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The Accuracy of the Titan 1+ 10 Hz Global Positioning System for Measures of Time, Distance, and Top Speed

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ABSTRACT

Introduction: Global Positioning System (GPS) technology provide quantifiable data concerning the number and types of movements athletes complete across training session and match player. The Titan 1+ is a novel GPS device that has not been investigated to establish measures of accuracy. The purpose of this study was to establish device accuracy for metrics including distance, top speed, and time between the Titan 1+ 10 Hz GPS device and criterion measures. Criterion measures include tape measure, stopwatch, and radar gun for measures of distance, time, and top speed, respectively.
Methods and Materials: 16 male NCAA collegiate soccer players completed running protocols of varying distances and speeds, including long and short duration straight-line running (100m Run and SLR), tight and gradual change of direction running (COD T and COD G), and a team-sport simulated circuit.
Results: The Titan 1+ was not significantly different from tape measured distance during the SLR protocol for 10m jog and all movements speed across 20m and 40m ($p < .05$). The Titan 1+ was significantly correlated to radar gun top speed measures for all distances and movement speeds during the SLR ($p < .01$). The Titan 1+ was significantly different from the stopwatch for measures of time accuracy ($p < .0001$), however significant correlations were identified for all jogging distances ($p < .01$), the 20m and 40m strides ($p < .01$), and the 10m sprint ($p < .01$). COD G and COD T distances were accurately measured between the Titan 1+ and tape measure ($p < .05$). The Titan 1+ revealed correlations for time measures during jogging and striding during the COD G ($p = .001$ and $p < .0001$) and during the COD T ($p < .0001$ and $p < .0001$). Device accuracy was established for measure of time during the TSSC ($p < .05$), with time measures significantly correlated between the Titan 1+ and stopwatch ($p < .01$). Top speed for the TSSC was significantly different between the radar gun and Titan 1+ device ($p = .001$), but both devices were significantly correlated ($p < .01$).
Conclusions: The results of the present study indicate that the Titan 1+ demonstrates accurate measures of time, distance, and top speed when compared to criterion measures.

Keywords: Global Positioning Systems; GPS; Titan Sensor; Accuracy; Validity; Catapult; Time: Distance; Top Speed; Speed Zone

INTRODUCTION

The validity of a tool involves the extent to which the instrument measures what it is intended to measure. Portney[1] states that validity places an emphasis on the objectives of a test and the ability to make inferences from test scores or measurements. This is vitally important, as all facets of GPS technology rely on the precise measurements provided by the device and software.[2] Validity of GPS technology implies that the data is relatively free from error. Data concerning player distance, top speed, and velocity is essential in establishing appropriate conditioning and training programs for athletes that mirror demands observed during match-play. Accurate reporting of velocities by GPS devices can help construct the activity profile of the athlete and provide information of the relative amount of high-intensity work they experience during a match.[2] Furthermore, accurate baseline movement data could serve as return to play criteria when initiating return to play protocols.[3]

The literature pertaining to validity of 10 Hz GPS devices for measures of distance is widely positive. When quantifying distance validity in running courses involving changes of direction, 10 Hz GPS devices do appear to provide accurate measures.[2] During straight-line running, 10 Hz GPS devices have also revealed accurate measures of distance.[4-6] Castellano et al6 reported acceptable distance measures for sprints at 15m (SEM = 10.9%) and 30m (SEM = 5.1%), similar to distance measures observed during cricket bowling and fielding protocols.[5] Additionally, Rampinini et al[7]reported good accuracy during intermittent shuttle running over moderate distances (70 m; CV = 1.9%), measures of total distance (CV = 1.9%) and high-speed running distance (CV = 4.7%). However, distance measures accuracy decreased from good to poor during very high-speed running (CV = 10.5%).[7] Interestingly, Nikolaidis and colleagues[8] also reported a statistical difference between GPS recorded distance and the known distance during slower speed 20 m shuttle running (8.0 – 9.0 $km \cdot h^{-1}$), and reporting that when running speed increased (9.5 – 11.5 $km \cdot h^{-1}$) no statistical differences were recorded. The authors[8] attributed these findings to human behavior, and not technological limitations, as participants may have performed excess movements during early changes of direction but as the shuttle run increased in difficulty they were cautious to avoid unnecessary energy expenditure.

During team-sport simulated circuits, measures of distance covered by 10 Hz GPS devices and criterion measures are conflicting. Both Johnston et al[9] and Willmott et al[4] reported no significant differences during these protocols. However, Willmott et al[4] reported a different between mean lap distance during the team sport simulated circuit and the 10 Hz GPS device ($p < 0.001$). While Hoppe et al[10] reported good to poor validity (typical error of estimate [TEE]: 3.0-12.9%; %CV 2.5% – 13.0%). However, the authors[10] reported that there was a considerable amount of noise during standing, resulting in a false accumulation of distance covered which could have likely impacted the data. Thus, the available evidence suggests that 10 Hz GPS devices should accurately measure distance when compared to criterion measures.[4-9]Further, compared to 1 Hz and 5 Hz GPS devices, the higher sampling rate of a 10 Hz device allows for more accurate distance measures, as it records data samples more frequently.[8]

Scott and colleagues[2] posited that the available literature suggests that 10 Hz GPS devices may have overcome problems and limitations in interpreting measures of instantaneous velocities observed in 1 Hz and 5 Hz GPS devices. The authors found that 10 Hz GPS devices appear to have good to moderate validity for measures of instantaneous velocities during constant velocity running and running involving accelerations, regardless of initial velocity.[2] Further, as the initial velocity increases, the validity of instantaneous velocities measures improves for 10 Hz devices.

Akenhead et al[11] reported that the validity the 10 Hz GPS device appeared to be acceleration-dependent, where a greater acceleration reduced the validity of the velocity measurement. The authors found that small systematic overestimations of instantaneous velocity during low accelerations were translated to underestimates during higher accelerations.[11] Similarly, Bataller-Cervero et al[12] reported that the 10 Hz GPS device underestimated instantaneous speed when compared to radar gun and overestimated speed in comparison to timing gates, despite nearly perfect correlations. Further, Vickery et al[5] reported that the 10 Hz GPS devices under-reported measures of both mean and peak speed across some field-based team-sport running drills. Importantly, Bataller-Cervero et al.[12] identified that inaccuracies in distance measures could interfere with mean speed measures, as observed by Beato et al.[13]

The available literature suggests that 10 Hz GPS devices may overestimate athlete peak speed during team sport matches, giving false information on max speed reached during individual efforts.[2] The difficulty in estimating peak and mean speed could likely be a measurement issue derived from the inability to perfectly quantify distance,[12]specifically during movements of short duration and high-intensity.[11] Additionally, 10 Hz GPS devices may also suffer from limitations in measuring mean and peak speed during team sport running and running involving frequent change of direction, as the devices may not estimate instantaneous velocity during very-high accelerations (> 4 m·s^{-2}).[2] This limitation, similar to that observed in 1 Hz and 5 Hz GPS devices, could be attributed to sampling rate.

As satellite signals are an integral factor in the functionality and use of GPS devices, many technical limitations associate with GPS devices involve satellite signals. The most substantial and impactful limitation is measurement error due to satellite obstruction. Atmospheric and local environmental objects, such as stadiums, buildings, and inclement weather, threaten the satellite signal reaching the GPS device.[14] Satellite signals can be interrupted by such conditions, resulting in an error in the distance from the satellite, consequently producing errors or missing data in speed and position measurements.[15] The inability to utilize GPS monitoring technology indoors is also a significant issue. Obstacles such as furniture, moving people, roofs, floors, and walls can cause degradations in satellite signals. These degradations lead to the decreased recording of signals, inability to detect multipath locomotion, and increased near-far effects where reception of a stronger signal makes it impossible to detect weaker signals. Further, the signal quality can be judged based on the number of satellites interacting with the receiver together with their orientation in the atmosphere.[14, 16]

The theoretical minimum for the number of satellites interacting with a GPS receiver is four. However, the higher the number of connected satellites, the more significant the coverage increase is for the device. Anecdotally, devices connected to less than six satellites tend to have a weaker connection and thus poorer data quality.[14] This is evident, as there is a moderate negative correlation between the total distance error recorded by a GPS receiver and the number of satellite signals.[14, 17] Therefore, as the number of satellite signals decreases, the error in measurements of velocity increases.[16] Further, the quantity of satellites interacting with a GPS receiver affects the quality of device measurements, but the location and distribution of satellite signals are also important factors. Currently, there are four constellations of satellites within the Global Position Navigation Systems (GNSS). These constellations include the European Galileo (22 operational satellites), Russian GLONASS (24 operational satellites), the US-American GPS (31 operational satellites), and the Chinese Beidou (33 operational satellites).[18]

The horizontal dilution of precision (HDOP) is the quantification of satellite distribution across the horizon.[2] The HDOP provides a measure of the accuracy of the GPS horizontal positional signal determined by the geometrical organization of the satellites.[14] The measurement of HDOP is inversely proportionate to the volume of the cone delineated by the satellite's position to the receiver.[2, 16] If the satellites are close together, the HDOP is high, and the precision is weak, whereas when the satellites are spread equally, the HDOP is low, and the accuracy is good.[14] Values of HDOP range from 0 to 50,[16] where a value of less than one being considered ideal.[14]

An HDOP value of 1 would represent the ideal distribution of satellites in the sky. In this instance, one satellite would be positioned directly above the receiver, with the remaining satellites equally distributed across the horizon (Figure 2).[19] If the HDOP value reaches 50, this will result in a situation where all the satellites are in a tight cluster directly above the receiver.[2, 16] Malone et al.[14] highlighted that while some researchers have detailed the average number of satellites or HDOP connected to the devices used during data collection, many have not provided these details, making study conclusions difficult to interpret. The authors further noted that all GPS devices could collect information on the number of satellites and HDOP. However, not all manufacturers make this data accessible for the user. They suggest that manufacturers make this information available to practitioners and researchers.[14]

The availability of information concerning data quality and HDOP values is essential for coaches, training staff, and researchers to tailor practice sessions confidently. The number of satellites and the HDOP values provide confidence in the data and allow users to identify and exclude data that may fall outside acceptable ranges. In addition to inspecting data based on the previous quality factors, GPS users should also inspect data for irregularities produced by the device itself. These irregularities may occur if there is a sudden loss in satellite signal connection. A loss of satellite signal can lead to delayed detection of locomotion, thus producing inaccurate data.[14] Other data irregularities may occur if there is a high-speed deviation in GPS device movement between captured data samples.

The present study aims to establish device accuracy for measures of time, distance, and top speed through a robust battery of field-based tests, including short and long-distance straight-line movements, movements involving changes of direction, and a team-sport simulated circuit. The establishment of device accuracy will not only add to the available body of literature surrounding GPS technology, but will provide insight on the validity of a cost-effective GPS device.

METHODS

Experimental Approach to the Problem

The Titan 1+ is a novel device that samples data at 10 Hz with triple a Global Navigation Satellite System (GNSS), including GPS, GLONASS, and Gaelileo capabilities.[20] To determine the accuracy of the Titan 1+ for measures of distance, time, and top speed, participants completed five running tasks designed to mimic athletic demands of field-based sports. Accuracy was established through comparison of device measurements of total distance, time, and top speed with criterion measures of a calibrated tape measure,[21] radar gun,[22] and stopwatch.[23] Speed during all trials of the straight-line running protocol and the initial sprint of the team-sport simulated circuit was evaluated via radar gun (Stalker ATS II). The radar gun was situated 5 meters behind the start line, aligning the radar gun to 1 meter high on a tripod.[24] Haugen and Buchheit[22] reported a near-perfect correlation between speed recorded with a Stalker ATS radar device and photocells. Regarding test-retest reliability, the authors reported ICC values ranged between 0.96-0.99, TE of 0.05 $m \cdot s^{-1}$, and CV between 0.7-1.9%.[22]

Subjects

Participants included 16 male, men's NCAA Division I soccer players from a university in southeast Texas (age: 20 ± 1.3 years, height: 175.73 ± 5.9 cm, mass: 71.55 ± 7.83 kg). During the study, 3 participants were removed, 2 participants sustained an injury and one tested positive for covid-19. A total of 20 Titan 1+ devices were used to gather data during this study. Devices that were assigned to participants who did not finish the study were assigned to other participants. Participants wore the same devices throughout the testing process.

All data was de-identified for the protection of study participants. Study design and methods were approval through the Institutional Review Boards at Houston Baptist University and Rocky Mountain University of Health Professions. Participants were required to sign an informed consent form following a complete explanation of all study procedures. Participants were given an additional copy of the informed consent and study procedures of personal record.

Procedures

All data were collected on a natural grass surface at a university in southeast Texas. Data collection sessions occurred at 7:00 AM CST over the course of 10 total, non-consecutive days during September and October 2020.

Prior to data collection, all GPS devices were turned on and set in an unobstructed area to allow for adequate acquisition of satellite signals.[4, 5, 21, 25] Devices were inserted into pockets on a customized garment at the start of each data collection session. GPS device pockets were aligned along the midline of the back between the scapulae, spaced approximately 3cm apart.[4] Previous studies,[4, 9, 24, 26] have used similar methods for wearing multiple devices; none referenced any technological deficiencies regarding proximity of devices. Daily satellite acquisition data was provided by Titan Sensors after all data collection was completed.

Running Protocols

Running protocols included in this study were designed to replicate movements demands observed in field-based sports, including straight-line jogging, striding, and sprinting, changes of direction. This study also includes a 140m circuit composed of a variety of movements and movement speeds,[4, 27-29] as well as a longer duration, fast paced sustained run of 100m. Course distances were measured with tape measure, marked with cones (height = 11cm), and turns were measured by goniometer.[27]

100m Run. Participants completed three 100m runs at a self-selected fast but comfortable pace (Figure 1). Between bouts, participants would turn around and were given 30 seconds of quiet stationary rest. After the rest period, participants were verbally cued to begin the next trial, where they would return toward the original start position. After the final bout, participants were instructed to rest quietly for an additional 30 seconds, before walking back toward the start where they would be relieved of their GPS

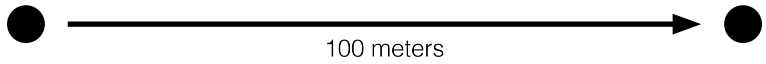

Figure 1. 100m Run Protocol

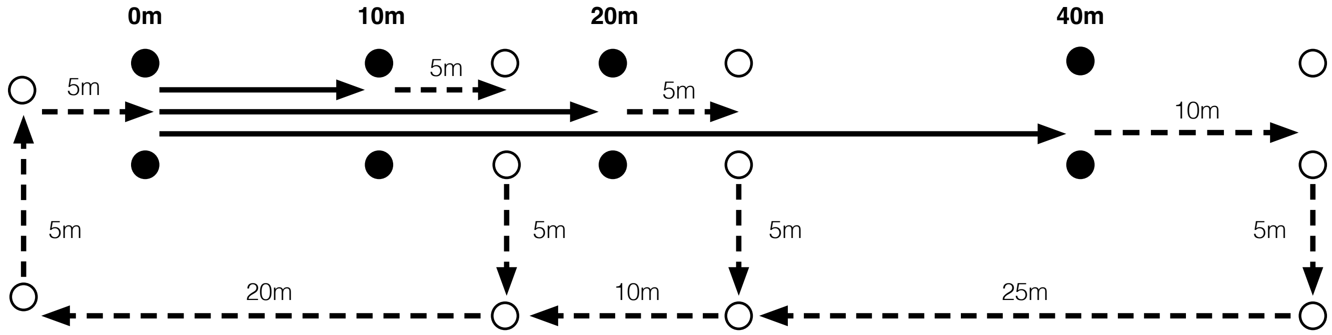

Figure 2. Straight-Line Running Protocol[4]

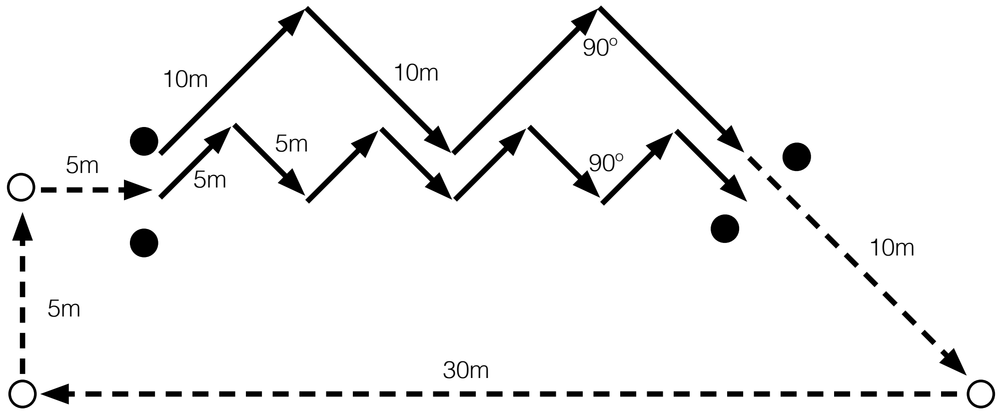

Figure 3. Change of Direction - Gradual and Tight Protocols[4]

devices.

Straight-Line Running. Participants self-selected speeds of jogging, striding, and sprinting to cover distances of 10, 20, and 40m (Figure 2). Three trials of each speed and each distance were completed in consecutive order. Therefore, participants would complete three 10m jogs before completing three 20m jogs.[4] Participants would rest stationary at the start line for 15 seconds before beginning a new trial.[30]

Change of Direction Running. Two change of direction (COD) courses were completed during this study. Both courses measured 40m in total distance and participants complete three trials of each self-selected jogging, striding, and sprinting speed per course. The gradual change of direction course (COD G) involved covering 40m that was interrupted by three 90° turns. The tight change of direction course (COD T) involved covering 40m containing seven 90° turns (Figure 3).[4, 27, 29] Participants would rest at the start line for 15 seconds between trials.[30]

Team-Sport Simulated Circuit. The team-sport simulated circuit (TSSC) is a 140m circuit involving two maximal sprints, a period of COD, three instances of walking, three jogs, one striding effort, and deceleration to complete stop (Figure 4).[4, 27] Before beginning the circuit, participants were guided through the course by the primary investigator and given the opportunity to familiarize themselves with the course. Following adequate familiarization, participants would begin the course. Participants were instructed to complete each lap of the circuit in one minute,[27] and were given 15 to 30 seconds of stationary rest at the start line between trials.[28]

STATISTICAL ANALYSIS

All statistical analyses were performed using Statistical Package for the Social Sciences (SPSS, Version 27.0.1.0). The validity of the Titan 1+ 10 Hz GPS devices was tested against criterion measures for distance, time, and speed. Statistical significance was set at $p < 0.05$. Data are presented as mean ± SD.

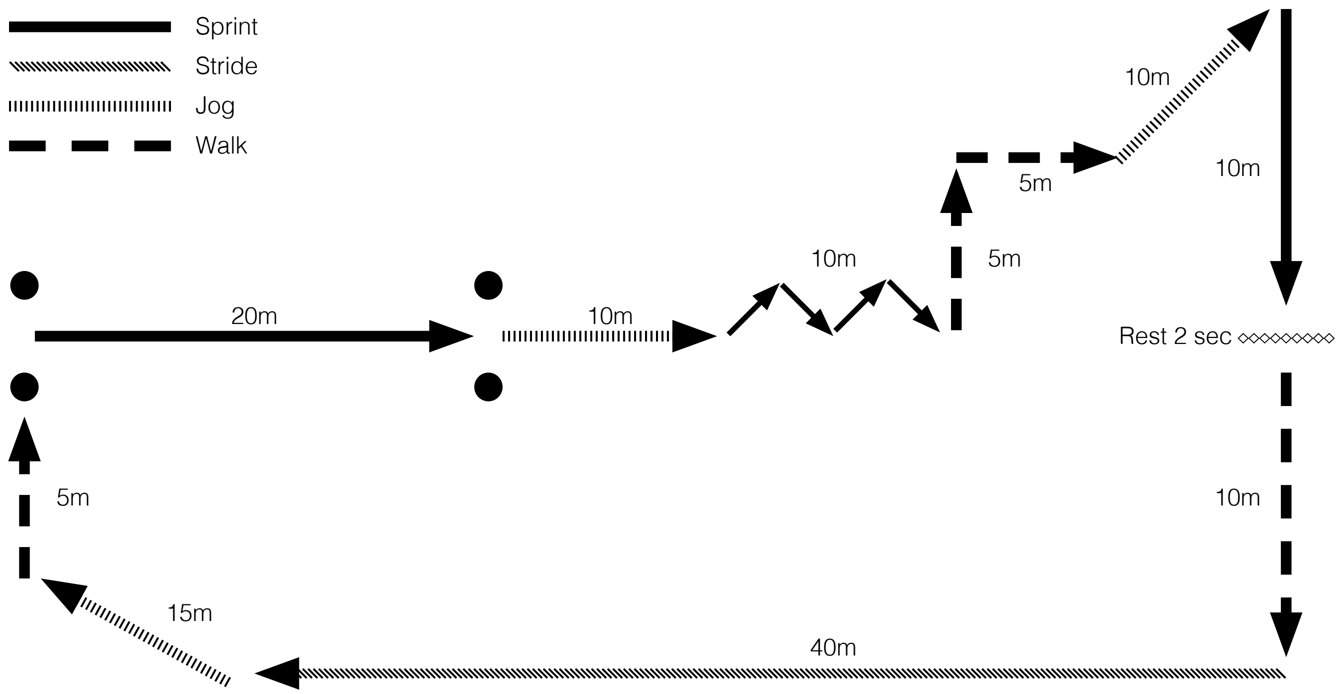

Figure 4. Team-Sport Simulated Circuit Protocol[27]

A paired-samples t-test was used to compare differences in criterion measures of distance, time, and top speed with measures by the Titan 1+ devices. The magnitude in differences was interpreted by using Cohen's *d* effect sizes.[31, 32] The strength of the relationship between criterion measures and the Titan 1+ devices were analyzed using a Pearson correlation score,[9] and the %CV.[4] The reliability of the relationships was analyzed using the SEM.[1]

RESULTS

Satellite Data and Environmental Conditions

Daily satellite acquisition for the Titan 1+ 10 Hz GPS devices for all trials ranged from 16 to 22 satellites with a mean of 19 ± 2.16 satellites. This availability is significantly greater than previously reported satellite acquisition, where the average number of satellites ranged from 6 to 14.[9, 17, 24, 25, 27, 33] Environmental conditions ranged from fair to partly cloudy, with temperatures ranging from 62-72°F (provided by the National Weather Service Forecast Office). HDOP data was not provided by Titan Sensors, nor was it available via the Titan 1+ software online dashboard.

Distance

A significant difference was found between the Titan 1+ devices and distance measures via tape measure for the 100m Run trials (*p* = .033, Table 1). The Titan 1+ devices underestimated distance (99.33 ± 1.3m) compared to criterion measures (100m) with a mean difference of -.67m (95% CI -1.3; -.6). The Titan 1+ displayed a good %CV of 1.3% for the 100m run distance measures.

Significant differences were found between the Titan 1+ devices and distance measure criterion via tape measure for the SLR trials for the 10m stride (*p* = .036) and 10m sprint (*p* = .032). The Titan 1+ devices overestimated distances during the 10m stride and sprint (10.4 ± .82 and 10.6 ± 1.16, respectively). Good to moderate %CVs were found for all measures of distance (3.4% - 7.9%), except for 10m sprint and 20m jog (10.9% and 11.5%, respectively).

No significant differences were found between the Titan 1+ devices and tape measure for the COD G running trials. Good %CVs were found for the Titan 1+ devices for all running speeds through the COD G trials (2.6% – 3.6%). During the COD T, no significant differences were found between the Titan 1+ devices and tape measured distances for all movement speeds. Good %CVs were found for the Titan 1+ devices (1.9% - 3.9%).

A significant difference was found between the Titan 1+ devices and the tape measure for TSSC lap distance (*p* = .030). The Titan 1+ devices reported a minimally larger lap distance than the criterion measures (140.98 ± 1.86m vs. 140m) with a mean difference of .978m (95% CI .106; 1.85). A good %CV was found the Titan 1+ devices (1.3%).

Table 1. Titan 1+ and Tape Measure - Distance

	Titan 1+	Tape Measured Distance	*p*	*%CV*
100m Run	99.33 ± 1.3	100	.033	1.3
10m SLR				
Jog	10.12 ± .8		.484	7.9
Stride	10.4 ± .82	10.00	.036	7.9
Sprint	10.6 ± 1.16		.032	10.9
20m SLR				
Jog	19.13 ± 2.2		.094	11.5
Stride	19.99 ± 1.04	20.00	.969	5.2
Sprint	20.35 ± 1.55		.331	7.6
40m SLR				
Jog	39.6 ± 1.36		.203	3.4
Stride	39.83 ± 1.57	40.00	.643	3.9
Sprint	40.21 ± 1.82		.606	4.5
COD G				
Jog	39.89 ± 1.45		.740	3.6
Stride	40.1 ± 1.03	40.00	.787	2.6
Sprint	40.5 ± 1.24		.096	3.1
COD T				
Jog	39.74 ± 1.55		.479	3.9
Stride	39.70 ± .99	40.00	.199	2.5
Sprint	40.1 ± .80		.610	1.99
TSSC	140.98 ± 1.86	140.00	.030	1.3

Time

Significant differences were found for measures of time between the Titan 1+ 10 Hz GPS devices and stopwatch for all SLR trials ($p < .0001$, Table 2). The Titan 1+ devices overestimated time for each running speed and distance compared to the stopwatch. Pearson's *r* correlations revealed significant relationships between the Titan 1+ 10 Hz GPS devices and the stopwatch for the 10m jog ($r = .76$, $p < 0.01$) and sprint ($r = .58$, $p <0.01$), 20m jog ($r = .79$, $p < 0.01$) and stride ($r = .838$, $p < 0.01$), and the 40m jog ($r = .95$, $p < 0.01$) and stride ($r = .73$, $p < 0.01$). Moderate %CV was found for the Titan 1+ devices for the 20m sprint (8.1%). Moderate %CV's were found for the stopwatch for the 10m sprint, 20m stride and sprint, and the 40m stride and sprint (6.5% - 9.5%).

Significant differences for the COD G time measures were found between the Titan 1+ and stopwatch ($p <.001$). The Titan 1+ devices overestimated time for all movement speeds during the COD G compared to the stopwatch. Pearson's *r* correlations revealed significant relationships between the Titan 1+ devices and stopwatch measured time for jogging ($r = .69$, $p = 0.001$) and striding ($r = .79$, $p < .0001$). Moderate %CVs were found for striding for both the Titan 1+ devices (7.8%) and stopwatch (6.2%), and a good %CV for the stopwatch (4.3%) during sprinting.

Significant differences were found for measures of time between the Titan 1+ devices and stopwatch across all movement speeds ($p < .0001$). The Titan 1+ devices overestimated time for all movement speeds during the COD T compared to the stopwatch. Pearson's r correlations revealed significant relationships in time measures between the Titan and stopwatch for movements speeds of jogging ($r = .939$, $p < .0001$) and sprinting ($r = .732$, $p <.0001$). Moderate %CVs were found for measures of times for striding and sprinting for the Titan 1+ devices (5.5% and 8.5%, respectively) and stopwatch (6.8% - 7.1%, respectively).

No significant difference was found between the Titan 1+ devices and stopwatch for TSSC lap time ($p = .66$). Pearson's r correlation revealed a significant relationship between the Titan 1+ devices and

Table 2. Titan 1+ and Stopwatch – Time

	Titan 1+	%CV	Stopwatch	%CV	*p*	*r*
10mSLR						
Jog	4.37 ± 1.14	26.0	3.49 ± .67	19.2	<.0001	.755**
Stride	3.52 ± .65	18.5	2.56 ± .33	12.9	<.0001	.422
Sprint	3.33 ± .64	19.2	2.04 ± .18	8.8	<.0001	.581**
20mSLR						
Jog	7.68 ± 1.47	19.1	6.46 ± 1.08	16.7	<.0001	.796**
Stride	5.63 ± .63	11.2	4.3 ± .41	9.5	<.0001	.838**
Sprint	4.58 ± .37	8.1	3.39 ± .25	7.4	<.0001	.388
40mSLR						
Jog	14.76 ± 3.07	20.8	11.96 ± 1.9	15.9	<.0001	.945**
Stride	9.66 ± 1.08	11.2	7.92 ± .75	9.5	<.0001	.732**
Sprint	6.8 ± .95	13.9	5.80 ± .377	6.5	<.0001	.351
COD G						
Jog	17.13 ± 2.96	17.2	15.1 ± 1.79	11.8	.001	.689**
Stride	12.59 ± .98	7.8	10.92 ± .68	6.2	<.0001	.795**
Sprint	10.35 ± 1.22	11.8	9.09 ± .39	4.3	<.0001	.300
COD T						
Jog	20.93 ± 2.9	13.9	17.21 ± 2.15	12.5	<.0001	.939**
Stride	16.04 ± .89	5.5	13.17 ± .90	6.8	<.0001	.722**
Sprint	13.37 ± 1.13	8.5	11.21 ± .79	7.1	<.0001	.382
TSSC	57.58 ± 3.39	5.9	57.20 ± 4.55	7.9	.656	.601**

**p <.05, **p <.01*

Table 3. Titan 1+ and Radar Gun – Top Speed

	Titan 1+	%CV	Radar Gun	%CV	*p*	*r*
10mSLR						
Jog	3.2 ± .51	15.9	3.3 ± .69	20.9	.415	.770**
Stride	4.34 ± .46	10.6	4.75 ± .78	16.4	<.0001	.904**
Sprint	5.64 ± .52	9.2	6.44 ± .75	11.6	<.0001	.849**
20mSLR						
Jog	3.6 ± .67	18.6	3.7 ± .79	20.5	.417	.858**
Stride	5.35 ± .51	9.5	5.53 ± .76	13.7	.019	.949**
Sprint	6.93 ± .57	8.2	7.62 ± .92	12.1	<.0001	.819**
40mSLR						
Jog	3.9 ± .69	17.7	3.7 ± .73	19.7	<.0001	.984**
Stride	5.83 ± .70	12.0	5.73 ± .50	8.7	.465	.527*
Sprint	8.2 ± .67	8.2	8.21 ± .76	9.3	.520	.871**
TSSC	6.64 ± .40	6.02	6.96 ± .58	8.3	.001	.788**

**p <.05, **p <.01*

stopwatch for TSSC lap time (r = .60, $p < 0.01$). Moderate %CVs were found for lap time for both the Titan 1+ devices (5.9%) and the stopwatch (7.9%).

Top Speed

Significant differences were found between the Titan 1+ devices and radar gun for top speed measures for the 10m and 20m stride and sprint and the 40m jog ($p < 0.05$, Table 3). The Titan 1+ devices reported lower top speeds for the 10m stride and sprint and the 20m sprint but a greater top speed during the 40m jog. Pearson's r correlation revealed significant relationships for top speed measures between the Titan 1+ devices and radar gun for all distances and running speeds ($p < 0.05$). The Titan 1+ devices had moderate %CVs for all sprints (8.2% - 9.2%) and the 20m stride (9.5%), while the radar gun had moderate %CV for the 40m stride and sprint (8.7% – 9.2%).

A significant difference was found between the Titan 1+ devices and radar gun to measure the top speed of the TSSC (p = .001). The Titan 1+ devices underestimated top speed compared to the radar gun with a mean of .315 ± .36 $m{\cdot}s^{-1}$. Pearson's r correlation revealed a significant relationship between the Titan 1+ devices and radar gun (r = .79, $p < 0.001$). Moderate %CVs were found for a top speed of the TSSC for both the Titan 1+ devices (6.0%) and radar gun (8.3%).

DISCUSSION

The purpose of this investigation was to determine the accuracy of the Titan 1+ 10 Hz GPS device for measures of time, distance, and top speed against criterion measures. The current study results reveal similarities in measurement between the Titan 1+ and criterion measures for distance, with good measurement accuracy and small mean differences between tools. The Titan 1+ consistently overestimated time during the SLR and COD running protocols than the stopwatch. However, mean differences trend smaller as movement speeds increase and change of direction moves from gradual to tight turns. Titan 1+ top speeds were similarly measured with radar gun speeds during straight-line running, with significant correlations across all bouts ($p < .01$). Overall, the Titan 1+ appears to measure time, distance, and top speed accurately compared to criterion measures.

Distance

The Titan 1+ devices measured distance similarly but significantly different than the known distance of the 100m run. However, the %CV was good (1.3%) for the Titan 1+, and the mean difference between the GPS device and tape measure was less than 1m (-.67m, 95%CI -1.3; -.6). These results suggest that significantly different distance measures between the Titan 1+ and the measured distance for the 100m run are trivial and therefore not clinically significant to the overall capability of the GPS device.

As movement speed increased across all SLR protocols, the distance measured by the Titan 1+ increased. However, significant differences were only found for 10m striding and sprinting, a predictable result given previously reported low accuracy measures of short duration, high-speed data produced by 10 Hz GPS devices.[11] Significant differences in high-speed 10m movements are further reflected in decreased measurement accuracy as speeds move from striding (7.9%) to sprinting (10.9%), suggesting that the Titan 1+ experiences increased measurement variability during high-speed short-duration movements. However, this is an expected measurement characteristic of a 10 Hz GPS device. During 20m SLR trials, the Titan 1+ underestimated distance while jogging with a high measurement error (11.5%). However, a minimal mean difference (< 1m) from the tape measured distance and lack of significant difference (p = .094) suggests that this underestimation is not a clinically significant finding and will not impact the overall effectiveness of the device. The Titan 1+ produced a low measurement error for all 40m movements speeds (3.4% - 4.5%). These findings indicate that the Titan 1+ device measures straight-line running distances with minimal measurement variability than the tape measure.

Similar to SLR protocols, Titan 1+ distance measures appeared to increase as movement speed increased during both COD protocols. However, the Titan 1+ produced minimally different mean distances with low measurement error. Measurement error decreased as movement speeds increased, indicating that the Titan 1+ provided distance measures with more accuracy as movement speeds increased. Further, moderate to high-speed COD T movements proved to be more accurate when compared to COD G striding and sprinting movements. The present study results indicate the Titan 1+ produces accurate distance measures for straight-line and change of directions movements, increasing accuracy as movement speed increases and direction changes become tighter.

While Titan 1+ distances measures for the TSSC were significantly different from the tape measured distance, the Titan 1+ measured distance within 1m of the known distance. The Titan 1+ consistently overestimated distance for each lap of the TSSC, except lap 3. This is a likely result considering TSSC movement distances were measured between cones marking the course, and participants moved around cones, which would lead to greater distance measures. Further, the mean difference between the Titan 1+ and the known distance was <1m. Therefore, a small mean difference paired with low measurement error (1.3%) indicates that the Titan 1+ will produce distance measures close with known distances during longer duration activities, including various movements. According to Scott et al.[2] measurement errors <10% can be considered acceptable for measurements during team sports. The authors highlight the ease of use of GPS technology in comparison to video-based time-motion, where real-time feedback is significantly delayed due to the time needed to analyze video data. Therefore, while small measurement errors in distance are observed with the Titan 1+, the ease of use is a much more palatable trade off when considering alternative motion analysis technology.[2]

The Titan 1+ provided accurate and similarly measured distances compared to the tape measure across all running protocols. Trivial significant differences were identified between the tools during short distance, moderate to high-speed straight-line running, and the longer duration TSSC. However, small mean differences between the Titan 1+ and tape measure during straight-line running indicate that while significant differences may be expected due to the 10 Hz sampling rate, they are likely not clinically significant. Additionally, a small mean difference between devices measuring <1m does not appear to negatively impact the accuracy of the Titan 1+, as measurement error was low (1.3%). Thus, the Titan 1+ can accurately measure distance during straight-line and change of direction movements of varying speed and longer duration activities that replicate field-based sport match-play.

Time

For time measures, the Titan 1+ and stopwatch followed similar trends as movement speed and distance increased. Across all SLR and COD protocols, the Titan 1+ overestimated time compared to the stopwatch. However, times were significantly correlated ($p < .01$), indicating that time measures were consistent between the Titan 1+ and stopwatch. The Titan 1+ overestimated time during the SLR protocols with similar mean differences for 10 and 20m jogging and striding movements. However, the mean difference for 10m striding to sprinting increased, while the 20m mean difference decreased from striding to sprinting. Compared to the stopwatch, the Titan 1+ overestimated time for jogging and striding during SLR and COD movements by ~1-3 seconds. Meanwhile, during the 40m SLR and both COD protocols, the mean difference between the two tools decreased as movement speeds increased, indicating that the Titan 1+ and stopwatch measure time with similarity during 40m straight-line and change of direction movements.

The Titan 1+ not only overestimated time compared to the stopwatch for all SLR and COD protocols, but the GPS device also produced consistently higher measurement errors. During SLR protocols, both tools were measured with increased variability for low-speed movements, regardless of distance. As movement speeds increased from jogging to striding, the Titan 1+ and stopwatch recorded improved measurement error. Measurement error steadily decreased for the stopwatch from striding to sprinting speeds, while the Titan 1+ displayed higher measurement error for 10 and 40m sprinting but lower for 20m sprinting (8.1%). The 20m sprint was the only protocol that produced an acceptable measurement error for the Titan 1+. At the same time, the stopwatch provided acceptable measures for all sprinting times and 20m and 40m strides.

Following a similar trend, measurement error for both tools across both COD protocols was highest during jogging movements. The Titan 1+ and stopwatch reported lower, acceptable measurement error during striding for COD protocols and sprinting during the COD T protocol. While measurement error only appears acceptable in a few SLR and COD protocols, the Titan 1+ and the stopwatch produced low measurement error during the TSSC. Interestingly, the Titan 1+ measured time very similarly with the stopwatch across all laps of the TSSC ($p < .01$), but stopwatch time appeared to hold more variability than the Titan 1+, suggesting that the Titan 1+ has good accuracy for timing team-sport activities.

The present study's findings suggest that while the Titan 1+ may have overestimated time than the stopwatch for all study protocols, measures were most accurate during moderate to high-speed movements and during a longer duration team-sport activity. Additionally, because mean time differences between devices were between ~1-4 seconds, an expected overestimation of time is likely not clinically important when evaluating longer activities. Therefore, the Titan 1+ is well equipped to measure time during one-minute exercises that replicate field-based team-sports activities. However, the Titan 1+ should not be used to measure time for individual short-duration movements, given the large variability in measurement accuracy. Additionally, caution should be taken when evaluating individual drills during team-sport training sessions, as overestimating time could affect the overall data. The primary investigator's opinion is that further research on time measures for field-based sport activities lasting multiple minutes instead of seconds should be pursued to evaluate best the impact of time measurement variability on the usefulness of Titan 1+ data.

Top Speed

The current study investigated top speed during the SLR and TSSC protocols. Previous research has shown that 10 Hz GPS devices have good to moderate validity for measures of instantaneous velocity during constant running and running involving accelerations compared to a radar gun.[11] As well as mean and peak speed during field-based running protocols compared to a 22 camera VICON motion analysis system.[5] Although not statistically significant, Vickery et al.[5] reported that a 10 Hz GPS device consistently under-reported mean and peak speed during sport-specific movements. Meanwhile, the present study results suggest that the Titan 1+ will consistently provide similar top speed measures to a radar gun.

The Titan 1+ and radar gun produced nearly identical top speed measures across the SLR protocols. All top speed measures were correlated between the Titan 1+ and the radar gun for all running protocols ($p < .01$). Significant differences were observed between the 10 and 20m stride and sprinting top speeds, as well as 40m jogging top speed. However, these differences are likely not clinically significant given the similarly measured mean top speeds and minimal mean differences (<1 $m{\cdot}s^{-1}$) during these trials. These results indicate that the Titan 1+ provides top speed measures comparable to the radar gun for straight-line running.

As speed increased across SLR protocols, the top speed measurement error decreased. However, the Titan 1+ only produced an acceptable measurement error for the 20m stride and sprinting top speeds. Meanwhile, the radar gun showed consistently higher measurement error values, with the only acceptable measurement error during 40m striding and sprinting. These results suggest that top speed measurement accuracy increases for the Titan 1+ as straight-line movement speeds increase, with less measurement variability than the radar gun.

During the TSSC, the Titan 1+ produced lower top speeds than the radar gun across all five laps. While significantly different, top speed was significantly correlated between the Titan 1+ and radar gun ($p < .01$), suggesting that a small mean difference (< .5 $m{\cdot}s^{-1}$) is consistent between the Titan 1+ and radar gun for the longer duration, field-based sports activity. Further, an acceptable measurement error (6.0%) indicates that the Titan 1+ can produce top speeds with low measurement variance. Therefore, while the Titan 1+ underestimates top speed compared to a radar gun, a mean difference of < .5 $m{\cdot}s^{-1}$ is not clinically significant and does not affect the overall usefulness of the device for top speed measures.

In summary, the present study results suggest that the Titan 1+ produces valid measures of time, distance, and top speed compared to criterion measures of the tape measure, stopwatch, and radar gun, respectively. Most notably, the Titan 1+ measured distance and top speed with the most accuracy compared to tape measured distance and radar gun top speeds. The Titan 1+ on average overestimated time during SLR and COD protocols compared to the stopwatch, with time measures becoming more similar between the tools as movement speeds increased. Time was most similar between the Titan 1+ and stopwatch during the TSSC, suggesting that the device is best designed to measure longer duration activities instead of short-duration linear movements. Therefore, the present study findings suggest the Titan 1+ is a valid device for measuring time, distance, and top speed. The Titan 1+ produced comparable and accurate data compared to criterion measures.

PRACTICAL APPLICATIONS

Through a robust battery of field-based tests, including short and long-distance movements, movements involving change of direction, and a team-sport simulated circuit, the present study results suggest that the Titan 1+ 10 Hz GPS device is accurate for commonly used measures of athlete movement. While significant differences were present among tests, differences held little clinical significance, as the magnitude of mean difference in many calculations was not large enough to pose a threat to the overall purpose of the device. Specifically, the Titan 1+ exceled in providing accurate time measures in the TSSC, suggesting that the device will provide accurate data during chaotic movements observed in team training and matches, compared to controlled straight-line testing. Similar to previous research,[8, 9, 11] the Titan 1+ lacks the capability of accurately assessing short duration, high intensity running. Therefore, caution should be used when evaluating these activities.

It is worthwhile to note that the Titan 1+ 10 Hz GPS device has the capabilities to connect to satellites within three constellations. While the HDOP data was not available for the purposes of this study, it is important to understand that these GPS devices have the ability to connect to a wide range of satellites that are scattered throughout the atmosphere, thus decreasing the HDOP and increasing the devices ability to accurately calculate the devices position on ground.

Overall, the Titan 1+ device showed clinically acceptable data for activities involving all aspects of field-based sports, such as moving at various speeds, changes of direction, and even stationary periods. Therefore, to quantify athlete movement and assess activity during field-based sports, the Titan 1+ 10 Hz GPS device is an acceptable tool.

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CONFLICTS OF INTEREST

There are no conflicting relationships or activities.

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