   Viper, StatSports, Belfast, UK), GPS-2 (augmented 10Hz Apex, StatSports, Belfast, UK) and

100   concomitantly by an optical tracking system using six semi-automated HD cameras sampling

101   at a frequency of 25Hz (TRACAB, Chyronhego, New York, USA). Information regarding

102   both validity and relative reliability of GPS-1 and GPS-2 is available within the literature

103   (Beato et al. 2018a, Beato et al. 2018b, Heidi et al. 2018). For example, GPS-1 has reported a

104   small mean bias (<5%) in the evaluation of distance, sports-specific activity and peak speed

105   (Beato et al. 2018b). More recently GPS-2, a 10Hz multi-GNSS augmented unit capable of

106   acquiring and tracking multiple satellites was validated, with a small error of 1-2% reported

107   compared to a criterion distance of 400m track, a 128.5m sports specific circuit, and peak

108   speed assessed using a gold standard criterion (radar gun) (Beato et al. 2018a). Furthermore,

109   GPS-2 inter-unit reliability was <2% for components of external load including total distance

110   and high-speed running (>5ms^{-1}) (Heidi et al. 2018).

111   GPS units were positioned between the players' scapulae housed by a specifically designed

112   vest garment used to minimise movement artefacts (Varley et al. 2017) and were activated

113   accordingly to manufacturer's guidelines prior to kick-off. To avoid potential inter-unit

114   variation players wore the same GPS unit for each match (Malone et al. 2017). The GPS

115   signal quality and horizontal dilution of position were unavailable for GPS-1. GPS-2 was

116   connected to a mean number of 18 satellites, range 16-20 between the two games, while

117   HDOP for both matches was 1.3 (1st team) and 1.1 respectively (under-23).

118   Following each match, raw GPS data files and TRACAB files (XML, DAT) were analysed

119   and position variables were derived automatically using the manufacturer's software (Viper

120   and Apex PSA software, StatSports, Belfast, UK). Position tracking variables analysed

121   consisted of total distance, high speed running distance (HSR, >5.5ms^{-1}), and sprint distance

122   (>7ms^{-1}) as defined by the manufacturer[1]. These position tracking variables were selected for

123   analysis as they were the top 3 variables monitored by professional clubs in high-level OR

124   "elite" football to quantify training practices and competitive matches (Akenhead and Nassis,

125   2016). Data were downloaded for analysis using the manufacturer's software, as software-

126   derived data is a more simple and efficient way for practitioners to obtain data in an applied

127   environment, with no differences reported between processing methods (software-derived to

128   raw processed; Heidi et al. 2018). The dwell time (minimum effort duration) was set at 0.5s

129   to detect high speed running and 1s to detect sprint distance efforts; in-line with

130   manufacturers recommended and default settings to maintain consistent data processing

131   (Malone et al. 2017). Furthermore, the internal processing of both GPS-1 and GPS-2 units

132   utilised the Doppler shift method to calculate both distance and velocity data which is shown

133   to display a higher level of precision and less error compared with data calculated via

134   positional differentiation (Townshend et al. 2008).

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[1] http://statsports.com/technology/apex-software/

137 *Statistical Analysis*

138 Data are presented as mean ± standard deviation (s). A two-sample Kolmogorov-Smirnov

139 goodness-of-fit hypothesis test was used to check the normality distribution of the data and

140 findings indicated normality in every examined measure ($p > 0.195$).

141 To examine the interchangeability between positional tracking variables derived from the

142 GPS-1, GPS-2 and TRACAB, a Bland-Altman plot and regression analysis were used. The

143 resulting correlation coefficient (Pearson) was used to examine shared variation ($r^2 < .3$

144 small, $.3 < r^2 < .5$ moderate and $r^2 > .5$ large), while the standard error estimate (SEE) as well

145 as the confidence interval (95 and 99%) of the square root of the error from the regression

146 equation was used to assess confidence in the observed values. To evaluate the existence of

147 proportional bias, the percentage difference between the devices was regressed to their

148 average (Bland et al. 1999). In addition to the test of relationship, a two-tailed paired-sample

149 t-test was used to examine differences between devices. Data was analysed using statistical

150 parametric mapping (spm0d version 0.4) and an alpha level of = 0.05 was utilised. Data

151 analysis was performed in MATLAB (The MathWorks, Massachusetts, USA).

152 **Results**

153 All examined measures demonstrated strong positive correlations between both GPS-1, GPS-

154 2 and TRACAB ($> r^2 = 0.92$), while, significant differences were observed for total distance

155 and HSR between GPS-1 and TRACAB ($p = 0.00$). GPS-2 displayed the stronger correlation

156 to the TRACAB system ($r^2 > 0.96$ vs. $r^2 > 092$). The SEE (expressed in % to mean) was

157 between 5-22% of for GPS-1 and 4-14% for GPS-2. The mean bias was between 6-10% for

158 GPS-1 and 1-4% for GPS-2. No proportional bias was observed ($p > 0.184$). Table 1 and

159 Table 2 report descriptive statistics and analysis for GPS-1 and GPS-2 compared to

160   TRACAB. The Bland-Altman plot and regression analysis alongside correction calibration

161   equations for GPS-1, GPS-2 are displayed in figure 1.

Discussion

163   Athlete-tracking technology is commonplace in contemporary sport research and practice

164   (Cummins et al. 2013) and it is important that practitioners are able to make confident

165   comparisons if different devices are used in training and competition.

166   In the current study, we examined the interchangeability between data for position tracking

167   variables captured by commercial global positioning systems (GPS) and that derived from a

168   semi-automatic HD camera system (TRACAB). Results showed that while there are

169   differences for both total distance and HSR between GPS-1 and TRACAB, both the GPS-1

170   and GPS-2 were highly correlated with TRACAB ($r^2 > .92$). GPS-1 generally demonstrated

171   higher mean biases compared to GPS-2: total distance (6% vs. 2%), HSR (10% vs. 1%) and

172   sprinting (10% vs. 4%). Furthermore, SEE's ranged from 5-22% for GPS-1 and 4-14% for

173   GPS-2.

174   Due to the current controversy in the sports science world regarding terminology, statistical

175   approaches and interpretation (Impellizzeri et al. 2019), the authors feel it important to clarify

176   the statistical approach used here to assess interchangeability. Agreement was identified

177   through regression analysis - a statistical technique to examine whether, and how strongly, a

178   pair share variation, which is expressed by correlation coefficient "r" (Giavarina, et al. 2015).

179   The regression analysis also computed a relationship formula that allows the prediction of the

180   magnitude of a measure from one device to another. The accuracy of this equation can be

181   described using the SEE (McHugh, 2008). The Bland-Altman analysis provides information

182   about the mean bias (how much does a device over or underestimate the other) as well as the

183   confidence limits of this bias, which explains potential systematic or random error between

184 tracking technologies (Myles and Cui, 2007). As such, a high correlation between devices

185 (representing the mean association) does not necessarily make it appropriate to use in

186 monitoring individual players, if for example there is also a high mean bias. However, a

187 practitioner could use the regression formula to enable align the data obtained with the two

188 systems.

189

190 Previous research investigating interchangeability between GPS and optimal tracking

191 technology (most commonly the Prozone optical tracking system) is limited, with

192 methodological differences accounting for discrepancies in the results reported across studies

193 (Buchheit et al. 2014; Harley et al. 2011; Randers et al. 2010). In agreement with previous

194 findings (Randers et al. 2010), Harley et al. (2011) reported higher total distance travelled

195 using GPS (GPS: $1,755.4 \pm 245.4$ m; Prozone: $1,631.3 \pm 239.5$ m; $p < 0.05$). Harley et al.

196 (2011) emphasised caution in interchanging sprint distance determined by the two

197 technologies due to a technical error of ~40% ($d = 0.68$). More recently, Buchheit et al.

198 (2014) highlighted small differences (5.4%) between GPS and optical tracking systems in

199 relation to total distance covered. The optical tracking technology tended to report greater

200 distance covered at higher movement speeds (>19.8 km/h - 26.5%) with a typical error of

201 estimates that was small (>0.2) to moderate (>0.6) (Buchheit et al. 2014). In contrast, smaller

202 differences were observed in the current investigation in relation to both total distance and

203 distances within high-velocity speeds thresholds. Factors such as device sampling rate,

204 satellite connection, data filtering and analysis within the associated software for both GPS

205 and optical tracking systems (Buchheit et al. 2014) could contribute to the differences

206 between the present results and those of previous reports. As such, caution is required when

207 using GPS units without knowing the quality of satellite connections or if there was a poor

208 satellite connection during a specific data collection period.

209 The present findings show that total distance can be interchanged between augmented 10 Hz

210 GPS (GPS-2) and the TRACAB system with an expected mean error of 4% .. However, it is

211 important to note that HSR and sprinting distance demonstrated larger errors than total

212 distance. Applying corrections through the extrapolation of the Y-intercept demonstrated a

213 SEE of 10% for HSR and 14% for sprinting distance for GPS-2.SEE's were similar for GPS-

214 1 apart from sprinting distance (14% vs 22%). These observed differences are likely due to

215 systematic error with technology used to track positional variables. They may be related to

216 data filtering and/or smoothing of the TRACAB co-ordinate data (X, Y) integrated into GPS

217 analysis software resulting in hysteresis (differences in distance at any measurement value

218 within specified range [speed threshold] recorded using TRACAB compared to raw GPS

219 data). Differences may have also been influenced by measurement error due to loss of

220 satellite connection. As such, the present observations could differ from those in similar

221 future studies due to the prevailing satellite connections, highlighting that data on satellite

222 connection (number of satellites/HDOP) should be included as a time varying covariate

223 within any future GPS study.

224 From a practical perspective, it is important to consider whether the small differences

225 between technologies reported here are meaningful regarding their influence on decisions

226 made/interpretation of data derived from monitoring concurrent loads (training and match-

227 play). Furthermore, meaningfulness and relevance need to be considered, as relationships

228 between running performance and competitive success are unclear (Carling et al. 2013),

229 whilst the impact of training and match-play upon fatigue (Nedelec, 2014) and fitness (Rollo

230 et al. 2014) is likely to be influenced by a host of factors including periodisation, recovery

231 and training methodology, which makes these relationships difficult to examine in an elite

232 environment. In the present study, applying the GPS-2 calibration equations to a sample

233 player's data set (a full-back); TRACAB – total distance: 11,022m, HSR: 1,220m: sprinting:

234   341m corrected to GPS-2; total distance: 10,730m, HSR: 1,398m, sprinting: 332m) highlights

235   in practice the magnitude of difference in absolute terms (minimal and maximum error;

236   Figure 1)) between GPS-2 and TRACAB; total distance 292m (15 to 355m) from TRACAB,

237   HSR; 37m (13 to 98m) from TRACAB and sprinting; 9m (8 to 18m) from TRACAB. In real-

238   world elite soccer, the question arises as to whether these differences are meaningful in

239   relation to player management in context of both the team performance and/or rehabilitation.

240   Recently, associations between increased acute loads, changes in week-to-week load and

241   injury risk have been demonstrated (Rogalski et al. 2013). Excessive and rapid increases in

242   load are recognised as an important risk factor for non-contact soft-tissue injuries (Gabbett et

243   al. 2016). Therefore, we can ask the question; are the aforementioned absolute differences

244   meaningful in relation to injury risk?Here, ~292m (less than one lap of an athletic track) and

245   in the context of a weekly micro cycle where players typically accumulate distances of

246   around 30 to 40km, an error of + or - this magnitude would not have any practical influence

247   on the interpretation of the data i.e. not have altered decisions regarding player load

248   management. Similarly, in relation to HSR, one of the commonly measured external load

249   metrics related to intensity, should an approximate error of + or - 37m should be considered

250   in the context of a full-back accumulating ~2000 to 2500m HSR within a weekly micro

251   cycle?

252   It has been advocated that to determine if change in load within individual players is

253   meaningful, the method proposed by Hopkins et al. (2009) should be used to express relative

254   change to intra-player reliability (Akenhead and Nassis, 2016). In team sport environments,

255   these changes (bandwidth determine by Hopkins method) maybe used to assess changes in

256   week-to-week loads, variations of the acute: chronic 'workload' ratio e.g. 7 to 28 days, or

257   more sensitive measures e.g. variations to match-day type specific sessions. From a

258   rehabilitation perspective, we suggest that following injury, retrospective external running

259 loads should be used to formulate a prospective return to chronic loading plan (Taberner et al.

260 2019).

261 We observed a lower mean error reported by GPS-2 in comparison to GPS-1, which could be

262 explained by technological enhancements between GPS units. Augmented GPS (GPS-2)

263 utilises a multi-band GNSS receiver capable of acquiring and tracking multiple satellite

264 constellations (e.g. GPS, GLONASS, Galileo, and BeiDou) concurrently, therefore providing

265 more accurate positional data quality (Beato et al. 2018a). Previous research has highlighted

266 that the number of satellites connected to a tracking device plays a pivotal role in GNSS

267 accuracy (Scott et al. 2016) and consequently the enhanced data quality provided by the

268 augmented GPS could explain the lower mean error recorded with TRACAB system

269 compared to GPS-1. Data was also recorded in what could be considered suboptimal

270 conditions due to the experiment being conducted within of high-rise stadiums. Previous

271 research has also reported that satellite pick up near high buildings can affect the validity and

272 reliability of data recorded in such environments (Scott et al. 2016). Hence practitioners

273 should interpret all data with caution in stadia and ensure raw traces of velocity and

274 acceleration are inspected for irregularities generated by the GPS devices, which may include

275 satellite signal loss leading to a delayed detection of locomotion (Malone et al. 2017).

276 Accounting for the satellite connection and horizontal dilution of position would allow the

277 development of formulas that could state when it is 'safe' to interchange or could give a

278 range of possible magnitude for different signal strength to help practitioners fully establish

279 interaction between all components of external load. We suggest professional clubs should do

280 their own diligence investing time and resources to assess their own systems, checking for

281 potential sources of error to ascertain confidence in their dataset when concurrently

282 monitoring training and match data.

283   Alongside total distance and distance within high velocities (HSR and sprinting), external

284   load in team sports is also characterised by frequent episodes of accelerated and decelerated

285   running actions (Osgnach et al. 2010). Hence, monitoring the demands that require athletes to

286   accelerate, decelerate and rapidly change direction is of high importance (Delaney et al.

287   2017). As by definition a proportion of these movements are performed at low speed and

288   despite being below the threshold for HSR ($>5.5ms^{-1}$), have a high mechanical demand with

289   important implications for planning training and recovery strategies (Osgnach et al. 2010;

290   Young et al. 2012). We suggest future research should aim to establish interchangeability

291   between acceleration, deceleration variables recorded by GPS and optical tracking

292   technologies, considering the number of satellites as a time dependent covariate, to help

293   practitioners fully establish interaction between all components of external running load.

294   **Conclusion**

295   The interchangeability between training and match load data is important to help practitioners

296   effectively and confidently monitor and interpret weekly volume of external running loads.

297   Current findings demonstrate that data can be interchanged between the present augmented

298   GPS units and TRACAB system with an expected mean error of 4%, which we estimate to

299   have no practical influence on the interpretation of weekly load data. Since the present

300   commercial GPS and TRACAB systems are used ubiquitously within professional soccer

301   clubs these findings will help enable practitioners to combine training (captured using GPS)

302   and match activity (captured using optical systems) data, to assist with planning of

303   appropriate training and recovery strategies to impact physical performance and potentially

304   reduce injury risk.

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445   **Table and Figure Captions**

446   Table 1. Relationships between GPS-1/TracAb for Total distance, High-speed distance, and

447   Sprint distance.

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449   Table 2. Relationships between GPS-2/TracAb for Total distance, High-speed distance, and

450   Sprint distance.

451

452   Figure 1. Correlations between GPS-1/TracAb and GPS-2/TracAb for Total distance, High-

453   speed distance, and Sprint distance.

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