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The Concurrent Validity and Reliability of a Global Positioning System for Measuring Maximum Sprinting Speed and Split Times of Linear and Curvilinear Sprint Tests

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Abstract: This study investigated the reliability and validity of linear sprint tests (LS) and curvilinear sprint tests (CS) using a GPS device (GPEXE lt). Twenty-one (21) student athletes completed a 40 m LS as well as a left and right CS. Maximum sprint speed (MSS) and split times at short (0–10 m), intermediate (0–20 m), and long (0–30 m) distances were determined using the GPEXE lt and single-beam timing gates (TG). Intrasession reliability and concurrent validity of GPEXE lt were assessed. The GPEXE lt consistently showed high reliability for MSS (ICC $\geq$ 0.95; CV $\leq$ 1.8%), despite underestimation compared to TG (bias = −2.57 to −0.95%; ICC $\geq$ 0.87). Acceptable reliability was observed for CS and LS intermediate and long distance split times (ICC $\geq$ 0.91; CV $\leq$ 2.1%), with lower reliability for short distances (ICC $\geq$ 0.70; CV $\leq$ 3.6%). The GPEXE lt split times for CS and LS showed good agreement with TG (ICC $\geq$ 0.66), but were overestimated at long distances (5.5–9.7%) and short distances (11.1–14.6%). Although the MSS was found to be the most reliable and valid variable to assess LS and CS speed performance with GPEXE lt, caution is needed due to limited validity.

Keywords: curvilinear sprint; GPS; reliability; validity; maximal sprinting speed; split times

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1. Introduction

Due to the importance of sprinting speed for athletic performance [1], researchers and coaches are constantly looking for new, reliable, and valid tests and devices to assess performance in different types and phases of sprinting. Traditionally, linear sprints (LS) have been the standard for speed testing, but in team sports, such sprints are rarely performed due to the unpredictability of game situations [1]. In football, for example, sprint actions are predominantly performed in the form of curved sprints [2]. As the neuromuscular system must operate under specific biomechanical conditions [3], a curvilinear sprint test (CS) has been proposed to assess specific speed performance [4]. Irrespective of the type of sprint, early acceleration ability is typically assessed by analyzing shorter distances (e.g., 5 to 10 m), late acceleration by considering intermediate distances (e.g., 20 m), and maximum speed by covering longer distances (e.g., 30 to 40 m). Meanwhile, commonly used indicators of running speed performance include the time taken to cover a given distance (referred to as split times) or the maximum sprinting speed (MSS) achieved during the selected distance [5].

As an alternative to valid and reliable split times of electronic timing gates (TG) [5–7], Global Position System (GPS) devices have been employed for speed performance assessment in team sports [8,9]. These devices are more practical compared to TG, as GPS does not necessitate time-consuming setup and rigorous measurement protocols, which is particularly advantageous when measuring a large number of athletes regularly [10,11]. However, the validity of GPS for assessing sprint performance was initially questioned due to several factors [9,12], and recent studies show discrepancies in the validity and reliability of the most accurate 16–20 Hz GPS devices [9,13,14]. In particular, there is a lack of information on the validity and reliability of assessing speed performance using GPS when performing more complex types of sprints, such as the CS.

Considering that the use of GPS for the assessment of speed performance in team sports could simplify testing procedures, the main objective of our study was to examine the feasibility of a commercially available GPEXE lt for the assessment of split times (10, 20, and 30 m) and MSS in both LS and CS. The intrasession reliability and validity of split times and MSS measured with the GPEXE lt were calculated and compared to corrected values obtained with the single-beam TG. We hypothesized that the GPEXE lt would provide split times and MSS with acceptable-to-high reliability in CS and LS. Furthermore, we anticipated comparable validity for LS and CS, with more valid variables associated with longer distances [5,14].

2. Materials and Methods

2.1. Participants

A sample size power was calculated a priori. For a minimum acceptable intraclass correlation coefficient (ICC) of 0.7, an expected ICC of 0.9, a significance level of 0.05, a statistical power of 0.8, and 3 repetitions per participant, a total of 17 participants was required [15]. Purposefully, 21 student athletes participated in this study (14 males [age: 24.6 ± 4.5 years; height: 182.2 ± 4.5 cm; body mass: 79.5 ± 6.6 kg] and 7 females [age: 21.3 ± 1.7 years; height: 161.4 ± 3.8 cm; body mass: 56.3 ± 3.6 kg]). Participants did not report any chronic disease or a recent injury, and signed a written informed consent form before the beginning of the study. The study protocol adhered to the tenets of the Declaration of Helsinki, and was approved by the Medical Ethics Committee (approval number 0120-690/2017/8).

2.2. Design and Procedures

Single-visit cross-sectional experimental design was conducted. At testing session participants performed a 40 m linear sprint (LS) and left and right 40 m CS. Split times at short (0–10 m), intermediate (0–20 m), and long (0–30 m) distances, as well as MSS, were recorded simultaneously using the GPEXE lt, and 9 pairs of TG as the gold-standard criterion.

2.3. Measures

Testing was performed on an open-space artificial grass soccer field whilst wearing soccer shoes. After the standardized warm-up, which included running at moderate pace for 10 min, 5 strengthening exercises, 5 dynamic stretching exercises, and 3 submaximal sprints [16], 3 trials of 3 different types of sprints were performed in balanced and randomized order with 5 min rest between trials. Therefore, participants performed 12 sprints in total [17]. Sprint start was performed 0.5 m behind the first pair of TG. For CS, the circumference of the center circle of the soccer field, with a radius of 9.15 m, was used [4] (see Figure 1).

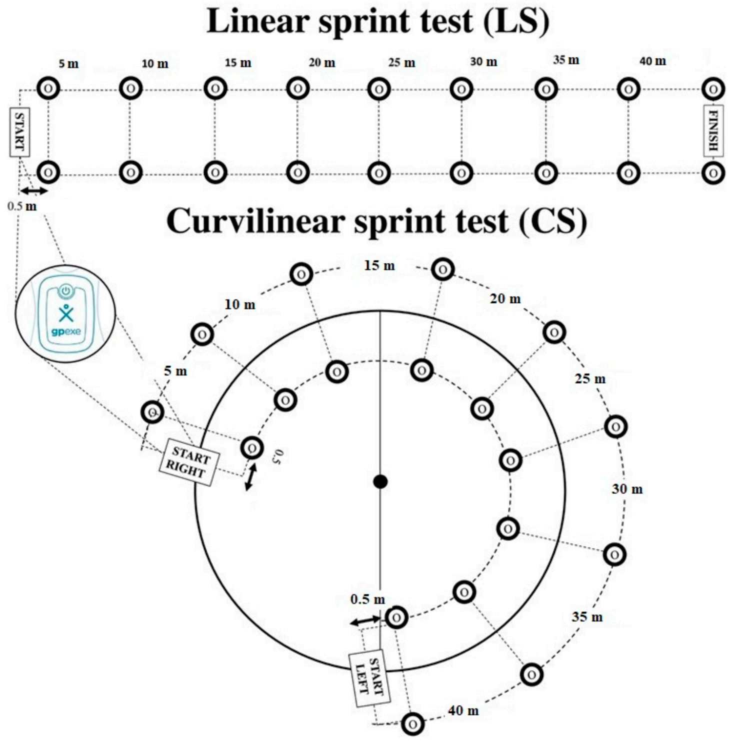

Figure 1. The setup for linear sprint test and curvilinear sprint test using the GPEXE lt and timing gates.

Single-beam TG (Brower Timing Systems, Utah, USA) were positioned at 5 m distances to capture split times at short ($t_{0–10}$), intermediate ($t_{0–20}$), and long ($t_{0–30}$), distances with an sampling frequency of 0.01 s [18]. The sensors were mounted at the hip height. Due to potential inconsistencies in sprint initiation with TG [19], corrected split times and the MSS during sprints were calculated in the R software (version 4.0.2, R Foundation for Statistical Computing, Vienna, Austria) using the package of Jovanović and Vescovi [20]. Utilizing 5 m split times for calculating MSS from the single-beam TG has been previously established to be highly reliable and valid [18]. For the validity analyses, the trial with the highest MSS recorded using TG in the first session was chosen, and the same trial was considered for the GPEXE lt.

The distance–speed–time signals of 40 m sprints were recorded by 18.18 Hz GPS (GPEXE lt System, Exelio SRL, Udine, Italy) and processed with the GPEXE web app (version 8.2.41, Exelio SRL, Udine, Italy). The devices were used as recommended by the manufacturer. The mean $\pm$ standard deviation (SD) number of satellites during the measurements was 9.20 $\pm$ 0.44. Given that each measurement constituted continuous data, a custom Python code (numpy, scipy, and pandas libraries) was employed to discern between sprint trials and determine the outcome variables. To synchronize TG and GPEXE lt, the initiation of the sprint start was defined at the point where the speed signal was three times greater than the SD of the signal at standstill. Additionally, the actual start was determined with a 0.5 m delay due to the preliminary start position behind the first TG. Subsequently, the $t_{0–10}$, $t_{0–20}$, $t_{0–30}$, and MSS of LS and CS were calculated from distance–speed–time signals. For the intrasession reliability analyses of the GPEXE lt, all trials were considered.

2.4. Statistical Analyses

Descriptive statistics are presented as means and SDs. Skewness and kurtosis were used to determine the normality of the distribution. The reliability of the GPEXE lt was evaluated through absolute measures, utilizing the coefficient of variation (CV; calculated as typical error [TE]/mean score $\times$ 100), and relative measures, using a two-way mixed

ICC for single measures with 95% confidence intervals. Based on predefined criteria, the reliability was considered acceptable (CV $\leq$ 10%; ICC $\geq$ 0.80) or high (CV $\leq$ 5%; ICC $\geq$ 0.90). Systematic and unsystematic biases were further explored through the ICC and the Bland–Altman plots with 95% limits of agreement (LoA). The magnitude of ES was interpreted following the recommendations of Hopkins et al. [21], while the magnitude of ICC was interpreted according to Koo and Li [22]. Data analyses were conducted using a Microsoft Excel spreadsheet (version 16.32, Microsoft Corp, Washington, WA, USA) [23] and SPSS version 25.0 (SPSS, Chicago, USA). Statistical significance was accepted at $p < 0.05$.

3. Results

All the variables from the first and second sessions were normally distributed (skewness < 1; kurtosis < 2). The descriptive statistics of GPEXE lt variables and the results of intrasession reliability can be found in Table 1.

Table 1. Descriptive statistics of GPEXE lt variables and intrasession reliability of the GPEXE lt for measuring linear and curvilinear short, intermediate, and long distance sprint times and maximum sprinting speed (MSS).

		Rep 1	Rep 2	Rep 3	Relative	Absolute
Sprint Type	**Variable**	**Mean (SD)**	**Mean (SD)**	**Mean (SD)**	**ICC (95% CI)**	**CV (95% CI)**
CSL	$t_{0–10}$ (s)	2.32 (0.16)	2.29 (0.14)	2.26 (0.11)	0.77 (0.57–0.89)	2.8 (2.3–3.8)
	$t_{0–20}$ (s)	3.92 (0.29)	3.87 (0.26)	3.87 (0.26)	0.93 (0.86–0.97)	1.8 (1.4–2.4)
	$t_{0–30}$ (s)	5.49 (0.41)	5.45 (0.36)	5.45 (0.37)	0.96 (0.91–0.98)	1.4 (1.3–1.9)
	MSS (m s^{-1})	6.61 (0.46)	6.53 (0.47)	6.46 (0.48)	0.96 (0.90–0.98)	1.5 (1.2–2.0)
CSR	$t_{0–10}$ (s)	2.28 (0.14)	2.3 (0.14)	2.29 (0.16)	0.79 (0.60–0.90)	2.9 (2.3–3.9)
	$t_{0–20}$ (s)	3.86 (0.25)	3.9 (0.27)	3.88 (0.27)	0.91 (0.81–0.96)	2.1 (1.7–2.8)
	$t_{0–30}$ (s)	5.45 (0.37)	5.49 (0.38)	5.48 (0.38)	0.94 (0.88–0.97)	1.8 (1.4–2.3)
	MSS (m s^{-1})	6.53 (0.48)	6.48 (0.48)	6.37 (0.48)	0.95 (0.89–0.98)	1.8 (1.5–2.4)
LS	$t_{0–10}$ (s)	2.22 (0.14)	2.26 (0.17)	2.23 (0.14)	0.70 (0.46–0.85)	3.6 (2.9–4.8)
	$t_{0–20}$ (s)	3.64 (0.26)	3.67 (0.28)	3.68 (0.26)	0.92 (0.83–0.96)	2.1 (1.7–2.8)
	$t_{0–30}$ (s)	4.98 (0.39)	4.99 (0.41)	5.01 (0.39)	0.96 (0.91–0.98)	1.6 (1.3–2.2)
	MSS (m s^{-1})	7.85 (0.81)	7.76 (0.79)	7.64 (0.79)	0.98 (0.95–0.99)	1.5 (1.2–1.9)

Note. $t_{0–10}$ = split time from 0 to 10 m, $t_{0–20}$ = split time from 0 to 20 m; $t_{0–30}$ = split time from 0 to 30 m; CV = coefficient of variation; ICC = intraclass correlation coefficient; 95% CI = 95% confidence interval; CSR = curvilinear sprint to the right; CSL = curvilinear sprint to the left; LS = linear sprint.

Notably, high relative and absolute intrasession reliability were observed for MSS and sprint split times at intermediate and long distances (ICC $\geq$ 0.91; CV $\leq$ 2.1%). In contrast, lower reliability was noted for short distances (ICC $\leq$ 0.79; CV $\geq$ 2.8%).

The validity results are presented in Table 2. Based on the split times and MSS, the GPEXE lt consistently underestimated CS and LS sprint speed performance. In both, CS and LS, the MSS was systematically underestimated (moderate to large ES; ICC $\geq$ 0.87), whereas the split times were overestimated (very large ES; ICC $\geq$ 0.66). The Bland–Altman plots with 95% LoA (Figures 2–4) further illustrate the agreement on an individual basis between GPEXE lt and TG. Notably, the highest agreement was observed for the MSS of LS and CS to the right (Figure 4), as well as the split times of LS (Figure 2).

Table 2. Concurrent validity of the GPEXE lt with respect to timing gates (TGs) for the measurement of linear and curvilinear short, intermediate, and long distance sprint times, and maximum sprinting speed (MSS).

Sprint Type	Variable	GPEXE lt Mean (SD)	TGs Mean (SD)	ICC (95 CI)	% Bias (SD)	*p*	ES	
CSL	$t_{0–10}$ (s)	2.26 (0.13)	1.99 (0.14)	0.66 (0.32–0.84)	13.10 (5.54)	<0.001	2.40	very large
	$t_{0–20}$ (s)	3.84 (0.24)	3.51 (0.25)	0.85 (0.67–0.93)	8.79 (3.71)	<0.001	2.47	very large
	$t_{0–30}$ (s)	5.40 (0.33)	5.01 (0.37)	0.98 (0.78–0.96)	7.65 (3.11)	<0.001	2.56	very large
	MSS (m s^{-1})	6.58 (0.43)	6.73 (0.60)	0.87 (0.70–0.94)	−2.19 (3.85)	0.015	−0.58	small
CSR	$t_{0–10}$ (s)	2.28 (0.15)	1.97 (0.14)	0.71 (0.41–0.87)	14.60 (5.33)	<0.001	2.78	very large
	$t_{0–20}$ (s)	3.86 (0.27)	3.51 (0.26)	0.89 (0.75–0.95)	9.73 (3.50)	<0.001	2.90	very large
	$t_{0–30}$ (s)	5.45 (0.38)	5.02 (0.39)	0.93 (0.83–0.97)	8.22 (2.89)	<0.001	3.00	very large
	MSS (m s^{-1})	6.50 (0.47)	6.68 (0.54)	0.96 (0.91–0.99)	−2.57 (2.09)	<0.001	−1.29	large
LS	$t_{0–10}$ (s)	2.21 (0.14)	1.98 (0.12)	0.70 (0.40–0.87)	11.10 (4.66)	<0.001	2.32	very large
	$t_{0–20}$ (s)	3.61 (0.24)	3.36 (0.21)	0.89 (0.75–0.95)	7.31 (2.96)	<0.001	2.42	very large
	$t_{0–30}$ (s)	4.93 (0.37)	4.66 (0.32)	0.94 (0.86–0.98)	5.52 (2.34)	<0.001	2.25	very large
	MSS (m s^{-1})	7.86 (0.74)	7.94 (0.79)	0.98 (0.94–0.99)	−0.95 (1.62)	0.015	−0.58	small

$t_{0–10}$ = split time from 0 to 10, $t_{0–20}$ = split time from 0 to 20; $t_{0–30}$ = split time from 0 to 30 m; 95% CI = 95% confidence interval; CSL = curvilinear sprint to the left; CSR = curvilinear sprint to the right; ES = Cohen's d effect size; LS = linear sprint; MSS = maximum sprinting speed.

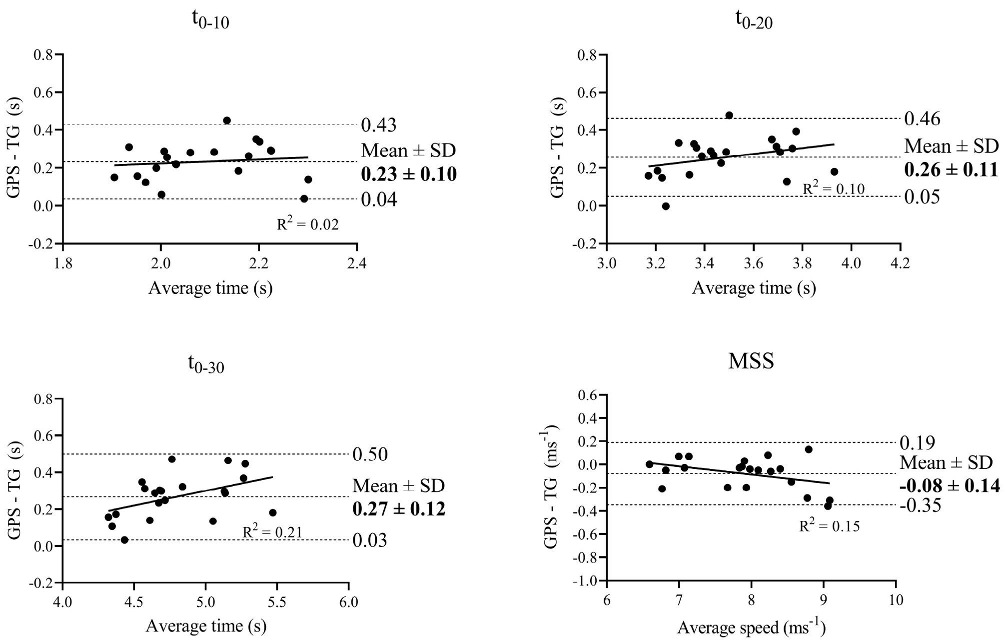

Figure 2. Bland–Altman plot showing differences between the GPEXE lt and timing gates in split times of short distance ($t_{0–10}$), intermediate distance ($t_{0–20}$), long distance ($t_{0–30}$), and maximum sprinting speed (MSS) for linear sprint. Each plot depicts absolute systematic bias, 95% limits of agreement (±1.96 standard deviation; dashed), and the regression line (solid). The strength of relationship (R^2) is also presented in each plot.

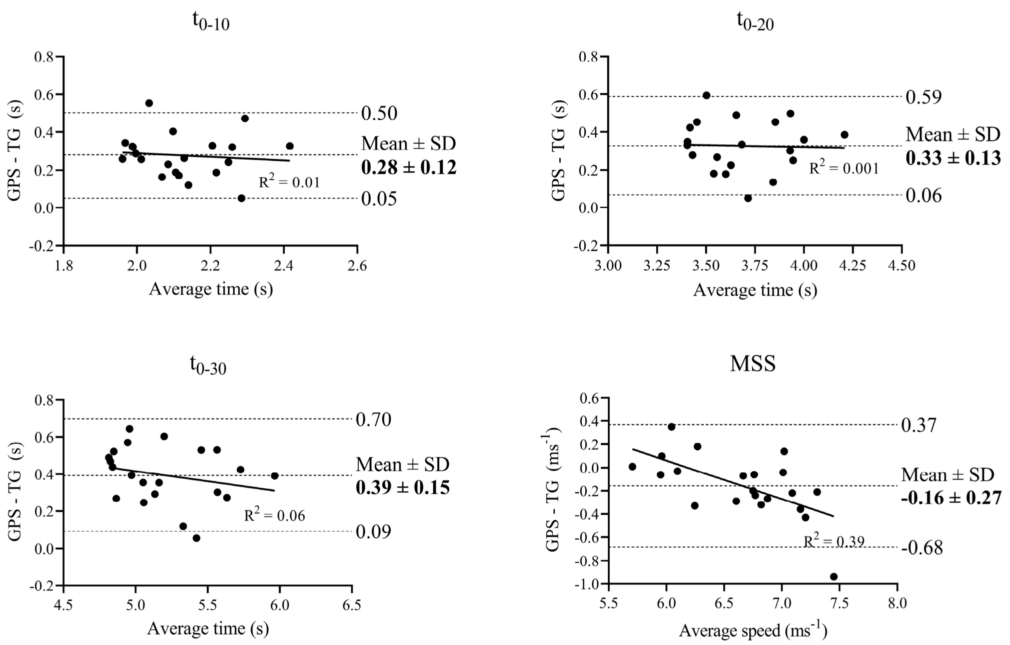

Figure 3. Bland–Altman plot showing differences between the GPEXE lt and timing gates in split times of short distance ($t_{0–10}$), intermediate distance ($t_{0–20}$), long distance ($t_{0–30}$), and maximum sprinting speed (MSS) for left curvilinear sprint. Each plot depicts absolute systematic bias, 95% limits of agreement (±1.96 standard deviation; dashed), and the regression line (solid). The strength of relationship (R^2) is also presented in each plot.

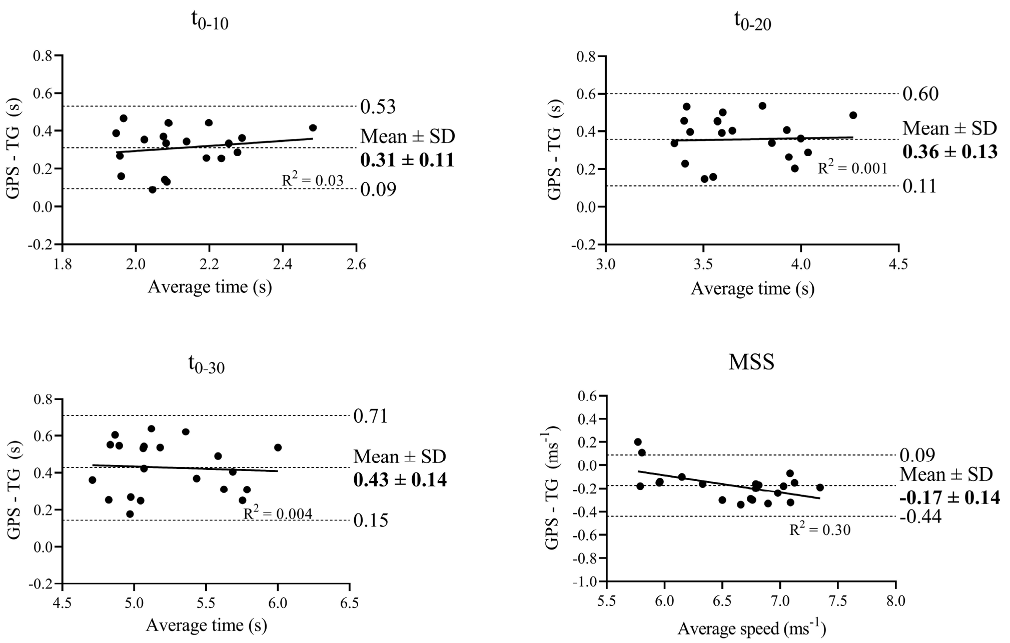

Figure 4. Bland–Altman plot showing differences between the GPEXE lt and timing gates in split times of short distance ($t_{0–10}$), intermediate distance ($t_{0–20}$), long distance ($t_{0–30}$), and maximum sprinting speed (MSS) for right curvilinear sprint. Each plot depicts absolute systematic bias, 95% limits of agreement (±1.96 standard deviation; dashed), and the regression line (solid). The strength of relationship (R^2) is also presented in each plot.

4. Discussion

This study aimed to investigate the reliability and validity of the CS and LS performance when used for measuring MSS and split times. We observed high intrasession reliability of GPEXE lt for assessing MSS and split times at intermediate and long distances, whereas lower reliability for split times at short distances was observed. The GPEXE lt systematically underestimated MSS and split times of CS and LS, and at the same time showed substantial agreement with TG. Such results are in line with previous indications about the GPS systems, and hold potential for application of the GPEXE lt in practice.

The previously established high intrasession reliability of the GPEXE lt for assessing LS MSS align with findings from prior studies [8]. However, its reliability for assessing MSS of CS has been relatively unexplored. The study that investigated intrasession reliability of 10 Hz GPS for measuring MSS during curvilinear sprints (9.15 m radius) reported comparable ICC (>0.92) to those in our study [24]. Thus, we can confirm good intrasession reliability of GPEXE lt for measuring MSS within a session.

In contrast, the reliability of GPEXE lt for measuring intermediate and longer distances split times was lower than for MSS. The observed CVs (95% CI upper limits $\leq$ 2.8%) and ICCs (95% CI lower limits $\geq$ 0.81) are comparable to highly reliable TG systems [25]. A preliminary study introducing a CS test has demonstrated an ICC ~ 0.90 and CV ~ 1% for the measurement of a 17 m split time using the TG [4]. This level of reliability closely aligns with the intrasession reliability of 20 m split times of CS to the left measured using GPEXE lt in our study (ICC = 0.93; CV = 1.8%). However, the GPEXE lt exhibited slightly poor reliability for measuring CS split times at a short distance. Because our results do not allow us to conclude if the lower reliability for assessment of 10 m split times was due to higher sprint acceleration at that particular distance [5], a low, 18 Hz, sampling frequency (random error of $\pm$0.055 s or 0.11 s in total), or other technical aspects of the device [9], future study should explore these factors.

Moreover, GPEXE lt demonstrated a substantial overestimation over TG when measuring CS and LS split times. This discrepancy may arise from split times being potentially obtained from a greater distance than actuality, as suggested by previous research [13], from differences in sprint start initiation between TG and GPEXE lt, or both. To address these issues, the models for correcting GPS-measured split times might be used. Employing these in further studies could enhance the usability of the device. Despite good overall agreement between GPEXE lt and TG, the Bland–Altman 95% LoA intervals were approximately 0.7 to 0.8 s for CS and 0.5 s for LS split times. These findings indicate that individual measurement error is considerably higher than previously measured training-induced changes in 10, 20, and 40 m split times observed in elite youth soccer players (i.e., 0.04, 0.2, and 0.3 s, respectively) [26,27]. Consequently, the practical implications of GPEXE lt for assessing split times in training and practice are limited, given the magnitude of individual measurement error relative to the expected changes in split times due to speed performance enhancement. This suggests a need for consideration of the device's limitations when utilizing it for the assessment of linear or curvilinear sprint timing in practical settings.

For measurement of CS and LS performance, the MSS seems to be more appropriate variable when utilizing the GPEXE lt. The high ICC between the criterion and the systematic underestimation of the MSS align with findings from previous studies that reported significant bias when using GPS devices for linear sprint MSS assessments [9,14,28]. However, the Bland–Altman graphs between GPS and TG during LS and CS revealed lower agreement at an individual level. Among all sprints, the 95% LoA intervals for CS to the right and LS were the smallest, ranging from 0.09 to -0.44 and 0.19 to -0.35 m$\cdot$s^{-1}, respectively. Previous studies that investigated the effects of sprint training on MSS found changes lower than 0.5 m$\cdot$s^{-1} to be significant [29]. However, when MSS during LS and CS is measured, the GPEXE LT might not be accurate enough to detect such changes.

Running fast over linear and curvilinear distances is particularly important in team-based sports such as football or rugby [2]. Because the sports are performed outdoors, GPS systems could be time-efficient tool for the assessment of athlete's speed performance in CS and LS. Overall, our study confirmed that the GPEXE lt is viable for the assessment of LS and CS test performances. We advise the use of MSS rather than the split times when assessing sprint performance with the two tests. However, the aforementioned limitations should be considered, especially in highly trained athletes where very small improvements in MSS are considered to be important [5].

This study had some limitations that should be acknowledged. First, the theoretical MSS of TG was used as a criterion. It is essential to note that the primary focus of this study was to evaluate sprint performance in CS, where TG represents the most common method for determining performance [4]. Additionally, the use of single-beam TG introduces the potential for measurement errors in split times [30]. To mitigate this, we rigorously standardized the protocol, visually anticipating TG initiation during sprint start by an experienced researcher, and used corrected split times and MSS [19]. Another consideration is the population sample, which comprised trained student athletes from various sport disciplines. Since the GPEXE lt usability and relevance to CS and LS performance primarily pertain to team sports like soccer, we acknowledge the potential benefit of repeating the study on elite soccer players. This approach would allow for the derivation of specific MDC values. At the same time, it is worth noting that our sample did include 12 amateur soccer players. Finally, we used automatically filtered GPEXE lt data, while previous studies have suggested that specific filters provide the most reliable results [11]. Our decision to use automatically filtered data were driven by the goal of aligning the results with the practices of practitioners who typically utilize preprocessed data directly from the GPEXE application. This pragmatic approach aimed to enhance the practical relevance and applicability of the study findings in real-world settings.

5. Conclusions

The findings suggest that the GPEXE lt could serve as a viable device for CS and LS performance assessment, particularly through the analysis of MSS rather than split times. Use of GPS for monitoring performance offers a less time-consuming alternative to TG, facilitating the testing of sport-specific speed performance across a substantial number of athletes regularly. However, coaches and scientists aiming to use the GPEXE lt for assessing LS or CS performance should be mindful that the device may be valid for determining only greater changes in in MSS and split times. This consideration is crucial for interpreting results accurately and ensuring that the limitations of the GPEXE lt are taken into account when monitoring CS and LS performance.

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Data Availability Statement: The data that support the findings of this study are available from the corresponding author (DS) upon reasonable request.

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Conflicts of Interest: Author Nejc Šarabon was employed by the S2P, Ltd. The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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