



## Accuracy of a 10 Hz GPS Unit in Measuring Shuttle Velocity Performed at Different Speeds and Distances (5 – 20 M)

by

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*The aim of this study was to validate the accuracy of a 10 Hz GPS device (STATSports, Ireland) by comparing the instantaneous values of velocity determined with this device with those determined by kinematic (video) analysis (25 Hz). Ten male soccer players were required to perform shuttle runs (with 180° change of direction) at three velocities (slow: 2.2 m·s<sup>-1</sup>; moderate: 3.2 m·s<sup>-1</sup>; high: maximal) over four distances: 5, 10, 15 and 20 m. The experiments were video-recorded; the “point by point” values of speed recorded by the GPS device were manually downloaded and analysed in the same way as the “frame by frame” values of horizontal speed as obtained by video analysis. The obtained results indicated that shuttle distance was smaller in GPS than video analysis ( $p < 0.01$ ). Shuttle velocity (shuttle distance/shuttle time) was thus smaller in GPS than in video analysis ( $p < 0.001$ ); the percentage difference (bias, %) in shuttle velocity between methods was found to decrease with the distance covered (5 m:  $9 \pm 6\%$ ; 20 m:  $3 \pm 3\%$ ). The instantaneous values of speed were averaged; from these data and from data of shuttle time, the distance covered was recalculated; the error (criterion distance-recalculated distance) was negligible for video data ( $0.04 \pm 0.28$  m) whereas GPS data underestimated criterion distance ( $0.31 \pm 0.55$  m). In conclusion, the inaccuracy of this GPS unit in determining shuttle speed can be attributed to inaccuracy in determining the shuttle distance.*

**Key words:** GPS technology; team sports; time-motion analysis; performance analysis; shuttle runs.

### Introduction

An intermittent aerobic and anaerobic game model characterizes many team sports (Impellizzeri et al., 2008; Makaje et al., 2012; Zadro et al., 2011). Team sport players perform many power activities with short recovery pauses such as shuttle runs, acceleration-deceleration actions, changes of direction and sprints, both during training and in regular matches (Ben Abdelkrim et al., 2007, 2010). The capacity to perform quick accelerations and decelerations in basketball, soccer and futsal is one of the most important abilities to acquire in order to improve performance. For this reason, monitoring and quantification of these actions are of critical importance in team sports (Buchheit et al., 2014).

Global positioning systems (GPS) are used for collecting and analysing movement data

allowing evaluation of the most important physical actions performed by players (i.e. the distance covered, the number of changes of direction and the time spent at high speed running) (Aughey, 2011; Buchheit et al., 2014; Cummins et al., 2013; Johnston et al., 2014). Some GPS units even allow estimating energy expenditure and metabolic power from data of acceleration and deceleration by means of the so-called “energetic approach” (di Prampero et al., 2005; Osgnach et al., 2010). The integration of this approach in GPS software contributes to the spread of this technology in team sports (especially in professional soccer clubs). Therefore, the validity and reliability of GPS devices for recording the athlete’s actions are of primary importance for coaches and sport

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scientists (Johnston et al., 2014).

Previous research has demonstrated that the GPS is an accurate and reliable instrument to evaluate external training loads (Vickery et al., 2014). Moreover, numerous studies have underlined that a higher sampling rate provides a more valid and reliable measure of the athlete's movement demands and that reliability decreases in small distance tracks and during high-speed movements (Coutts et al., 2010; Cummins et al., 2013; Jennings et al., 2010; Johnston et al., 2014). Indeed, higher sampling frequency instruments (10-15 Hz) are more reliable than 1-5 Hz GPS units so that increasing the sampling rate is a solution to improve the capacity of a GPS unit to correctly record power actions (large accelerations and decelerations). Previous evidence has also proved that large variability does exist in the accuracy of different GPS brands and that some variability may be observed between GPS units of the same model (Coutts et al., 2010; Johnston et al., 2014; Varley et al., 2012). The validity of velocity data, as well as the validity of the acceleration and deceleration counts, is the critical factor for a correct estimation of training volume and intensity in team sports where power actions are the typical bout model (Buchheit et al., 2014); thus, coaches and sport scientists should know the reliability of their GPS units to limit misleading interpretations of GPS reports. Since a global statement on the validity of GPS devices for measuring team sports actions is not possible, every GPS brand should be validated independently (Akenhead et al., 2014).

To validate a GPS device (to assess its validity/accuracy/reliability), several methods can be utilized. The most popular method is to evaluate distance measurement accuracy while completing a standard circuit that reflects team sports movements; in this case, data of distance as measured with a GPS over the time needed to complete the circuit (e.g. measured by means of timing gates) are compared with the actual circuit distance (Coutts et al., 2010; Jennings et al., 2010; Rawstorn et al., 2014). Based on the distance and time data, the average speed to complete a circuit, or sections of it, can be calculated and average speed accuracy can also be evaluated; in many studies the reported values of peak speed are indeed values of average speed over "a short distance", generally 10 m. However, validation of

GPS devices by a standard circuit does not give information on instantaneous velocity during short shuttle running and change of direction (COD).

GPS measurement distance accuracy decreases during high intensity COD, the more so the larger the number of speed changes (tight vs. gradual COD) and the movement speed (walk, jog, sprint) (Jennings et al., 2010). Rapid directional changes indeed degrade GPS accuracy: distance is overestimated during curvilinear tracks and underestimated during shuttle trials (Rawstorn et al., 2014). Varley et al. (2012) measured the accuracy of different GPS units in determining the instantaneous velocity during straight-line running; these authors report that, for a 10 Hz GPS model, the bias in instantaneous velocity is negligible during constant speed running (0.2-0.6%), it increases during accelerations (2-4%) and especially in decelerations (9%). Thus, the effects of COD on instantaneous speed accuracy still need to be investigated (Varley et al., 2012).

To our knowledge, there is limited evidence in literature that compares the instantaneous values of speed recorded by a GPS unit with the instantaneous values of speed recorded with kinematic analysis (video data, as a criterion) to assess the accuracy of GPS units for team sports. Only two recent studies used kinematic analysis (VICON system) to evaluate GPS validity. Duffield et al. (2010) used a VICON motion analysis system to record movement patterns in a confined space (for court based sports), while Vichery et al. (2014) analysed sport specific movement patterns related to cricket, tennis and field-based team sports. Therefore, the aim of this study was to evaluate the accuracy of a 10 Hz GPS device (STATSports, Ireland) by comparing the instantaneous values of speed with those determined by kinematic (video) analysis. To our knowledge, there are no previous studies that have analysed the accuracy of this GPS model. The movements considered in this analysis were shuttle runs over different distances (5, 10, 15 and 20 m, with a change of direction of 180°) covered at different speeds to test the effect of speed, distance and COD on GPS accuracy. We hypothesized that the differences between video and GPS data would be rather small over longer distances and at slow speeds and that larger

differences would be observed over short shuttle distance especially when covered at high running speeds.

## Material and Methods

### Subjects

Ten healthy male soccer players (mean  $\pm$  standard deviation (SD); age  $24 \pm 1.5$  years, body mass  $80 \pm 8.6$  kg, body height  $1.84 \pm 0.06$  m) were enrolled. The experimental protocol was in agreement with the Declaration of Helsinki for the study on human subjects. The University of Verona ethical committee approved the experimental protocol and all participants gave their written informed consent.

*Design and research questions.* A descriptive design was used in this study. The accuracy of a 10 Hz GPS device (STATSports, Ireland), currently used by a large number of professional sports teams, was investigated by comparing the instantaneous values of speed determined with this device with those determined by kinematic (video) analysis (25 Hz).

### Experimental protocol and data analysis

The participants were asked to perform shuttle runs (with a  $180^\circ$  change of direction) on an athletic track at different velocities:  $V_1$ : slow ( $2.2 \text{ m}\cdot\text{s}^{-1}$ );  $V_2$ : moderate ( $3.2 \text{ m}\cdot\text{s}^{-1}$ );  $V_3$ : high (maximal) over the following distances: 5, 10, 15 and 20 m. Shuttle distance ( $SD_c$ , criterion) was measured by means of a tape and indicated by means of two cones positioned on the track. The subjects were requested to adopt a "standardized" starting position (the left foot at the level of the first cone, the right hand on it), to bend and touch the second cone during the turn and to turn again when back to the first cone; at the beginning of the test ( $t_1$ )  $v_x = 0$  and at the end of the test ( $t_2$ ) the horizontal speed values crossed the zero line due to the second change of direction.

The GPS units were turned on about 10-15 min before the beginning of the test; meanwhile the subjects familiarised with the equipment as well as the procedures and performed a warm up.

During the experiments a GPS unit (10 Hz, STATSports, Ireland) was placed on the back of the participants by means of a harness at the level of the chest. We utilized the same GPS unit for all participants to avoid inter-unit variability (a possible confounding factor). Thus, we do not know the magnitude of variability between

different units of the same device. GPS data were analysed by the STATSport Viper Software Version 1.2. The "point by point" values of speed recorded by the GPS were manually downloaded and further analysed in the same way as the video data.

The experiments were video-recorded (Sony, Handycam HDR-CX410ve,  $25 \text{ frames}\cdot\text{s}^{-1}$ ) and the video clips were analysed by means of open source software (Kinovea, <http://www.kinovea.org>). The video clips were calibrated by using the shuttle distance as a criterion.

The subjects were asked to wear a black vest and a white belt was securely fixed to their waist; its middle point was digitized "frame by frame"; from these data the instantaneous values of horizontal speed were obtained ( $v_x, \text{m}\cdot\text{s}^{-1} = D_x / D_t$ , where  $D_x$  is the "frame by frame" horizontal displacement and  $D_t = 0.02 \text{ s} = 1/25 \text{ Hz}$ ). A typical profile of  $v_x$  during a shuttle run over the 5 and 20 m distances at  $V_2$  is reported in Figures 1a and 1b. Open dots are the data acquired at 25 Hz by means of the digital camera (video data) and full dots are the data acquired at 10 Hz by means of the GPS (GPS data). To prepare this figure, video data recorded after the turn were multiplied by -1; indeed, after the turn the  $v_x$  values are negative due to the change of direction while  $v_x$  is always positive when assessed with the GPS.

The time needed to cover the shuttle distance ( $T_{tot}$ , s) was determined for each subject, distance and speed:  $T_{tot} = t_2 - t_1$  where  $t_1$  is the starting time and  $t_2$  is the time corresponding to the second change of direction (see Figures 1a and 1b and the experimental procedure). The average velocity of the shuttle run was calculated in two different ways:

- 1- from the ratio  $SD_c / T_{tot}$  ( $V_M, \text{m}\cdot\text{s}^{-1}$ ), where  $SD_c$  is the "criterion distance"
- 2- as the average of the instantaneous values of horizontal speed ( $V_A, \text{m}\cdot\text{s}^{-1}$ )

Shuttle distance was then calculated as:  $d = T_{tot} \cdot V_A$ ; distance measurement accuracy was thus estimated by comparing these values ( $d$ ) with the criterion ( $SD_c$ ).

### Statistical analysis

Data are presented as means  $\pm$  SD. A Shapiro-Wilk test was performed for the evaluation of normality (assumption) for statistical distribution.

Figure 1a

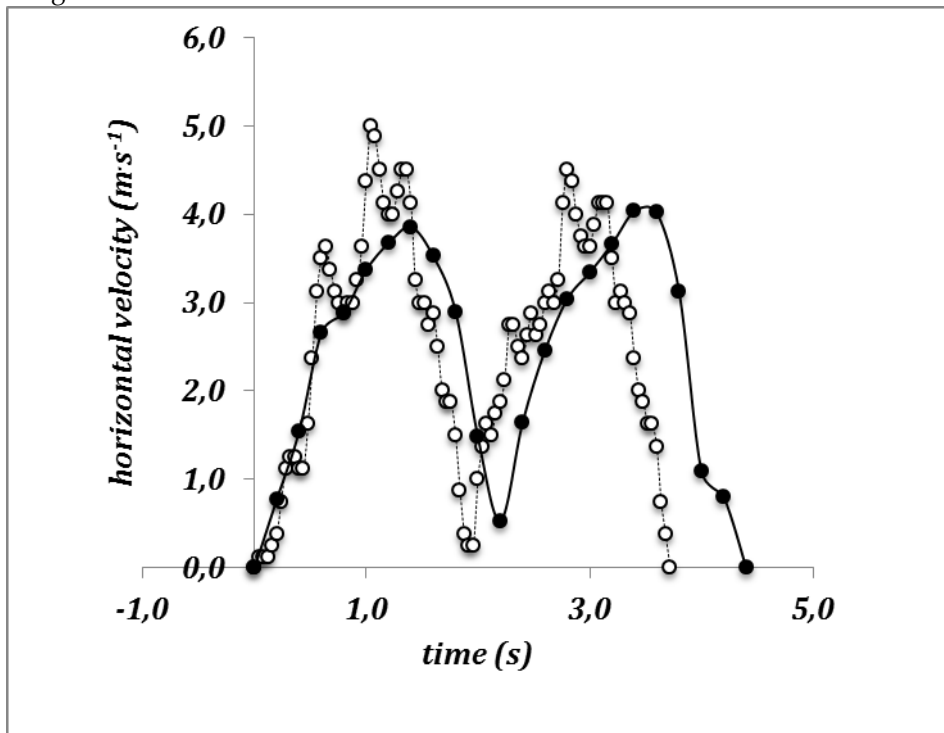
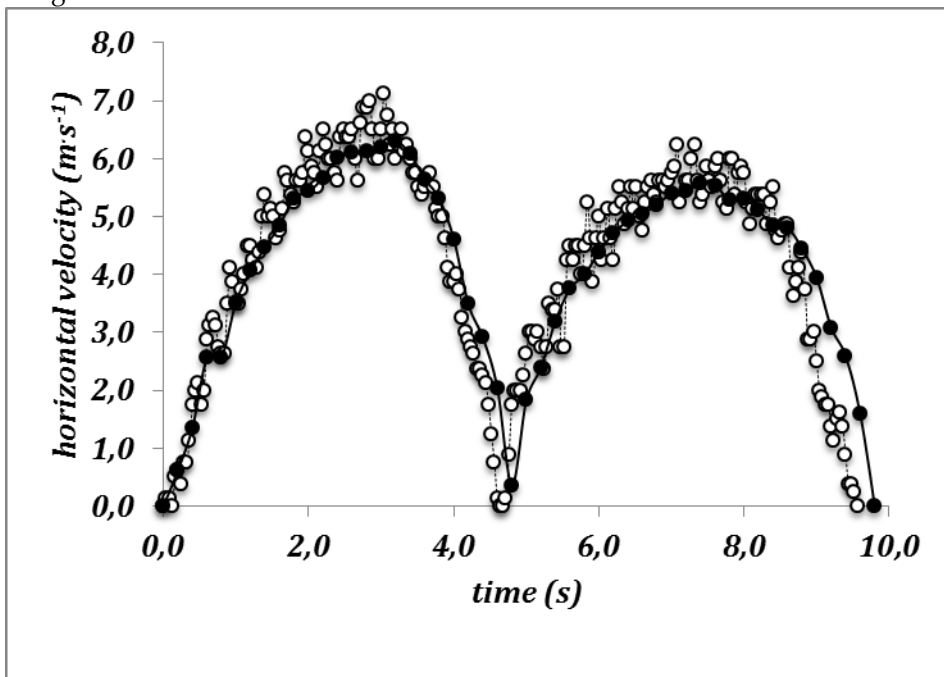
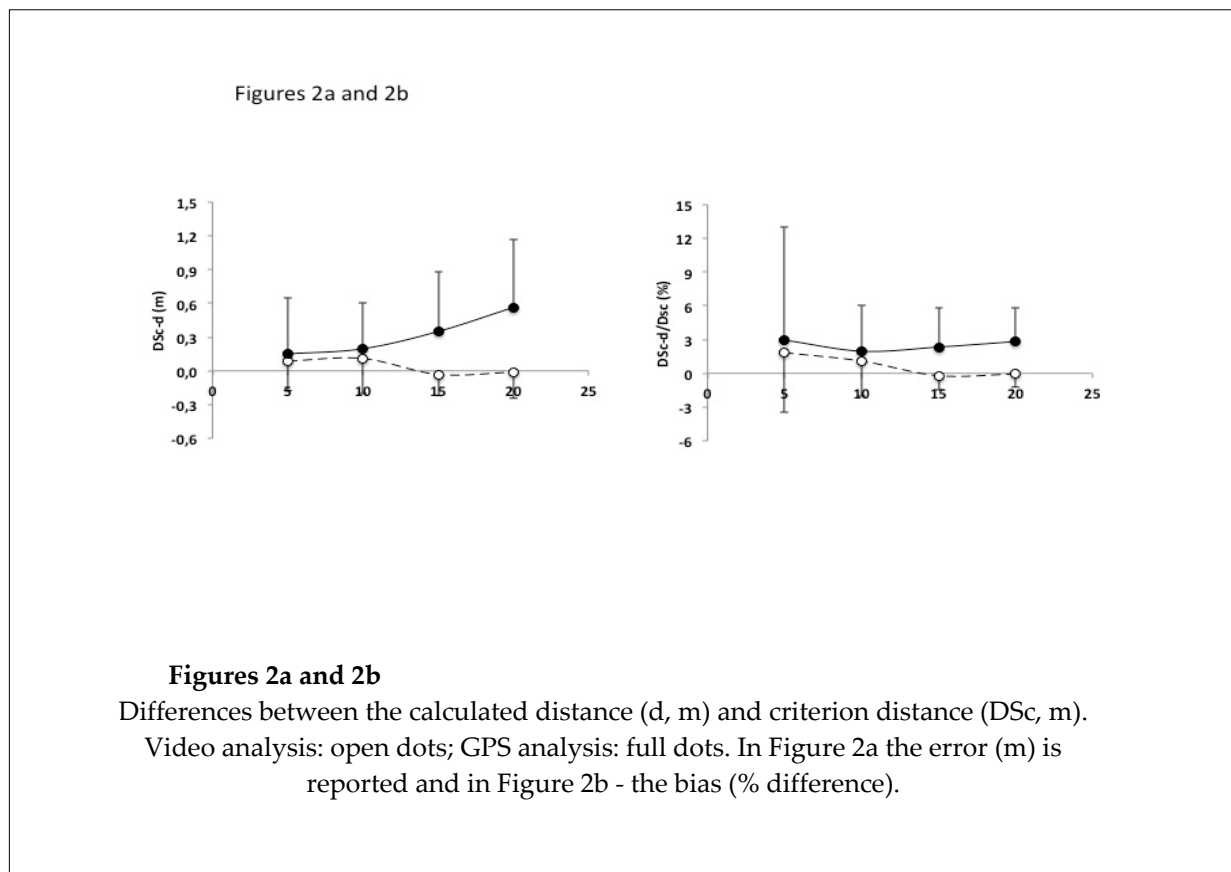


Figure 1b

**Figures 1a and 1b**

*Instantaneous values of horizontal speed during a shuttle run over a distance of 5 m (Figure 1a) and 20 m (Figure 1b). Open dots are the data acquired at 25 Hz by means of the video camera and full dots are the data acquired at 10 Hz by means of the GPS.*



For each variable a 2-way ANOVA for repeated measures (between Video and GPS data and within 5, 10, 15 and 20 m distances) was applied. Statistical significance was set at  $p < 0.05$ . When a significant F-value was found, the Bonferroni post hoc test was applied. The effect size of independent variables on dependent ones was evaluated by partial eta-squared ( $\eta_p^2$ ), and values of 0.01, 0.06, and above 0.15 were considered small, medium and large, respectively (Hopkins, 2000). Statistical analysis was performed using SPSS for Windows (SPSS Statistics 17.0).

## Results

In Figures 1a and 1b, the horizontal speed during a shuttle run over a distance of 5 and 20 m at V2 is reported, as an example, for one subject. The open dots are the data acquired at 25 Hz by means of the digital camera and full dots are the data acquired at 10 Hz by means of the GPS unit. In both cases, the horizontal speed increases up to a maximum in correspondence of about half the shuttle time, both before and after the turn, and it is nil at the start and during the turn; after the turn the profile of the velocity is a mirror of the

first half of the shuttle.

Significant differences in VA and VM were observed between methods: average shuttle velocity was lower in GPS than video analysis ( $p < 0.001$ ,  $N = 120$ ) by  $8.2 \pm 7.2\%$  (VA) and  $5.9 \pm 4.9\%$  (VM), respectively. The percentage difference (bias) between methods decreased with the distance covered: from  $11.9 \pm 11.3\%$  (5 m) to  $6.6 \pm 3.5\%$  (20 m) for VA and from  $8.7 \pm 5.8\%$  (5 m) to  $3.5 \pm 3.3\%$  (20 m) for VM.

The errors between the actual criterion distance ( $SDc$ ) and the distance calculated as Ttot VM ( $d$ ) are reported in Figures 2a and 2b: on the average ( $N = 120$ ) the error was lower for video data ( $0.04 \pm 0.28$  m) than for GPS data ( $0.31 \pm 0.55$  m); for GPS data the error tended to increase with distance covered (up to  $0.57 \pm 0.61$  m over the 20 m distance). The percentage difference between criterion and calculated distance was lower for video data ( $0.55 \pm 3.34\%$ ) than for GPS data ( $2.53 \pm 6.03\%$ ). As shown by Figure 2a, standard deviation in bias was larger the shorter the distance and larger in GPS than in video data.

In Table 1 the average values ( $\pm$  SD) of the measured variables are reported for the three

investigated speeds (V1, V2 and V3) and for the four shuttle distances (5, 10, 15 and 20 m) as collected with the two methods (video and GPS data). In this table the post hoc results are also reported. As shown by the ANOVA analysis (between factors: video and GPS data), average shuttle speed (VA and VM) was larger in video than in GPS analysis ( $F = 110.7$ ,  $p < 0.001$ ,  $\eta^2 =$

$0.92$ ;  $F = 172.6$ ,  $p < 0.001$ ,  $\eta^2 = 0.95$ , respectively); the calculated distance (d) was larger in video than in GPS analysis ( $F = 10.8$ ,  $p < 0.01$ ,  $\eta^2 = 0.55$ ). The distance  $\times$  method interaction was not significant VA ( $p = 0.78$ ) whereas significant interactions were observed for VM ( $p = 0.01$ ) and d ( $p = 0.02$ ).

**Table 1**

Average shuttle speed ( $V_A$ , calculated from the instantaneous values of speed), shuttle time ( $T_{tot}$ ), shuttle distance (d, calculated as  $T_{tot} \times V_A$ ) and average shuttle speed ( $V_M$ , calculated as the ratio:  $d / T_{tot}$ ) as a function of the distance covered (DSc, criterion: 5, 10, 15 20 m) at the three investigated shuttle speeds (V1: low; V2; medium; V3 high).

Data are means  $\pm$  SD.

			5 m	10 m	15 m	20 m
Video	$V_A$ ( $m \cdot s^{-1}$ )	V1	2.21 $\pm$ 0.16 <sup>b</sup>	2.23 $\pm$ 0.05 <sup>b</sup>	2.25 $\pm$ 0.07 <sup>b</sup>	2.27 $\pm$ 0.09
		V2	2.54 $\pm$ 0.18 <sup>b</sup>	3.18 $\pm$ 0.13 <sup>b</sup>	3.47 $\pm$ 0.11 <sup>b</sup>	3.21 $\pm$ 0.12 <sup>a</sup>
		V3	2.59 $\pm$ 0.23 <sup>a</sup>	3.52 $\pm$ 0.16 <sup>b</sup>	3.98 $\pm$ 0.18 <sup>b</sup>	4.20 $\pm$ 0.15 <sup>b</sup>
	$T_{tot}$ (s)	V1	4.69 $\pm$ 0.32 <sup>b</sup>	8.96 $\pm$ 0.20 <sup>b</sup>	13.35 $\pm$ 0.39 <sup>b</sup>	17.64 $\pm$ 0.64
		V2	3.95 $\pm$ 0.27 <sup>b</sup>	6.30 $\pm$ 0.25 <sup>b</sup>	9.27 $\pm$ 0.34 <sup>b</sup>	11.87 $\pm$ 2.07
		V3	3.67 $\pm$ 0.63 <sup>a</sup>	5.70 $\pm$ 0.27 <sup>b</sup>	7.55 $\pm$ 0.34 <sup>b</sup>	9.54 $\pm$ 0.34 <sup>b</sup>
	d (m)	V1	4.95 $\pm$ 0.22	10.09 $\pm$ 0.29	15.19 $\pm$ 0.21	20.2 $\pm$ 0.23 <sup>b</sup>
		V2	4.91 $\pm$ 0.30	9.81 $\pm$ 0.24	14.98 $\pm$ 0.18 <sup>a</sup>	19.99 $\pm$ 0.30 <sup>a</sup>
		V3	4.87 $\pm$ 0.28	9.77 $\pm$ 0.41	14.93 $\pm$ 0.17 <sup>a</sup>	19.91 $\pm$ 0.25 <sup>a</sup>
	$V_M$ ( $m \cdot s^{-1}$ )	V1	2.12 $\pm$ 0.17	2.25 $\pm$ 0.08 <sup>a</sup>	2.28 $\pm$ 0.05 <sup>a</sup>	2.29 $\pm$ 0.09 <sup>b</sup>
		V2	2.49 $\pm$ 0.13 <sup>b</sup>	3.12 $\pm$ 0.12 <sup>b</sup>	3.23 $\pm$ 0.11 <sup>b</sup>	3.21 $\pm$ 0.12 <sup>b</sup>
		V3	2.51 $\pm$ 0.18 <sup>b</sup>	3.44 $\pm$ 0.21 <sup>b</sup>	3.96 $\pm$ 0.15 <sup>b</sup>	4.17 $\pm$ 0.16 <sup>b</sup>
GPS	$V_A$ ( $m \cdot s^{-1}$ )	V1	1.98 $\pm$ 0.14	2.15 $\pm$ 0.06	2.17 $\pm$ 0.07	2.23 $\pm$ 0.09
		V2	2.33 $\pm$ 0.12	3.00 $\pm$ 0.13	3.09 $\pm$ 0.12	3.12 $\pm$ 0.18
		V3	2.38 $\pm$ 0.18	3.19 $\pm$ 0.21	3.78 $\pm$ 0.18	3.98 $\pm$ 0.16
	$T_{tot}$ (s)	V1	5.08 $\pm$ 0.34	9.30 $\pm$ 0.25	13.82 $\pm$ 0.43	17.98 $\pm$ 0.76
		V2	4.30 $\pm$ 0.24	6.68 $\pm$ 0.29	9.72 $\pm$ 0.39	12.84 $\pm$ 0.68
		V3	4.22 $\pm$ 0.30	6.30 $\pm$ 0.40	7.96 $\pm$ 0.36	10.07 $\pm$ 0.41
	d (m)	V1	5.09 $\pm$ 0.42	10.06 $\pm$ 0.29	14.84 $\pm$ 0.63	19.33 $\pm$ 0.72
		V2	4.75 $\pm$ 0.52	9.67 $\pm$ 0.29	14.56 $\pm$ 0.43	19.38 $\pm$ 0.70
		V3	4.71 $\pm$ 0.55	9.68 $\pm$ 0.58	14.55 $\pm$ 0.54	19.59 $\pm$ 0.40
	$V_M$ ( $m \cdot s^{-1}$ )	V1	2.01 $\pm$ 0.20	2.17 $\pm$ 0.09	2.15 $\pm$ 0.14	2.15 $\pm$ 0.10
		V2	2.21 $\pm$ 0.23	2.90 $\pm$ 0.11	3.00 $\pm$ 0.14	3.02 $\pm$ 0.13
		V3	2.23 $\pm$ 0.13	3.08 $\pm$ 0.10	3.66 $\pm$ 0.16	3.90 $\pm$ 0.18

Significant differences between VIDEO and GPS data: <sup>a</sup> =  $p < 0.05$ ; <sup>b</sup> =  $p < 0.01$ .

## Discussion

In this study we analysed the accuracy of the 10 Hz STATSports GPS in measuring average speed and shuttle distance, while subjects performed shuttle runs at different speeds and over different distances by comparing the instantaneous velocity data acquired by this device with a criterion (video analysis at 25 Hz).

Data reported in this study show that video analysis is more accurate in determining shuttle distance (the average error is of  $0.04 \pm 0.28$  m, the bias is  $0.66 \pm 3.34\%$ ) than GPS analysis (the average error is of  $0.31 \pm 0.55$  m, the bias is  $2.53 \pm 6.03\%$ ). Both the average values and the standard deviations are lower in video than in GPS analysis. VM (calculated) is 6% lower in GPS than in video analysis; the percentage difference in VM, however, decreases with the distance covered (from 8.7 to 3.4% at 5 and 20 m, respectively). Similar results are reported in the literature: GPS units tend to underestimate sprint or shuttle speed and GPS accuracy decreases in small distance tracks and during high-speed movements (Akenhead et al., 2014; Duffield et al., 2010; Jennings et al., 2010; Koklu et al., 2015; Vickery et al., 2014). As reported in the literature, rapid directional changes degrade GPS accuracy (Rawstorn et al., 2014) and, as observed in this study, the GPS speed error could thus be attributed to the COD. The inaccuracy of these GPS units in determining shuttle speed can thus be attributed to inaccuracy in recording of shuttle distance. This was also shown by Vickery et al. (2014) who reported that multi-direction movement patterns typical of team sports (i.e. soccer) affect GPS accuracy and inter-unit reliability. These authors also suggested that such limitations did not seem fully resolved by an increase in sampling frequency (e.g. from 5 to 15 Hz).

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A limitation of this study was the use of video analysis as a criterion since other technologies are generally considered more accurate; as an example, instantaneous values of speed can be recorded by using a laser/radar gun and thus, the GPS speed measurement accuracy can also be evaluated against this criterion (Akenhead et al., 2014; Rampinini et al., 2015; Varley et al., 2012). However, the average error in the distance as measured in this study (e.g.  $0.04 \pm 0.28$  m for video data) is comparable to that reported for laser data (LAVEG sport, Germany): e.g.  $0.10 \pm 0.06$  m (over a distance of 100 m) so that both methods can be considered adequate to be used as a criterion for this type of analysis (Arsac and Locatelli, 2002).

## Conclusions

These findings have an important practical application since they underline that the inaccuracy of this 10 Hz GPS device (Statsport) in determining average speed (bias, %; 5 m:  $9 \pm 6\%$ ; 20 m:  $3 \pm 3\%$ ) depends on inaccuracy of the evaluation of the shuttle distance; however, the bias in VM is rather small over the longer distances (3-4%). Sport scientists should be conscious of these limitations when analysing data in team sports. Such external load variables as total distance and high speed running distance may be underestimated by the GPS, and this underestimation increases in short distance tracks, as well as in field-base scenarios including COD. These limitations should be considered even in sport science research, especially because they could affect the estimates of accelerations, decelerations and metabolic power during short shuttle running and COD with consequent underestimation of total energy expenditure.

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