Validity and Interunit Reliability of 10 Hz and 15 Hz GPS Units for Assessing Athlete Movement Demands

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Abstract

Johnston, RJ, Watsford, ML, Kelly, SJ, Pine, MJ, and Spurrs, RW. Validity and interunit reliability of 10 Hz and 15 Hz GPS units for assessing athlete movement demands. *J Strength Cond Res* 28(6): 1649–1655, 2014—The purpose of this study was to assess the validity and interunit reliability of 10 Hz (Catapult) and 15 Hz (GPSports) Global Positioning System (GPS) units and investigate the differences between these units as measures of team sport athlete movement demands. A team sport simulation circuit was completed by 8 trained male participants. The movement demands examined included: total distance covered (TD), average peak speed, and the distance covered, time spent, and the number of efforts performed low-speed running (0.00–13.99 $km \cdot h^{-1}$), high-speed running (14.00–19.99 $km \cdot h^{-1}$), and very high-speed running (>20.00 $km \cdot h^{-1}$). The degree of difference between the 10 Hz and the 15 Hz GPS units and validity was assessed using a paired samples *t*-test. Pearson's correlations were also used for validity assessment. Interunit reliability was established using percentage typical error of measurement (%TEM) and intraclass correlations. The findings revealed that 10 Hz GPS units were a valid ($p > 0.05$) and reliable (%TEM = 1.3%) measure of TD. In contrast, the 15 Hz GPS units exhibited lower validity for TD and average peak speed. Further, as the speed of movement increased the level of error for the 10 Hz and 15 Hz GPS units increased (% TEM = 0.8–19.9). The findings from this study suggest that comparisons should not be undertaken between 10 Hz and 15 Hz GPS units. In general, the 10 Hz GPS units measured movement demands with greater validity and interunit reliability than the 15 Hz units, however, both 10 Hz and 15 Hz units provided the improved measures of movement demands in comparison to 1 Hz and 5 Hz GPS units.

Key Words team sports, high-speed running, sampling rates, training

Introduction

The importance of collecting and analyzing the movement demand data of team sport athletes during training sessions and matches has been established (8,9,26). In addition, movement demands, such as the distance covered and the time spent high-speed running (HSR) have a demonstrated relationship to the match performance of an individual and a whole team (21,25). Consequently, the instruments used to collect these data need to be valid and reliable. Global Positioning System (GPS) units are currently being used by professional sporting teams to collect movement demand data from athletes, because of the ease of data collection and the quality of analysis provided by these systems (3,13,14,21). Therefore, the validity and interunit reliability of GPS units as measures of movement demands is of primary importance.

The validity and interunit reliability of 1 Hz and 5 Hz GPS units as measures of athlete movement demands has been established. These movement demands include total distance covered (TD), peak speed and the distance covered, time spent, and the number of efforts performed at speeds ranging from walking to sprinting (7,20,22). The main findings of these studies was that the level of GPS interunit reliability decreased when relatively small distances were used for assessment when sharp changes in direction occurred and when the speed of movement increased (7,20,22). Further, 1 study revealed that in comparison to 5 Hz Catapult GPS units, the 5 Hz GPSports (Canberra, Australia) GPS units had slightly improved interunit reliability results when measuring the distance covered striding (14.4–18 $km \cdot h^{-1}$) and sprinting (>18 $km \cdot h^{-1}$) (23). In contrast, there has been limited examination of the validity and interunit reliability of 10 Hz and 15 Hz GPS units (6,27). The research on 10 Hz GPS units reported a mean level of error of 10.9% and 5.1% when analyzing the distance covered

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during 15-m and 30-m straight-line running tests, respectively (6). Then, these 10 Hz GPS units were shown to have good interunit reliability for measuring the distance covered over 15 m and 30 m (coefficient of variation (CV) $<1.5\%$) (6). However, this 1 variable (distance covered) was only examined using straight-line tests and over short distances. Consequently, a more thorough investigation of a range of movement demands, such as the distance covered, time spent, and the number of efforts performed at different speeds is required. Further, a more comprehensive assessment protocol such as a testing circuit based on the movement demands of team sport athletes seems necessary.

Recent increases in the sampling rates of GPS units from 5 Hz to 10 Hz (Catapult Innovations, Melbourne, Australia) and 15 Hz (GPSports) have occurred. Previous examinations into the impact of increases in sampling rate from 1 Hz to 5 Hz revealed that units with a higher sampling rate provided a more valid and reliable measures of athlete movement demands, such as TD and peak speed (10,22,23). The 15 Hz units sampling rate is calculated by supplementing a 10 Hz GPS sampling rate with accelerometer data (2). Consequently, the effect of this calculation and increases in sampling rates on the ability of 15 Hz GPS units to measure movement demands warrant further research. Additionally, the limited research investigating these newer GPS units highlights the need for detailed examinations into this area (6,27). The differences in validity and interunit reliability between 10 Hz Catapult and 15 Hz GPSports GPS units for measuring athlete movement demands require inspection, as it is important for coaches and conditioning staff to understand their chosen devices. This is especially the case as Catapult Innovations and GPSports are currently the 2 most commonly used and commercially available GPS units for professional team sports (1,13,15,24).

The purpose of this pilot study was to determine the validity and interunit reliability of 10 Hz and 15 Hz GPS units for measuring team sport athlete movement demands. Also, this study aimed to examine the differences in validity and interunit reliability between the 10 Hz Catapult units and 15 Hz GPSports units. It was hypothesized that both GPS units would provide a valid and reliable measure of TD and peak speed, although the GPS level of error was expected to increase as the speed of exercise increased. And, it was expected that increases in sampling rate from previously examined 1 Hz and 5 Hz to the current 10 Hz and 15 Hz would further improve the validity and interunit reliability of GPS units.

Methods

Experimental Approach to the Problem

This pilot study used 8 trained male participants to investigate the validity and interunit reliability of 10 Hz and 15 Hz GPS units. In addition, whether data collected by 10 Hz GPS units can be compared with data collected by 15 Hz GPS units was evaluated. Testing was conducted over 2 days, with day 1 involving the collection of data from two 10 Hz units (for 10 Hz interunit reliability assessment) and day 2 involving the collection of data from one 10 Hz unit and two 15 Hz units (for 15 Hz interunit reliability assessment and between-unit comparisons). Participants were required to complete a team sport simulation circuit (TSSC), which enabled the assessment of 10 Hz and 15 Hz GPS units under conditions similar to team sport matches (7,20,22). For the analysis of the 10 Hz GPS units, 3 participants completed the TSSC twice and 4 participants completed it once. The testing of the 15 Hz GPS units and 10 vs. 15 Hz GPS units involved 1 participant completing the TSSC 3 times, 3 participants completing it twice, and 1 participant completing it once. This ensured that a sufficient number of GPS files (10) were collected for reliability purposes (17).

Subjects

Eight trained male participants (26.1 ± 4.1 years, 84.3 ± 14.0 kg, and 185.7 ± 5.9 cm) volunteered to participate in this study, with no participants aged younger than 21 years used. All participants were involved in regular exercise and capable team sport athletes. All tests were performed in the afternoon. In the 24 hours before testing, participants were encouraged to maintain adequate levels of hydration and to eat a well-balanced diet. Further, participants were required to refrain from strenuous exercise. Study design and methods approval were granted by the Human Research Ethics Committee at the University of Technology, Sydney, Australia. Additionally, participants were required to complete a written informed consent form, following a full explanation of all procedures.

Experimental Procedures

A TSSC was designed to assess the ability of the 10 Hz and 15 Hz GPS units to measure team sport movement demands. The TSSC used was based on previous research examining the validity and interunit reliability of 1 Hz and 5 Hz GPS units (7,20,22). The GPS units used for the current study were 10 Hz Catapult MinimaxX units (MinimaxX S4, 10 Hz, Firmware 6.70, Catapult Innovations) and 15 Hz GPSports (SPI-ProX, 15 Hz, Firmware V2.4.3, GPSports). As mentioned in the "Introduction," the manufacturers have supplemented a 10 Hz GPS sampling with accelerometer data to produce this 15 Hz sampling rate (2). Participants were required to wear either 2 (day 1) or 3 (day 2) GPS units during the 2 testing days. These units were placed inside separate specially designed garments and positioned so that they sat between the participants' scapulae. Finally, it was ensured the GPS antennas were fully exposed.

The validity of the 10 Hz and 15 Hz GPS units was determined by comparing GPS reported TD and peak speed with the criterion measures of these variables. Specifically, TD was assessed with a tape measure, and peak speed was examined using timing lights (Figure 1), as performed previously (4,7). The interunit reliability of both the brands of GPS units was established through comparing the movement demand data collected by the two 10 Hz or 15 Hz GPS units

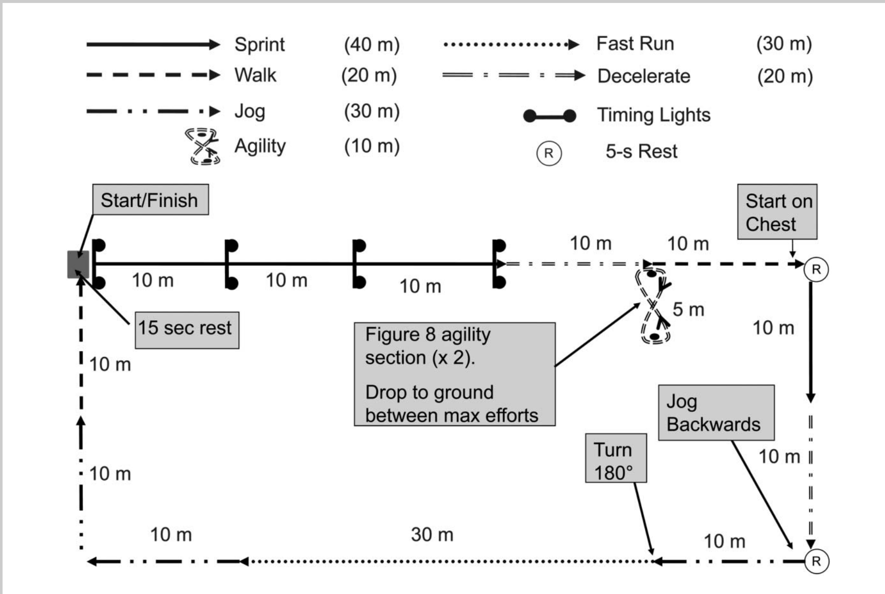

Figure 1. Team sport simulation circuit (TSSC) used to assess validity and interunit reliability of MinimaxX and GPSports Global Positioning System units. Includes description of different movement demands assessed (with total distances covered for each lap).

worn by each participant. Further, the differences between the 10 Hz and 15 Hz units were assessed by comparing the data collected on testing day 2, by the 10 Hz unit with 15 Hz GPS unit one.

The speed zones selected and the movement demands investigated were in part determined by research examining the validity and interunit reliability of 1 Hz and 5 Hz GPS units (7,22,23,25). For this study, they included: (a) TD, (b) average peak speed, and (c) when considering low-speed running (LSR) (0.00–13.99 $km\cdot h^{-1}$), HSR (14.00–19.99 $km\cdot h^{-1}$), and very high-speed running (VHSR) (>20.00 $km\cdot h^{-1}$) the distance covered while performing each activity, time spent performing each activity, and the number of efforts performed.

The TSSC was designed to contain the components of standing, walking, jogging, running, and sprinting along with accelerations and decelerations to replicate the movements of team sport athletes. Additionally, the TSSC was designed to assess the capabilities of GPS when measuring movement demands at speeds in excess of 20 $km\cdot h^{-1}$. The criterion distance of the TSSC (165 m) was assessed during the setup using a tape measure. Participants were required to complete 8 laps of the TSSC resulting in a total distance of 1,320 m, which is comparable with previous examinations into GPS and movement demands (7,12). It was found that each lap was finished within approximately 1 minute, with participants provided with a 15-second rest at the start of each subsequent lap. This meant that testing maintained a similar intensity to team sport matches (5,29).

Table 1. Raw data for interunit reliability of Catapult 10 Hz Global Positioning System units.*

Athlete movement demands	MinimaxX–unit 1 (mean ± *SD*)	MinimaxX–unit 2 (mean ± *SD*)	ICC	%TEM
TD (m)	1,331.9 ± 23.9	1,330 ± 23.0	0.51	1.3
Peak speed ($km\cdot h^{-1}$)	22.98 ± 2.08	22.99 ± 2.14	0.97	1.6
Distance covered (m)				
LSR	762.4 ± 67.4	770.4 ± 62.9	0.97	1.7
HSR	388.6 ± 48.8	386 ± 44.3	0.88	4.8
VHSR	175.1 ± 59.8	169.5 ± 46.6	0.89	11.5
Time spent (s)				
LSR	529.3 ± 38.0	534.0 ± 38.4	0.99	0.8
HSR	82.1 ± 9.7	81.6 ± 8.3	0.86	4.6
VHSR	28.1 ± 9.5	27.1 ± 7.4	0.89	11.7
Number of efforts performed (n)				
HSR	22.9 ± 1.7	23.5 ± 1.0	0.8	2.0
VHSR	8.1 ± 2.6	7.9 ± 2.3	0.84	13.7

*ICC = intraclass correlation; %TEM = percentage typical error of measurement; TD = total distance covered; LSR = low-speed running; HSR = high-speed running; VHSR = very high-speed running.

Table 2. Raw data for interunit reliability of GPSports 15 Hz Global Positioning System units.*

Athlete movement demands	GPSports–unit 1 (mean ± *SD*)	GPSports–unit 2 (mean ± *SD*)	ICC	%TEM
TD (m)	1,301.8 ± 26.1	1,306.1 ± 17.6	−0.20	1.9
Peak speed (km·h^{-1})	24.09 ± 1.51	23.54 ± 2.06	−0.14	8.1
Distance covered (m)				
LSR	810.3 ± 108.3	812.6 ± 101.1	0.98	2.0
HSR	323.3 ± 84	293.7 ± 79.8	0.94	7.6
VHSR	168.6 ± 50.5	199.8 ± 42	0.81	12.1
Time spent (s)				
LSR	564.0 ± 57	567.1 ± 59.9	0.99	1.0
HSR	64.1 ± 14.1	59.2 ± 13.8	0.94	6.3
VHSR	26.1 ± 7.5	30.7 ± 5.7	0.85	9.9
Number of efforts performed (n)				
HSR	38.8 ± 8.5	39 ± 5.7	−0.77	9.9
VHSR	15.8 ± 5.0	17.7 ± 7.5	0.77	19.9

*ICC = intraclass correlation; %TEM = percentage typical error of measurement; TD = total distance covered; LSR = low-speed running; HSR = high-speed running; VHSR = very high-speed running.

To establish the construct validity of GPS as a measure of peak speed, timing lights (Swift Performance Equipment, Lismore, Australia) were used as the criterion measure of peak speed (4,7). These timing lights were placed at the start 0, 10, 20, and 30 m marks along the 30-m sprint at the commencement of the TSSC. Average velocity from the 20–30 m split was used to calculate peak speed.

To ensure the TSSC was correctly followed and participants had a clear understanding of the different sections of the circuit, participants were walked through the circuit before testing commenced. Cones and instructional markers were used throughout the TSSC to assist participants to understand what was required of them and to ensure the circuit was correctly followed. Additionally, strong verbal encouragement was provided by the researcher throughout the testing, which helped participants to maintain the required intensity.

Statistical Analyses

The movement demand data were downloaded using either Logan Plus version 4.7.1 (Catapult Innovations) or Team AMS firmware V2.5.4 (GPSports) specialized software. This

Table 3. Raw data comparison between 10 Hz and 15 Hz Global Positioning System units.*

Athlete movement demands	10 Hz MinimaxX unit (mean ± *SD*)	15 Hz GPSports unit (mean ± *SD*)	*p*	T value
TD (m)	1,326 ± 24.6	1,301.8 ± 26.1	0.25	−2.68
Peak speed (km·h^{-1})	24.28 ± 1.54	24.09 ± 1.51†	0.00	3.781
Distance covered (m)				
LSR	821.5 ± 99.5	810.3 ± 108.3	0.30	−1.10
HSR	301 ± 99.3	323.3 ± 84	0.11	1.80
VHSR	198.4 ± 37.8	1,686 ± 50.5†	0.03	−2.51
Time spent (s)				
LSR	603.2 ± 56.1	564.0 ± 57†	0.00	−11.57
HSR	64.2 ± 20.5	64.1 ± 14.1	0.98	−0.24
VHSR	31.1 ± 5	26.1 ± 7.5†	0.02	−2.71
Number of efforts performed (n)				
HSR	20.6 ± 4.1	38.8 ± 8.5†	0.00	7.39
VHSR	8.4 ± 0.8	15.8 ± 5.0†	0.04	3.91

*TD = total distance covered; LSR = low-speed running; HSR = high-speed running; VHSR = very high-speed running.
†Significantly different from MinimaxX Score.

software was used to convert the raw GPS data into the movement demands and speed zones to be analyzed.

Descriptive statistics were calculated for all variables and reported as mean ± *SD*. To establish the difference between the criterion measures and the 10 Hz and 15 Hz GPS unit scores for TD and peak speed, a paired samples *t*-test was used. This was calculated using Statistical Package for Social Sciences (version 18, PASW Statistics for Windows, Version 18.0, SPSS Inc., Chicago, IL, USA). Similarly, a paired samples *t*-test was used to determine the variation between the 10 Hz and 15 Hz GPS units for the movement demands investigated. An alpha level of $p < 0.05$ was set as the level of significance for all statistical tests. The strength of the relationship between the 10 Hz and 15 Hz GPS units and the criterion measure of peak speed was further analyzed using Hopkins (18) validity spreadsheet to produce a Pearson correlation score. A correlation system involving trivial (0.0), small (0.1), moderate (0.3), large (0.5), very large (0.7), nearly perfect (0.9), and perfect (1.0) scores was used (16).

The interunit reliability of the 10 Hz and 15 Hz GPS units was determined using Hopkins's (19) reliability spreadsheet to calculate the percentage typical error of measurement (% TEM) and the intraclass correlation (ICC) values, as has been performed previously (3,22). This involved comparing the reported values for units 1 and 2 of the 10 Hz GPS units and 15 Hz GPS units. These tests assisted with understanding the degree of error and the amount of variation between the units. The magnitudes of %TEMs used included poor (>10%), moderate (5–10%), or good (<5%) (11). The strength of the ICC scores was based on the system previously mentioned for the Pearson correlation scores (16).

Results

The 2 days of data collection occurred in conditions that were considered good for gathering valid and reliable GPS data (no cloud cover and the satellite numbers for all units ranged from 9 to 14 during all testing days).

Validity

No significant difference was reported between actual TD (1,320 m) and Catapult 10 Hz unit 1 (1,331.9 ± 23.9 m, $p = 0.149$, $t = -1.577$) and 2 (1,330 ± 23 m, $p = 0.202$, $t = -1.376$). In contrast, there was a significant difference between actual peak speed (22.47 ± 2.64 $\text{km}\cdot\text{h}^{-1}$) and 10 Hz GPS unit 1 (22.98 ± 2.08 $\text{km}\cdot\text{h}^{-1}$, $p = 0.01$, $t = -3.610$) and 2 (22.99 ± 2.14 $\text{km}\cdot\text{h}^{-1}$, $p < 0.01$, $t = -4.010$) reported peak speed. However, the Pearson Correlation scores were $r = 0.89$ and $r = 0.91$ for Catapult GPS unit 1 and 2, respectively, when compared with the criterion measure.

There was a trending difference reported between actual TD (1,320 m) and GPSports 15 Hz unit 1 TD (1,301.8 ± 26.1, $p = 0.055$, $t = 2.20$), although no significant difference was reported between actual TD and GPSports 15 Hz unit 2 TD (1,306.1 ± 17.6 m, $p = 0.034$, $t = 2.49$). There was a significant difference between actual peak speed (24.05 ± 1.76 $\text{km}\cdot\text{h}^{-1}$) and GPSports 15 Hz unit 1 peak speed results (23.54 ± 2.06 $\text{km}\cdot\text{h}^{-1}$, $p = 0.009$, $t = 2.66$). In contrast, there was no significant difference between actual peak speed and GPSports 15 Hz unit 2 peak speed score (24.09 ± 1.51 $\text{km}\cdot\text{h}^{-1}$, $p = 0.76$, $t = -0.30$). These results were further confirmed by the Pearson Correlation scores for GPSports GPS unit 1 ($r = 0.64$) and unit 2 ($r = 0.76$).

Interunit Reliability

All interunit reliability results are reported in Tables 1 and 2 (10 Hz GPS units) and 2 (15 Hz GPS units). For the multitude of variables examined, the %TEM results revealed that the degree of GPS error for both the 10 Hz and 15 Hz units ranged from good to poor. It was apparent that as the speed of movement increased the level of GPS error for both the types of GPS units also increased. Overall, it was apparent that the 10 Hz GPS units displayed higher levels of interunit reliability for all movement demands examined when compared with the 15 Hz GPS units.

Comparison Between 10 Hz and 15 Hz Global Positioning System Units

The paired samples *t*-test results revealed that there were significant differences between the 10 Hz and 15 Hz GPS units for peak speed, distance covered VHSR, time spent LSR and VHSR, and number of efforts performed HSR and VHSR (Table 3). For all other variables, there were no significant differences reported between the 2 units.

Discussion

The aim of this study was to establish the validity and interunit reliability of 10 Hz Catapult and 15 Hz GPSports GPS units. This study demonstrated the criterion-referenced validity and the interunit reliability of 10 Hz GPS units, as measures of TD and the interunit reliability of these GPS units, for measuring the distance covered, time spent, and number of efforts performed LSR and HSR. In comparison, although the 15 Hz units were shown to be reliable for most movement demands, the validity of these units as measures of TD and peak speed was lower. Therefore, the hypotheses was accepted as both 10 Hz and 15 Hz GPS units were valid and reliable measure of TD and were more reliable measures of movement demands than 1 Hz and 5 Hz GPS units.

The comprehensive examination of TD in this study demonstrated that the 10 Hz GPS units provide a valid measure of TD (<1% error) despite tending to overestimate TD, which is in agreement with previous research (6). This, along with previous studies on 1 Hz and 5 Hz GPS units (<5% error) (7,12,22), establishes that GPS provides a valid measure of TD. In contrast, the results revealed that 10 Hz GPS units were not a valid measure of peak speed, a finding which is also supported by a recent study examining 5 Hz GPS units (28). However, these findings are in contrast to the majority of studies that have reported on the validity of 1 Hz and 5 Hz GPS units for measuring peak speed (<10% error, $p > 0.05$) (7,22,23). This may be a consequence of the use of timing lights to measure the criterion peak speed, as they only provide an average peak speed score. Further, this difference may be an outcome of the increased sampling rate improving the ability of GPS to measure a "true" peak speed. Additionally, the placement of the timing lights at 10-m intervals may also have impacted on the results. Therefore, the use of timing lights at 5-m intervals would potentially provide a more comprehensive speed profile of the participants.

The examination of the 15 Hz GPS units in this study revealed contrasting results between the 2 units when compared with the criterion measures of TD and peak speed scores. Therefore, it is difficult to definitively determine whether they provide valid measurements, especially, because there is no other research to compare these findings with. These results are interesting as previous examination of the 1 Hz and 5 Hz GPSports units revealed high levels of validity when measuring TD and peak speed (<10% error, $p > 0.05$) (7,23). The method used in the 15 Hz GPS units to enable the higher sampling rate as described by Aughey (2) may contribute to r the increased error of these GPS units as previous research has revealed low validity when using the accelerometer to assist in measuring speed and distance traveled (28). Consequently, further research is warranted to examine whether these units are valid and reliable measures of TD and peak speed and whether the increased sampling rate has had any beneficial impacts.

In comparison to the validity results, the interunit reliability findings revealed that both the 10 Hz and 15 Hz GPS units had good levels of repeatability when measuring TD (<1.9%). This is an improvement on the research examining 1 Hz and 5 Hz for TD (<7.2%) (7,22). When examining peak speed while the 10 Hz GPS (1.64%) units interunit reliability results were a clear improvement on previous findings examining both 1 Hz and 5 Hz units (2.3–7.2%) (4,7,22), this was not the case for the 15 Hz GPS units (8.1%). The ICC scores suggested a large amount of variation between the units, particularly for the 15 Hz GPS units. Consequently, some caution is required when comparing movement demands between the units. Nevertheless, these results demonstrate that when designing and planning training programs and recovery sessions, coaching and conditioning staff can more confidently depend uon the movement demand data recorded by 10 Hz and 15 Hz GPS units than 1 Hz or 5 Hz GPS units.

The interunit reliability results for the distance covered, time spent, and number of efforts performed LSR and HSR demonstrated that the level of error for both the 10 Hz and 15 Hz GPS units ranged from moderate to good (<10%). This was a substantial improvement on what has been reported for 1 Hz (<32.5%) (7) and 5 Hz units (<17%) for the same speed zones (22). A poor level of error was evident for the distance covered, time spent, and number of efforts performed VHSR (>10%), which was also reported for 1 Hz and 5 Hz units (7,20,22). Despite these %TEM results, the large ICC scores for these movement demands demonstrate the small amount of variation between the units. Therefore, in contrast to previous research (7,22), these findings mean that depending on the movement demands being examined, it may not always be necessary to monitor a player with the same device. Interestingly, the 10 Hz GPS units displayed lower levels of error (<14%) and stronger ICC scores (>0.8) for all movement demands examined when compared with the 15 Hz GPS units (%TEM ≤20%, ICC ≥0.75). This further questions the benefits of an increase in sampling rate to 15 Hz on the interunit reliability of GPS and the technique used to increase the sampling rate of these units from 10 Hz to 15 Hz. Similarly, these results suggest that the examined 10 Hz GPS units provide a more reliable measure of movement demands than the examined 15 Hz GPS units. This is important information for practitioners, coaches, and conditioning staff who wish to monitor athletes.

When comparing the between unit reliability of the 10 Hz GPS units and 15 Hz GPS units, significant differences were evident for a number of variables. Specifically, differences were found between the units for peak speed, the distance covered VHSR, time spent LSR and VHSR, and the number of efforts performed HSR and VHSR. Consequently, it is not methodologically sound to make comparisons between the movement demand data collected by 10 Hz Catapult and 15 Hz GPSports units. The differences between the units consistently occurred at the higher speed zones. This confirms the reduced levels of interunit reliability of both the types of GPS units at speeds >20 $km \cdot h^{-1}$, as reported previously for 5 Hz GPS units (20,22,23). Therefore, caution is required when analyzing movement demand data at these speeds.

A limitation of this study was the use of a circuit to provide movement demand data, as some of the reported error may have been because of participants not correctly following the course (7). A limitation of this study was that different software programs were used to collect and analyze the GPS data collected by the alternative brands of GPS units. This may have influenced the movement demand data reported and consequently affected the validity and interunit reliability of these GPS units.

This study has demonstrated the improved ability of the 10 Hz Catapult GPS units to measures team sport movement demands when compared with 1 Hz and 5 Hz units. However, this finding was not as apparent with 15 Hz GPSports units, although these units were still shown to be capable of measuring certain movement demands. This information is important as it demonstrates that the 10 Hz GPS units provide more valid and reliable feedback on training and match movement demands to coaches and conditioning staff. However, it is apparent that some limitations still remain with both 10 Hz and 15 Hz GPS, especially regarding recording movement demands performed at speeds > 20 $km \cdot h^{-1}$, regardless of the sampling rate. Further, it is apparent that comparisons should not be made between data collected by 10 Hz and 15 Hz units, especially data recorded at higher speeds. In conclusion, the results of this study demonstrate that the 10 Hz Catapult units have higher levels of validity and interunit reliability for team sport movement demands when compared with 15 Hz GPS units.

Practical Applications

The increased sampling rate and updates in firmware data from 1 Hz and 5 Hz to 10 Hz GPS units have improved the validity and interunit reliability of GPS units. Therefore, it is recommended that sporting teams use these GPS units as coaches and conditioning staff can more confidently depend on the data provided when analyzing and designing training programs, recovery sessions, and matches. It is recommended that practitioners do not make comparisons between movement demand data collected by 10 Hz MinimaxX GPS units and 15 Hz GPSports GPS units. Currently, the 10 Hz MinimaxX GPS units seem to be a superior measure of athlete movement demands than 15 Hz GPS units, however, it is still evident that 10 Hz and 15 Hz GPS units are incapable of reliably measuring movement demands performed $>20\ km\cdot h^{-1}$. Accordingly, coaches and conditioning staff should use caution when analyzing movements performed at these speeds.

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