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**Original research**

# Intra-system reliability of SICS: Video-Tracking System (Digital.Stadium®) for performance analysis in football

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BACKGROUND: The correct evaluation of external load parameters is paramount in football. The instrumentations usually utilised to quantify the external load parameters during official matches are Video-Tracking Systems (VTS). VTS is a technology that records two-dimensional position data (x and y) at high sampling rates (over 25 Hz). In this study we want evaluate the intra-system reliability of SICS VTS. Such information is paramount for its application at top-level contests.
METHODS: 28 professional male football players taking part in the Italian Serie A (age 24 ± 6 years, body mass 79.5 ± 7.8 kg, stature 1.83 ± 0.05 m) during 2015/16 season were enrolled in this study (Team A and Team B). Video-analysis was done during an official match and data analysis was performed immediately after the game ended and replicated a week later.
RESULTS: This study reported a near perfect relationship between Match 1 and its replication (Match 2) data. $R^2$ coefficients (relationships between Match 1 and Match 2) were highly significant for each of the performance parameters, $p < 0.001$. Team A reported a mean TD = 8141 ± 3398 and 8129 ± 3387 in Match 1 and Match 2, respectively. Team B reported a mean TD = 8038 ± 3145 and 8017 ± 3139 in Match 1 and Match 2, respectively.
CONCLUSIONS: The findings reported in this study have an important practical application since they underlined that all data reported by SICS VTS showed high levels of absolute reliability.

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**Keywords:** team sports; time-motion analysis; match-analysis.

## Introduction

Football is played in almost every nation at the professional level, making it the world's most popular sport.[1] Football is a team sport characterised by an intermittent model where aerobic and anaerobic components are highly taxed.[2] Football players' on the basis of their roles and game level, usually cover a range of distances from 10 km to 13 km.[3] Players perform several specific activities during official matches such as: high speed running, accelerations-decelerations and changes of direction, such as technical and tactical actions.[2] The correct evaluation of external load parameters is paramount for sport science strategies.[4] For instance, this evaluation can be used to aid areas of post-match analysis such as: management of recovery protocols, personalised training (with different training loads on the bases of the previous workloads carried out) and nutrition strategies suitable to enhance the restoration of energetic stores.[1,5]

The instrumentations usually utilised to quantify the external load parameters are Global Positioning Systems (GPS) and Video-Tracking Systems (VTS).[6–8] GPS is a navigational system originally developed by the American Department of Defence for military use and it has since been made available to the public and commercialized.[9] GPS are used (especially during training sessions) to collect and analyse time-motion data such as, total distance covered (TD), number of changes of direction, acceleration and deceleration activities, as well as time spent at high speed running and metabolic power.[10–12] GPS accuracy, validity and reliability have been commonly investigated.[9,13,14] It is well reported that GPS devices suffer a reduction in accuracy during power actions such as, change of direction, acceleration and decelerations.[15,16] GPS with higher sampling rates (e.g. 10 Hz) provides a more valid and reliable measure of an athlete's movement demands compared to their respective less powerful counterparts (e.g. 1-5 Hz).[13] Improving the sampling rate is one of the main ways to improve GPS accuracy.[10] FIFA recently allows the use of GPS during official matches, however the use of such technology could be limited in an ecological context because validity and reliability could be affected by signal quality, which might be obstructed by the atmosphere and objects in the local environmental (e.g., tall buildings, stadium).[9,20]

VTS is a technology that records two-dimensional position data at high sampling rates (over 25 Hz). Much research has been conducted on the validity and reliability of video and electronic tracking systems.[17,18] Generally, VTS systems have been revealed to have some advantages compared to GPS devices, for example, players need not carry any extra weight or specialised equipment during official matches, which could hinder their performance. Moreover, as reported above, sampling rates are a crucial factor for validity and reliability, and video and electronic

tracking systems (25 Hz) currently on the market offer higher sampling frequency than GPS (10-15 Hz).[5,6,19] VTS is one of the most popular choice for physical performance analysis in elite football (especially during official matches).[19] Research has revealed a large amount of variability in the accuracy of different video-tracking systems (produced by different companies), and for sport scientists, it is crucial they know the accuracy and reliability of a system in order to limit misleading interpretations.[15] It is assumed that the VTS production company responsible for creating the technology independently validate their system, especially if it took in account the differences reported among different technologies and brands.[6] In the past years several information were reported about VTS reliability, and poorer data were found during curvilinear and high-intensity movements.[7,8] For instance, intra-day test-retest in 10 m sprint time reported a coefficient of variation moderate to low, but higher variation was reported during accelerations and change of directions.[6] In semi-automatic VTS part of the analysis is done by operators that perform manual corrections (i.e. when players are occluded), therefore VTS reliability could be affected by human intervention.[8] Quality of human intervention is dependent of training level and personal experience. As previously reported, VTS are common limitations as difficulties to tracking several players in congestion, as well as when players are occluded by others (e.g. corner, box).[21] This is particularly important during official competitions, when several players are simultaneously monitored.[7]

SICS VTS is a performance analysis device widely used at national and international level (Italian Serie A and Euro 2016). The evaluation of its reliability could be paramount for its application at top-level contests, as well as in research studies. The main purpose of this study is to assess the intra-system reliability of SICS video-tracking system by evaluating of several football-specific parameters (i.e. metabolic power, TD, distance covered in several speed categories) during an official match with professional football players (ecological context). We hypothesize that SICS VTS will show a valid grade of intra-system reliability. Reliability evaluation is the first step of SICS VTS validation.



## Methods

*Subjects:* 28 professional male football players (age 24 ± 6 years, body mass 79.5 ± 7.8 kg, stature 1.83 ± 0.05 m) were enrolled. Goalkeepers were considered in this study. The experimental protocol was in agreement with the Declaration of Helsinki for the study on human subjects. The SICS board and the Sport Science Area of University of Suffolk (UK) approved the experimental protocol.

*Design and research questions.* SICS video tracking system named Digital.Stadium® (Bassano, Italy) is current used by a large number of professional football teams and by Italian national football team. Digital.Stadium® is a semi-automatic technology, therefore the evaluation of reliability of the system is paramount for its utilisation in elite contexts. This study evaluates the intra-system reliability by replication analysis of an official football match with professional football players. By this protocol we ensured the most ecological approach.

Considering that this VTS is semi-automatic, the analysis of intra-system reliability takes in account also intra-operator reliability (throughout the text we will use only the word "intra-system reliability"). In order to satisfy also this criteria (intra-operator reliability), the same operators performed both the analysis.

*Experimental protocol and data analysis.*

Two teams taking part in the Italian Serie A during 2015/16 season were recorded in this study (Team A and Team B). Video-analysis was done during an official match and data analysis was performed immediately after the game ended (Match 1) and replicated a week later (Match 2). The Football match analysed in this study, took place on natural grass field playing surface at the Luigi Ferraris stadium in Genova. None of the participating players were equipped with external detectors, devices or additional instruments.

SICS Digital Stadium® version 4.3 is a portable hardware and software system that can be installed at a venue before a match. The installation and configuration procedure usually takes between 30 to 45 minutes. The main components of the Digital.Stadium® system are:

- Video Recording System: a set of 4 HD IP fixed cameras equipped with special no distortion lenses to record on a PC the match being played. Every part of the football field is covered by at least one camera, with some areas of overlay among the different cameras (Figure 1). The 4 cameras are installed on a horizontal bar mounted on a single tripod located in an elevated position in the stadium corresponding to the midfield line.
- File Transfer to Operational Centre module: to transfer the video files recorded by the cameras to the SICS operational offices;
- Automatic Tracking: a software that detects the moving objects (players, ball, referees) on the field and calculates the position of each object for each frame with a frequency of 25 Hz;
- Manual Tracking: the movements of each object on the pitch are recorded by a group of operators (usually 4 per match) and the label with the identification of each object (players' names and numbers) reassigned if needed;

- Technical Tagging Module: to tag each touch of the ball with its technical detail (pass, cross, shot, corner, etc.);
- Data Export Module: to obtain a full set of reports and raw data for each analysed player;
- VideoMatch for Digital.Stadium® to analyse and present the data obtained by the above process both from a physical and technical point of view.

Please Figure 1 here

Before performing the Automatic Tracking step a process named "Masking" is performed that defines the areas like stairwells and seating areas for supporters, this ensures that movements in these areas are not detected by the software. Masking also consists of a "Field Calibration" where some relevant points in the recorded videos are located to create a digital map (e.g. corners, goal area lines, midfield line) and the x, y coordinates in the digital mapping of the field.

Video recorded was analysed by the computer system and then corrected by a human operator (semi-automatic system). Four operators were involved in the first analysis (Match 1) and the same four operators replicated the analysis (a week later) on the same match (Match 2). The analysis took into account several parameters deeply studied in football science as: TD, distance covered over 15 Km $h^{-1}$, mean distance covered over 20 Km $h^{-1}$, distance covered between 19-22 Km $h^{-1}$ and distance covered over 22 Km $h^{-1}$. In addition, video-analysis recorded data about mean distance covered over 25 w $kg^{-1}$ and mean metabolic power (w $kg^{-1}$).[22]

The indirect estimation of the metabolic power utilised the rationale that accelerated running on a flat terrain is energetically analogous to uphill running at constant speed: [23]

$$EC\ (J\ kg^{-1}\ m^{-1}) = (155.4\ ES5 - 30.4\ ES4 - 43.3\ ES3 + 46.3\ ES2 + 19.5\ ES + 3.6)\ EM$$

Where EC is the energy cost of accelerated running on grass, EM is the equivalent mass and ES is the equivalent slope.[22]

*Statistical analysis.*

Data are presented as means ± 1 SD. A Shapiro-Wilk test was performed for the evaluation of normality (assumption) for statistical distribution. Log transformation was done for non-normal data. Pearson's Correlation Coefficient reported in this study as the variance explained ($R^2$) was used to determine the relationship between matches' data and thus the validity of the variable.[24] Statistical significance was set at $p < 0.05$. Absolute reliability (between Match 1 and Match 2) was assessed using the typical error of measurement expressed as percentage coefficient of variation

(CV) and interclass correlation (ICC). Differences between Match 1 and Match 2 were reported as a mean of change with confidence intervals (CI 90%).[24] Statistical analysis was performed using SPSS (SPSS Statistics 20.0) for Mac OS X Yosemite.

## Results

Data recorded in this study is presented for Team A and Team B. Reliability of Team A and Team B data (Match 1 and Match 2) was reported as CV, ICC and mean of change with CI 90%, these parameters are presented in table 1. This study reported a near perfect relationship between Match 1 and Match 2 data. $R^2$ coefficients (relationships between Match 1 and Match 2 data) were highly significant for each of the performance parameters, $p < 0.001$ (Table 1).

Team A reported a mean TD = 8141 ± 3398 and 8129 ± 3387 in Match 1 and Match 2, respectively (TD, as well as every other parameter, took in consideration GKs and players substitutions). Team B reported a mean TD = 8038 ± 3145 and 8017 ± 3139 in Match 1 and Match 2, respectively. Team A reported a mean distance covered over 25 w $kg^{-1}$ equivalent to 1351 ± 725 m and 1341 ± 728 m in Match 1 and Match 2, respectively, while Team B covered a distance over 25 w $kg^{-1}$ equivalent to 1258 ± 621 m and 1248 ± 617 m in Match 1 and Match 2, respectively. Team A reported a mean metabolic power of 9.72 ± 1.64 w $kg^{-1}$ and 9.69 ± 1.60 w $kg^{-1}$, respectively, whereas Team B reported a mean metabolic power of 9.52 ± 1.66 w $kg^{-1}$ and 9.47 ± 1.63 w $kg^{-1}$, respectively.

Distance covered over 15 Km $h^{-1}$ by Team A was 1664 ± 967 m and 1651 ± 956 m in Match 1 and Match 2, respectively, while distance covered over 15 Km $h^{-1}$ by Team B was 1546 ± 804 m and 1551 ± 803 m in Match 1 and Match 2, respectively. Team A reported a mean distance covered over 20 Km $h^{-1}$ equivalent to 552 ± 371 m and 548 ± 354 in Match 1 and Match 2, respectively, whereby Team B reported a mean distance covered over 20 Km $h^{-1}$ equivalent to 485 ± 309 m and 488 ± 311 m in Match 1 and Match 2, respectively. Team A reported a mean distance covered between 19-22 Km $h^{-1}$ equivalent to 380 ± 237 m and 373 ± 228 in Match 1 and Match 2, respectively, whereby Team B covered a mean distance between 19-22 Km $h^{-1}$ equivalent to 333 ± 175 m and 343 ± 185 in Match 1 and Match 2, respectively. Distance covered over 22 Km $h^{-1}$ by Team A was 325 ± 246 m and 328 ± 240 m in Match 1 and Match 2, respectively, while distance covered over 22 Km $h^{-1}$ by Team B was 283 ± 215 m and 286 ± 214 m in Match 1 and Match 2, respectively.

## Discussion

SICS VTS (Digital.Stadium®) is a technology commonly used to evaluate external load parameters (e.g. TD, speed categories, metabolic power) in professional football (Italian Serie A). The validation process of this technology is crucial for scientific acknowledgment and credibility. In this study we reported the first step (intra-system reliability) of SICS validation process. All data reported in this study showed high levels of absolute reliability (ICC and CV), as well as a small mean of change (between Match 1 and Match 2) in every parameter (Table 1). In this study intra-system reliability was successful tested, therefore sport scientists and coaches can use such technology in an ecological context.

Previous evidences about reliability of VTS during linear speed and accelerations reported a CV from 1-3% to 17-23%,[5,6] however our data reported CV lower than 1% in all the parameters analysed. During our protocol SICS VTS was tested in an ecological context, where reliability could be affected by human intervention.[8] As previously reported, VTS are common limitations as difficulties to tracking several players in congestion and when occluded by others, and this is particularly true during official competitions (especially during set-balls).[21] Moreover, high intensity, high speed, and power data are associated with a low level of reliability,[5,6,18] but this was not the case in this particular instance. A close to perfect reliability value was reported for every metabolic power parameters ($R^2$ and ICC equivalent to around 0.995 and 0.99, respectively). These findings support the optimal reliability of Digital.Stadium® also during high speed and high power activities that commonly occur in professional football and have been taken into account in previous researches.[22,25]

External load parameters are usually evaluated in football by GPS and VTS (generally during training and official competitions, respectively).[6,7,26] VTS is a technology that records two-dimensional position data at high sampling rates.[7,19] These systems showed some advantages in accuracy compared to GPS.[17] Moreover, sport scientists can evaluate players' load parameters by VTS without requiring them to wear additional devices (such as GPS). Scientific literature has revealed that sampling rate is a parameter closely associated with validity and reliability.[10] Currently, GPS devices available on the market have lower sampling frequency (e.g. 5-10-15 Hz) than VTS (e.g. 25 Hz).[20,27] Previous research has also found that GPS devices underestimate physical exertion during high intensity bouts as well as sprinting and shuttle running, especially with low acquisition frequency GPS devices (i.e. 1-5 Hz).[28,29] Moreover, it seems that the improvement of sample rates to over 10 Hz in GPS technology (e.g. 15 Hz) has not offered any additional advantages (e.g. speed validity).[9,14]

Current regulation (FIFA) allows the use of GPS technology during official matches. However, literature suggests to be cautious with the use of GPS technology in such context, because

stadiums can highly affect GPS precision and reliability, revealed that artificial barriers can result in the "dilution of precision" (measurement associated volume of a cone delineated by the position of the satellites in relation to the receiver).[30] Another possible limitation is assocaited to the number of satellites interacting with the GPS, which is an important factor in determining distance (negative correlation between distance recorded, actual distance and number of satellites) and speed inter-day reliability.[9,31] Anyway, GPS devices are less expensive and required less operators for their daily utilisation than VTS, therefore GPS might be a valid alternative to VTS during training sessions especially when performed in open spaces far from flats and buildings.[17]

Another type of device used to evaluate performance are electronic tracking systems (local position measurement, LPM). LPM reportedly provides accurate data on, positioning, average speeds and peak speed measurements as well as other maximal intensity actions performed in football.[18] However, LPM technology has two main limitations. Firstly, players have to wear antennas during the football activity (which they may be reluctant to do as this could hamper their performance) and secondly, the antennas position, near the body's centre of gravity, is associated with signal problems, which leads to an increase in positional errors.[32] The discussion about which is the best technology present on the market today is not the focus of this study, thus we did not report a systematic comparison between VTS, GPS, and LPM. Future research could expand on this and evaluate the strengths and weaknesses of these technologies mentioned above.

We consider intra-system reliability as the first step necessary to validate SICS VTS (Digital.Stadium®). The evaluation of its reliability is paramount to its application at top-level context, as well as in research studies where high standard of quality is required. Future studies will also be able to analyse the validity of the technologies mentioned above against criterion evaluations such as time gates, laser and radar gun during specific football circuits,[28,33] or other VTS.[17] Inter-observer reliability regarding technical-tactical tagging might also be evaluated in future studies.



## Conclusions

SICS VTS is a performance analysis device widely used at a national and international level (Serie A, and Euro 2016). The findings reported in this study have an important practical application since they underlined that all data reported by SICS VTS showed high levels of absolute reliability. In particular, actions of high intensity, high speed, and power data are usually associated with low levels of reliability,[18] but this study revealed that the SICS VTS is more than capable of recording this data accurately. Sport scientists should be conscious that accuracy of external load

data such as high-speed running distance covered and metabolic power parameters are not affected by intra-system reliability. Therefore, data of this type can be utilised to offer accurate information necessary for the interpretation of physical performance in football. Such information may be useful for planning recovery protocols and personalised training sessions (with different training loads on the bases of the previous workloads carried out).

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**References**

1. Reilly T, Williams AM. *Introduction to Science and Soccer*. (Reilly T, Williams A, eds.). London: Routledge; 2003.
2. Impellizzeri FM, Rampinini E, Castagna C, et al. Validity of a Repeated-Sprint Test for Football. *Int J Sport Med*. 2008;29:899-905. doi:10.1055/s-2008-1038491.
3. Di Salvo V, Gregson W, Atkinson G, Drust B. Analysis of High Intensity Activity in Premier League Soccer. *Int J Sports Med*. 2009;30:205-212. doi:10.1055/s-0028-1105950.
4. Zamparo P, Zadro I, Lazzer S, Beato M, Sepulcri L. Energetics of shuttle runs: The effects of distance and change of direction. *Int J Sports Physiol Perform*. 2014;9(6):1033-1039. doi:10.1123/ijspp.2013-0258.
5. Buchheit M, Haddad H Al, Simpson BM, et al. Monitoring Accelerations With GPS in Football□: Time to Slow Down□? *Int J Sports Physiol Perform*. 2014;9:442-445.
6. Buchheit M, Allen A, Poon TK, Modonutti M, Gregson W, Di Salvo V. Integrating different tracking systems in football: multiple camera semi-automatic system, local position measurement and GPS technologies. *J Sports Sci*. 2014;32(20):1844-1857. doi:10.1080/02640414.2014.942687.
7. Carling C, Bloomfield J, Nelsen L, Reilly T. The role of motion analysis in elite soccer. *Sport Med*. 2008;38(10):839-862. doi:10.2165/11536850-000000000-00000.
8. Barris S, Button C. A Review of Vision-Based Motion Analysis in Sport. *Sport Med*. 2008;38(12):1025-1043.
9. Scott TU, Scott TJ, Kelly VG. The validity and reliability of global positioning system in team sport: a brief review. *J Strength Cond Res*. 2016;30(5):1470-1490.
10. Cummins C, Orr R, Connor HO. Global Positioning Systems ( GPS ) and Microtechnology

Sensors in Team Sports□: A Systematic Review. *Sport Med*. 2013;43:1025-1042. doi:10.1007/s40279-013-0069-2.

11. Vickery WM, Dascombe BJ, Baker JD, Higham DG, Spratford WA, Duffield R. Accuracy and reliability of GPS devices for measurement of sports-specific movement patterns related to cricket, tennis, and field-based team sports. *J Strength Cond Res*. 2014;28(6):1697-1705.
12. Varley MC, Fairweather IH, Aughey RJ. Validity and reliability of GPS for measuring instantaneous velocity during acceleration , deceleration , and constant motion. *J Sports Sci*. 2012;30(2):121-127. doi:10.1080/02640414.2011.627941.
13. Coutts AJ, Duffield R. Validity and reliability of GPS devices for measuring movement demands of team sports. *J Sci Med Sport*. 2010;13:133-135. doi:10.1016/j.jsams.2008.09.015.
14. Johnston RJ, Watsford ML, Kelly SJ, Matthew JP, Spurrs RW. Validity and interunit reliability of 10 Hz GPS units for assessing athletes movement demands. *J Strength Cond Res*. 2014;28(6):1649-1655.
15. Rawstorn JC, Maddison R, Ali A, Foskett A, Gant N. Rapid Directional Change Degrades GPS Distance Measurement Validity during Intermittent Intensity Running. *PLoS One*. 2014;9(4):1-6. doi:10.1371/journal.pone.0093693.
16. Jennings D, Cormack S, Coutts AJ, Boyd L, Aughey RJ. The Validity and Reliability of GPS Units for Measuring Distance in Team Sport Specific Running Patterns. *Int J Sports Physiol Perform*. 2010;5:328-341.
17. Di Salvo V, Collins A, McNeill B, Cardinale M. Validation of Prozone ®□: A new video-based performance analysis system. *Int J Perform Anal Sport*. 2006;8(MAY):108-119.
18. Stevens TGA, De Ruiter CJ, van Niel C, et al. Measuring Acceleration and Deceleration in Soccer-Specific Movements Using a Local Position Measurement ( LPM ) System. *Int J Sports Physiol Perform*. 2014;9(FEBRUARY):446-456. doi:10.1123/ijspp.2013-0340.
19. Carling C. Interpreting physical performance in professional soccer match-play: Should we be more pragmatic in our approach? *Sport Med*. 2013;43(8):655-663. doi:10.1007/s40279-013-0055-8.
20. Beato M, Bartolini D, Ghia G, Zamparo P. Accuracy of a 10 Hz GPS unit in measuring shuttle velocity performed at different speeds and distances ( 5 – 20 m ). *J Hum Kinet*. 2016;54(5):ahed of print. doi:10.1515/hukin-2016-0031.
21. Barros RML, Misuta MS, Menezes RP, et al. Analysis of the distances covered by first division Brazilian soccer players obtained with an automatic tracking method. *J Sport Sci Med*. 2007;6(2):233-242.

22. Osgnach C, Poser S, Bernardini R, Rinaldo R, Di Prampero PE. Energy cost and metabolic power in elite soccer: A new match analysis approach. *Med Sci Sports Exerc*. 2010;42(1):170-178. doi:10.1249/MSS.0b013e3181ae5cfd.
23. Minetti AE, Moia C, Roi GS, et al. Energy cost of walking and running at extreme uphill and downhill slopes. *J Appl Physiol*. 2002;93:1039-1046.
24. Hopkins W. Measures of reliability in sports medicine and science. *Sport Med*. 2000;30:1-15.
25. Zamparo P, Bolomini F, Nardello F, Beato M. Energetics (and kinematics) of short shuttle runs. *Eur J Appl Physiol*. 2015. doi:10.1007/s00421-015-3180-2.
26. Beato M. Manuscript Clarification. *J Strength Cond Res*. 2016;30(2):1-2. doi:10.1519/JSC.0000000000001472.
27. Christopher J, Beato M, Hulton AT. Manipulation of exercise to rest ratio within set duration on physical and technical outcomes during small-sided games in elite youth soccer players. *Hum Mov Sci*. 2016;48:1-6. doi:10.1016/j.humov.2016.03.013.
28. Akenhead R, French D, Thompson KG, Hayes PR. The acceleration dependent validity and reliability of 10 Hz GPS. *J Sci Med Sport*. 2014;17:562-566.
29. Duffield R, Reid M, Baker J, Spratford W. Accuracy and reliability of GPS devices for measurement of movement patterns in confined spaces for court-based sports. *J Sci Med Sport*. 2010;13:523-525. doi:10.1016/j.jsams.2009.07.003.
30. Witte TH, Wilson AM. Accuracy of non-differential GPS for the determination of speed over ground. *J Biomech*. 2004;37:1891–1898.
31. Gray AT, Jenkins D, Andrews MH, Taaffe DR, Glover ML. Validity and reliability of GPS for measuring distance travelled in field-based team sports. *J Sports Sci*. 2010;28:1319-1325.
32. Sathyan T, Shuttleworth R, Hedley M, Davids K. Validity and reliability of a radio positioning system for tracking athletes in indoor and outdoor team sports. *Behav Res Methods*. 2012;44(4):1108–1114.
33. Rampinini E, Alberti G, Fiorenza M, et al. Accuracy of GPS Devices for Measuring High-intensity Running in Field-based Team Sports. *Int J Sports Med*. 2015;36:49-53.

Table 1. Reliability data recorded in Team A (14 players) and Team B (14 Players) after replication of VTS analysis.

| Variables | Mean of change (CI 90%) | Typical Error as CV (%) | ICC | $R^2$ |
|---|---|---|---|---|
| TD (m) Team A | 12.7 (-50.7; +25.3) | 0.2 | 0.99 | 0.999 |
| TD (m) Team B | 21.7 (-57.8; +14.4) | 0.2 | 0.99 | 0.999 |
| Distance (m) >25 w $kg^{-1}$ Team A | -9.9 (-28.7; +8.8) | 0.3 | 0.99 | 0.997 |
| Distance (m) >25 w $kg^{-1}$ Team B | -9.9 (-36.7; +16.7) | 0.5 | 0.99 | 0.992 |
| Metabolic power (w $kg^{-1}$) Team A | -0.03 (-0.08; +0.03) | 0.02 | 0.99 | 0.995 |
| Metabolic power (w $kg^{-1}$) Team B | -0.05 (-0.10; +0.01) | 0.02 | 0.99 | 0.996 |
| Distance (m) over 15 Km $h^{-1}$ Team A | -13.3 (-34.5; +7.97) | 0.4 | 0.99 | 0.997 |
| Distance (m) over 15 Km $h^{-1}$ Team B | 4.97 (-10.9; +20.8) | 0.3 | 0.99 | 0.998 |
| Distance (m) over 20 Km $h^{-1}$ Team A | -4.0 (-16.4; +8.3) | 0.2 | 0.99 | 0.997 |
| Distance (m) over 20 Km $h^{-1}$ Team B | -0.2 (-7.8; +8.3) | 0.1 | 0.99 | 0.997 |
| Distance (m) 19-22 Km $h^{-1}$ Team A | -6.9 (-22.7; +8.8) | 0.3 | 0.98 | 0.981 |
| Distance (m) 19-22 Km $h^{-1}$ Team B | +9.8 (-5.6; +25.2) | 0.3 | 0.98 | 0.97 |
| Distance (m) over 22 Km $h^{-1}$ Team A | +3.2 (-3.2; +9.7) | 0.1 | 0.99 | 0.997 |
| Distance (m) over 22 Km $h^{-1}$ Team B | +2.9 (-6.6; +12.5) | 0.2 | 0.99 | 0.996 |

ICC = interclass correlation, CV = coefficient of variation, CI = confidence intervals, $R^2$ = variance, TD = Total distance.