Original Article

The validity and reliability of a 5-hz GPS device for quantifying athletes' sprints and movement demands specific to team sports

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ABSTRACT

GPS systems are commonly used to analysis football performance during either trainings or matches. While many studies have investigated the validity and reliability of these devices, there is a lack of objective procedures regarding synchronization with gold standards such as real distance or timing gates. The objective of this study was to study the validity and reliability of a 5Hz GPS system (WIMU) during 10m and 30m sprints and during team sports specific movements and the reliability during very high speeds (> 30 km/h). The Total Distance (TD) BIAS for Circuit A, 10m sprint and 30m sprint were -2.73 ± 1.64 m ($p < 0.001$), -0.80 ± 0.58 m ($p<0.001$) and 0.42 ± 2.50 m ($p=0.515$) respectively. Average ICC for GPS speed point-to-point were 0.976 ± 0.012 and 0.991± 0.003 for Circuit B and Motorized Sprints, respectively. The average BIAS compared with each unit mean laps (intra-unit reliability) results for TD, Peak-Speed and Avg-Speed were 0.00 ± 1.68, 0.00 ± 1.73 and 0.00 ± 0.33 for Circuit A, 0.00 ± 0.49, 0.00 ± 0.53 and 0.00 ± 0.77 for 10m sprints and 0.00 ± 2.34, 0.00 ± 0.76 and 0.00 ± 0.74 for 30m sprints, non-significant difference in all cases. In conclusion, despite a lower than recommended sample frequency, the WIMU GPS showed to be valid and reliable for measuring sprints at speed higher than 20 km· h^{-1}, as well as for team sport movements.

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This might be practical on daily physical demands testing during training sessions. **Key words:** TESTING, FITNESS, TEAM SPORT, TECHNOLOGY, TRAINING

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INTRODUCTION

The use of global positioning system (GPS) devices is common in team sports, allowing coach to analyse real-time movement demands during training sessions and competition (Akenhead, French, Thompson, & Hayes, 2014). In this sense, GPS has been applied extensively in team sports such as Australian football (Coutts, Quinn, Hocking, Castagna, & Rampinini, 2010; Mooney et al., 2011), hockey (Gabbett, 2010; Macutkiewicz & Sunderland, 2011), cricket (Petersen, Pyne, Dawson, Kellett, & Portus, 2011; Petersen, Pyne, Portus, & Dawson, 2011), rugby (Hartwig, Naughton, & Searl, 2011; McLellan, Lovell, & Gass, 2011), and soccer (Buchheit, Mendez-Villanueva, Simpson, & Bourdon, 2010a, 2010b). This technology has been used to quantify physical stress, assess different positional activities profiles in competition, establish training intensities, and measure changes in player physiological demands (McLellan et al., 2011). Thus, GPS must be enough accurate and reliable to measure basic components the game such as player movement patterns, speed, and distance travelled and the number of accelerations and decelerations (Cummins, Orr, O'Connor, & West, 2013).

Several studies have analysed the reliability and validity of different GPS devices. Common findings of validation studies include measurement accuracy being related to the speed and distance of the measurement, with accuracy compromised when measuring short distances and when the speed of movement increased (Akenhead et al., 2014; Coutts et al., 2010; Johnston et al., 2012). The first difficulty encountered when investigating GPS validity is the gold standard criterion measure that GPS has been compared with (Aughey, 2011a). The most popular method is to use timing gates at the start and finish to measure the duration of the trial (Coutts et al., 2010; Jennings, Cormack, Coutts, Boyd, & Aughey, 2010). However, this method has a possible error in the ability of accurately determining the starting point for movement in the GPS software. In this sense, a possibility would be to synchronize the GPS device with photocells and / or a video system, measuring the total distance and duration of effort registered by the GPS.

Team sport athletes perform changes of directions, which may create discrepancies in the trajectory measured by GPS devices (Akenhead et al., 2014). Different studies have examined the validity of GPS under conditions relative to field sport athletes (Coutts et al., 2010; MacLeod, Morris, Nevill, & Sunderland, 2009). Traditionally, participants complete multiple laps of a circuit while wearing one or multiple GPS receivers. Those laps consisted of varied movement intensities (e.g. walking, running, standing) interspersed with agility-based movements such as a zigzag shuttle. Therefore, the protocols simulated the movement patterns of field- based team sports.

Validity is generally referred to as the ability of a measurement tool to reflect what it is designed to measure (Atkinson & Nevill, 1998). In the current study, criterion validity was determined, with respect to total distance and speed, for 5-Hz GPS devices. In addition to validity, even more important is to know the intra and inter-unit reliability of a measurement device. In the case of a GPS system, the intra-unit reliability in terms of speed might result difficult because is almost impossible to run exactly at the same speed during different laps of the same circuit. Consequently, most of the researches test the inter-unit reliability measuring travelled distances (Buchheit et al., 2010a; Jennings et al., 2010; Johnston, Watsford, Kelly, Pine, & Spurrs, 2014; Vickery et al., 2014), resulting on questionable reliability levels when speeds are higher than 20 $km \cdot h^{-1}$, (Rampinini et al., 2015), commonly known as high intensity running. In addition, the inter-unit reliability has not been shown to be frequency dependant (Akenhead et al., 2014; Coutts & Duffield, 2010; Rampinini et al., 2015).

Although researches have been questioned the validity and reliability of 5-Hz GPS devices on measuring travelled distances and peak or average speeds above 20 km·h^{-1}, in our opinion there is a lack of objectively synchronization of the GPS device with photocells when measuring short and medium sprint distances. Moreover, many studies have studied the GPS devices reliability using only 2 devices. Thus, it is important to test if GPS devices validity and reliability is enough for team sports movements and distances travelled at high intensity running with more objective methods.

According to this, the aims of the current study were to assess: (1) the validity of 5-Hz GPS devices for measuring distance during a circuit with different movements (straight lines, curves and changes of direction) and intensities (accelerations, decelerations, and runs at constant speed), (2) the inter-unit reliability and (3) the intra-unit reliability of the GPS devices for measured average and peak speed and distance, regarding special interest on high intensity running speeds.

MATERIALS AND METHODS

Experimental approach to the problem

The Total Distance (TD) measured by the GPS was compared to the real distance as criterion during 10m and 30m sprints, and during a team sports circuit. The average speed (Avg-speed) and peak speed (Peak-Speed) were also used to test either inter and intra-unit reliability during a second team sports circuit and Motorized Sprints. Testing protocols took placed at 06.00 pm (CET +0), on different synthetic football pitches, free from obstruction or adjacent buildings on clear sky situations with good weather conditions. In both situations, all the GPS units were simultaneously activated and left for 15 min. Antennas in all the GPS units were placed at the top for a better satellite signal reception. The typical number of available satellite signals in both situations ranged between 7 and 8. GPS raw data was analysed with the provided manufacturer software (Qüiko, Realtrack Systems, Almeria, Spain).

Participants

Two well-trained physical active men (28.5 ± 2.1 years, 72.0 ± 5.7 kg, 178.0 ± 5.7 cm, 10 weekly training hours) participated in the study. Subjects were informed about the research proposal and gave a consent written following Helsinki declaration guidelines.

Procedures

The validity was determined using a team sports movements based circuit (Circuit A, Figure 1), with a similar protocol and circuit which was previously used in a research with the same purpose (Coutts & Duffield, 2010). The circuit and its parts were measured with a tape measure. In total, the circuit was 146 m. Participants performed 3 laps prior to the testing as part of the familiarization protocol. Each participant wore a special t-shirt provided by the manufacturer with a pocket to hold the GPS unit between both scapulae. The circuit started with a 30 m straight line to test distance measure during sprints, by using a dual-beam electronic timing gate OptoJump System (Polifemo Radio Light, Mi- crogate, Bolzano, Italy) placed at the start position, 10 m and 30 m. The rest of the circuit was based on specific team sports movements with runs at different speeds, changes of speeds and changes of directions, including a 2 seconds stop. Participants were asked to start the circuit without any particular signal at maximum voluntary speed for the first 30 m, starting with their preferred foot and from a static position, preventing pre-emptive backwards movements (Waldron, Worsfold, Twist, & Lamb, 2011). During the circuit, subjects were instructed to run at different speeds marked by an acoustic signal every 2.5-5 m. At the end of each lap the participants were instructed to stop and maintain the same final position for at least 10 s. Twenty minutes before the exercise, participants were taken for a supervised warm-up consisted on moderate-intensity movement, dynamic stretching and 3 maximal 20 m sprint. To identify the beginning of each lap a high speed video-camera at 120 fps (GPro Hero 3+ Black Edition, California, USA) was synchronized with the GPS signal using the provided manufacturers software (Qüiko, Realtrack Systems, Spain), recording the moment when the participant cut the first timing gate line. The first 10 and 30 m in the software were later identified summing each timing gate time to the started identified point. The end of each lap was identified when GPS speed was equal or less than 1 km/h for more than 1 s. The average peek speed reached for both athletes calculated by GPS during 10m, 30m and whole Circuit A were 22.13 ± 0.95 km·h^{-1}, 29.00 ± 0.78 km·h^{-1} and 29.02 ± 0.76 km·h^{-1}, respectively. The same circuit was used to test the intra-unit reliability over all the laps performed by the two athletes (16 laps in total).

A second team sport movements based circuit was used to test the inter-unit reliability (Circuit B, Figure 2). The circuit and its parts were measured with a tape measure. In total, the circuit was 277 m. Eight GPS units were placed on a wood self-made structure on the roof of a golf cart for an ideal satellite signal acquisition, separated by 3 cm. The circuit include straight lines, curvilinear lines and changes of direction movements. The same golf cart driver performed eight laps, and was instructed to make different random changes of speeds all over the circuit. Both the beginning and ending of each lap were identified when the GPS speed increments or decrement respectively more than 1 km/h for more than one s. The average peak speed for all the units calculated by GPS during the Circuit B was 23.79 ± 0.09 km·h^{-1}.

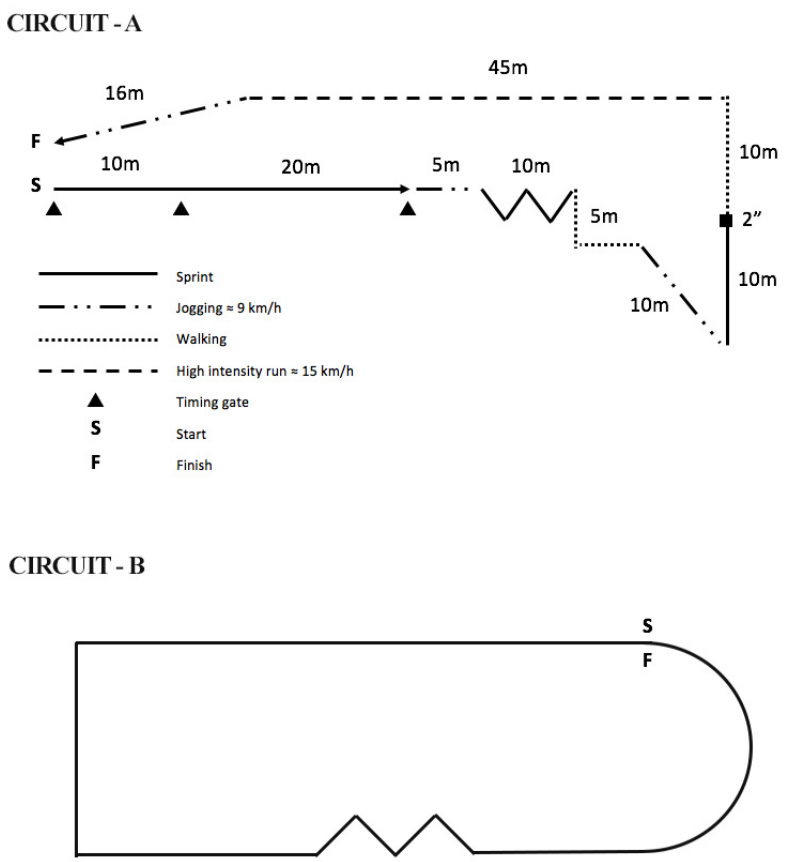

Figure 1 Caption. Circuits used for the study. Circuit-A was performed by athletes with 1 GPS at the same time. Circuit-B was performed by a golf cart with 8 GPS at the same time.

In addition to this circuit, in order to test the reliability at very high and sprint speeds during changes of speeds, the same structure with the eight GPS units was tight fixed on the back seat of a motorcycle. The same motorcycle driver performed eight straight sprints, and was instructed to accelerate at the maximum from the beginning during 30 m, ceasing to accelerate from this point. The beginning of each sprint was identified when the speed increased for more than one second more than 1 km/h. Each sprint higher peak speed was considered as the end of the sprint. The average peak speed for all the units calculated by GPS during the motorized sprints was 36.17 ± 0.06 $km \cdot h^{-1}$.

TD was calculated for the validity study during Circuit A, while TD, Avg-Speed and Peak-Speed were calculated for the both reliability study, as main variables directly related to GPS receivers. No other parameters were taken into account in this study (Vickery et al., 2014) due to gold-standard data recommendation (Cummins et al., 2013)

Statistical analyses

To assess the validity, BIAS and limits of agreement at 95% (LOA 95%) were calculated using Bland-Altman plots comparing the criterion (real distance) and the GPS measured TD. One sample Student's test was used to test the BIAS between criterion and GPS measurements. The BIAS was considered as low <5%, moderate 5 – 10%, and high > 10% (Coutts & Duffield, 2010).

The intra-unit reliability was calculated during Circuit A, 10m sprint and 30m sprint using Bland-Altman plots, calculating the BIAS and LOA (95%) for the mean TD, Avg-Speed and Peak-Speed measured with each unit over all the laps, used as criterion, and each lap individual unit difference with the mean.

Intraclass correlation coefficients (ICCs) and confidence intervals (CI) at 95% were used to determine the inter-unit reliability (2-way mixed model for absolute agreement) during Circuit B and motorized sprints for GPS speed measured point to point (5 points per second). Vicent criteria was used to interpret ICC coefficients, in which values greater than .90 were considered high, from 0.80 to 0.89 moderate, and below 0.80 questionable. All statistical analyses were completed using IBM SPSS Statistics for Windows software (release 20; SPSS Inc, Chicago, IL, USA). Significance was set at $p<0.005$.

RESULTS

Validity

Validity study results are shown in Table 1. The mean BIAS for TD during Circuit A, 10m sprint and 30m sprint were -2.73 ± 1.64 m ($p < 0.001$), -0.80 ± 0.58 m ($p<0.001$) and 0.42 ± 2.50 m ($p=0.515$) respectively. Relatively, those meters represented -1.87 ± 1.12 %, -8.0 ± 5.8 % and 1.4 ± 8.3 % of BIAS respectively. Bland-Altman plots showed 94% of the data inside limits of agreement (LoA) in all the situations.

Table 1. Validity study results for Circuit A, 10m and 30m sprints. The Peak-Speed was used to detect if there were high-speed movements. ES = effect size. LOA = Bland-Altman limits of agreement.

Distance	Criterion (m ± sd)	WIMU (m ± sd)	Peak speed ($km \cdot h^{-1}$ ± sd)	BIAS (m)	p-value	ES	95% LOA
Circuit	146 ± 0	143.27 ± 1.64	29.02 ± 6.69	-2.73 ± 1.64	0.000	2,35	-5.94 ; -0.48
10 m	10 ± 0	9.20 ± 0.58	22.13 ± 7.21	-0.80 ± 0.58	0.000	1,95	-1.93 ; 0.35
30 m	30 ± 0	30.42 ± 2.50	28.99 ± 9.40	0.42 ± 2.5	0.515	-0,23	-4.48 ; 5.32

Reliability

Inter-unit reliability results are show in Table 2. Average ICC for GPS speed point-to-point were 0.976 ± 0.012 and 0.991± 0.003 for Circuit B and Motorized Sprints, respectively.

Table 2. Circuit B and motorized sprints GPS Speed inter-unit reliability results. ICC = intraclass correlation coefficient. CI = confidence interval.

	Circuit			Motorized sprints		
	N	ICC	CI 95%	N	ICC	CI 95%
Lap 1	384	0.977	0.980-0.973	25	0.996	0.993-0.998
Lap 2	344	0.986	0.984-0.988	23	0.985	0.973-0.992
Lap 3	348	0.986	0.984-0.988	26	0.992	0.987-0.996
Lap 4	339	0.982	0.979-0.985	22	0.990	0.982-0.995
Lap 5	339	0.971	0.966-0.975	23	0.990	0.982-0.995
Lap 6	335	0.950	0.942-0.957	23	0.992	0.987-0.996
Lap 7	332	0.974	0.969-0.978	24	0.994	0.990-0.997
Lap 8	337	0.983	0.980-0.985	24	0.992	0.987-0.996

Intra-unit reliability results are shown in Table 3. The average BIAS compared with each unit mean laps results for TD, Peak-Speed and Avg-Speed were 0.00 ± 1.68, 0.00 ± 1.73 and 0.00 ± 0.33 for Circuit A, 0.00 ± 0.49, 0.00 ± 0.53 and 0.00 ± 0.77 for 10m sprints and 0.00 ± 2.34, 0.00 ± 0.76 and 0.00 ± 0.74 for 30m sprints, non-significant difference in all cases.

Table 3. Circuit A, 10m sprints and 30m sprints intra-unit reliability results. LOA = Bland-Altmant limits of agreement.

	Circuit A		10m Sprints		30m Sprints	
Outcomes	Mean ± SD	95% LOA	Mean ± SD	95% LOA	Mean ± SD	95% LOA
TD	0.00 ± 1.68	-3.29 ; 3.29	0.00 ± 0.49	-0.96 ; 0.96	0.00 ± 2.34	-4.59 ; 4.59
Peak-Speed	0.00 ± 0.73	-1.43 ; 1.43	0.00 ± 0.53	-1.04 ; 1.04	0.00 ± 0.76	-1.49 ; 1.49
Avg-Speed	0.00 ± 0.33	-0.65 ; 0.65	0.00 ± 0.77	-1.51 ; 1.51	0.00 ± 0.74	-1.45 ; 1.45

DISCUSSION

Prior works tested the validity and reliability of different frequency sample GPS devices for measure TD, Avg-Speed or Peak-Speed. Traditionally, it has been suggested a minimum of 10-Hz to provide good data validity and reliability for such kind of measurements, especially for quick movements performed at high speed running levels. In this research, we tested the validity of the WIMU 5-Hz GPS devices for measuring TD and Peak-Speed during team sports movements, and the inter-unit reliability and the intra-unit reliability of the GPS devices to measure TD, Avg-Speed and Peak-Speed, regarding special interest on high intensity running speeds. Concretely, the WIMU-GPS significantly underestimated the TD during team sport movements. However, this level of BIAS has been previously considered as a good level of accuracy, in agreement with previous research with lower frequency rate (Coutts & Duffield, 2010) same sample frequency (Gray, Jenkins, Andrews, Taaffe, & Glover, 2010) and higher sample frequency (Johnston et al., 2014). Regarding inter-unit reliability, our results showed very good reliability levels of the WIMU-GPS even during high intensity running, either in short distances (10m), medium distances (30m) or longer distances with variations on speeds, directions and trajectories.

Nowadays GPS technology provides a huge amount of information and variables. Some of these interesting variables are related to distance, including TD, high-speed distance or sprint distance (Buchheit et al., 2010a; Jennings et al., 2010; Johnston et al., 2014; Vickery et al., 2014), accelerations/decelerations (Aughey, 2011a; Buchheit et al., 2010a), and other mixed variables with other sensors such as power metabolic (Rampinini et al., 2015). Despite many of these variables have been studied on many validation studies, comparing them with a good and real criterion during specific team sport movements might result very difficult and questionable. Thus, due to validity specific criteria, TD is easier, more accurate and more real to compare with a criterion. In this study, real distance was chosen as criterion and compared with TD measured with the WIMU-GPS.

Validity during straight line sprints has been widely studied in the literature (Cummins et al., 2013), even more tan TD during team sports circuits. Our results showed larger errors associated with human sprints rather than with total Circuit A (Table 1). The validity for sprints was distance depending. The WIMU-GPS significantly underestimated the distance during 10m sprints (-8.0 $\pm$ 5.8 %).. These results were in agreement with previous studies using same (Jennings et al., 2010; Waldron et al., 2011) and higher (Castellano, Casamichana, Calleja-Gonzalez, Roman, & Ostojic, 2011) frequency rate devices. In contrast, there were no significant differences in the 30m sprints compared to the criterion. Although many studies has shown a low validity of TD measured by GPS devices during sprints, especially during high or very high-speed movements (usually, higher than 20 km·h^{-1}, (Rampinini et al., 2015)), the Peak-Speed achieved during Circuit A, 10m or 30m sprints were much higher than those 20 km·h^{-1}. Therefore, our results suggested that the validity is not frequency rate depending, if not objective synchronization with the chosen criterion.

To our knowledge, this is the first study that uses a high-speed video camera synchronized via software with a GPS device and timing gates to determine the sprint start point and sprint splits. Most of the studies did not provide this synchronization methodology information or use approaches that are questionable. For example, Waldron et al. (2011) determined the sprint start as a continuous increase from 0 to 0.1 km·h^{-1}. However, if the GPS device does not include any filter to cut the almost stopped speeds, the own Earth speed rotation would result in about 0.5 km·h^{-1} (private data, non-published). What is more, GPS devices are usually placed on a vest chest and, at the beginning of a sprint, the trunk itself might achieved around 4 km·h^{-1}. Thus, this criterion may have cause a failure on the sprint time determination and an error on any related variable calculated, especially during short distances. Hence, our results showed a worse validity for 10m than 30m sprints, in accordance with other studies (Castellano et al., 2011; Cummins et al., 2013; Jennings et al., 2010; Waldron et al., 2011). Thought a lower validity over shorter distances, the BIAS found in our study might be classified as low (<5%), including a low effect (< 0.5) size for measuring TD during 3 m sprints, despite of the high speed running achieved during those sprints.

Testing reliability with GPS devices present some difficulties. First, it is technically impossible to repeat the same speed at the same exactly movement by a human over different laps in a team sports movements circuit. Thus, to our knowledge, there is no study that analyses the pure speed intra-unit reliability point-to-point. Despite of this, many studies analysed the reliability of some interesting average variables values such as TD (Jennings et al., 2010; Johnston et al., 2014; Vickery et al., 2014), Avg-Speed (Varley, Fairweather, & Aughey, 2012; Vickery et al., 2014) or Peak-Speed (Johnston et al., 2014; Vickery et al., 2014). In our study, we found a good inter and intra-reliability values for the WIMU-GPS for TD, Avg-Speed or Peak-Speed during team sport movements and, even more important, during very high-speed sprints. The inter-unit reliability is in accordance with previous studies using GPS devices with same frequency rate (Waldron et al., 2011) despite a better reliability found in other research (Jennings et al., 2010). These differences could be related to different sprinting time determination methods. The ICCs found on the intra-unit reliability study were high (>0.9) during either team sport movements or motorized sprints, with similar results showed in other research (Johnston et al., 2014). However, it has been suggested that GPS devices from the same manufactured may not be interchangeable due to a low intra-unit reliability (Akenhead et al., 2014; Coutts & Duffield, 2010; Rampinini et al., 2015). Nonetheless, this study showed a high ICC during very high-speeds achieved during short (10m) and medium (30m) distances in motorized sprints, even during Circuit B were the Peak-Speed achieved was more than 20 $km \cdot h^{-1}$. Furthermore, the Peak-Speeds achieved during the motorized sprints are much higher than those described as usual during a team sports match (36 $km \cdot h^{-1}$ vs 27 $km \cdot h^{-1}$, (Varley et al., 2012). Thus, it proves the ecological validity of the methods used to test the reliability in a whole range of speed even higher than those do that occurs during a typical team sports match.

Future studies should focus on describe sprints profiles using, at least, 5-Hz GPS systems during specific and non-specific team sports tasks. In this regard, one of the main limitations of the present study was that it did not examine the validity and reliability of other interesting variables related to accelerations, decelerations or impacts, calculated via in-built accelerometers. In this case, the WIMU also contains a 1000 Hz triaxial accelerometer that could be combine together with its GPS to provide a more objective and useful data.

CONCLUSIONS

In conclusion, although it has been suggested that due to variability exercise activity and statistical methods applied, direct comparison of GPS devices validity within team sports is difficult (Aughey, 2011b), our data suggests that the WIMU-GPS is a practical and reliable tool for measuring TD during team sport movements and straight sprints, despite a lower frequency rate compared with other higher frequency rate units. In addition, despite other investigations showed how the criterion validity and reliability of GPS devices decreased over 20 $km \cdot h^{-1}$ speeds, our results showed that the WIMU-GPS did not presented this issue during medium sprints (30m). This could be explained by several facts: 1) the synchronization method used on this study may be more precise for determining sprint times together with timing gates and 2), using a motorbike during motorized sprint may lead on higher amount of data at higher speeds comparing with human sprints, resulting on more probability to have a better accuracy with the current available statistical methods. This last point has been demonstrated on previous research, suggesting that the accuracy of the GPS devices is improved when the total distance covered is higher (Jennings et al., 2010).

This study provides an objective method to synchronize a GPS system with timing gates. The results highlight that a frequency sample of 5-Hz is enough to have valid and reliable distances measurements over 30m sprints and team sport movements. In addition, the WIMU GPS showed to be reliable even at high speeds. Thus, to replace traditional timing gates with this system may provide a more simple and practical tool to assess strength and conditioning adaptations through sprint tests during more specific exercises regarding the team sports demands.

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