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Assessing maximal sprinting speed in soccer – criterion validity of commonly used devices

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ABSTRACT

This study aimed to investigate the criterion validity of commonly used devices to assess maximal sprinting speed (MSS) in soccer. Thirty elite youth soccer players completed three trials of a 30-m sprint test to assess MSS. All sprints were simultaneously captured via a radar gun (Stalker ATS II), timing gates (Smartspeed Pro, Fusion Sport), a magnetic timing system (Humotion SmarTracks) and a global navigation satellite system (GNSS) (Kinexon Perform GPS Pro). The radar gun and the GNSS recorded sprinting speed continuously, while the fastest 5-m split during the 30-m sprint was used for the timing gates and the magnetic system. The best trial of the radar gun (i.e. criterion measure) and corresponding values of the other devices were analyzed. Equivalence testing was performed to assess the statistical equivalence of MSS between the radar gun and the three other devices against a difference value of ± 0.36 km/h and Bland & Altman's 95% limits of agreement (LoA) were computed to investigate the agreement between MSS results. Differences between GNSS versus radar gun suggested a lack of systematic bias (−0.01 km/h, 95% confidence interval [CI] −0.15 to 0.15 km/h), whereas timing gates-based MSS assessments were prone to larger uncertainty compared to the criterion method (−0.19 km/h, 95% CI: −0.37 to 0.00 km/h) given the pre-defined region of equivalence. The magnetic system (−0.54 km/h; −0.71 to −0.37 km/h) overestimated MSS compared to the radar gun with mean differences being non-equivalent. Based on the practically important difference bounds of ± 0.36 km/h, the width of the 95% LoA was broad enough to suggest a lack of reasonable agreement for MSS assessment regardless of device of interest (GNSS: −0.79 to 0.78 km/h, timing gates: −0.79 to 1.16 km/h, magnetic system: −0.24 to 1.32 km/h). While our results suggested a lack of systematic bias for the investigated GNSS and the timing gates when compared against the radar gun for MSS assessment over 30 m in elite youth soccer players on a team level, the width of the 95% LoAs did not indicate reasonable measurement interchangeability on an individual level. Based on the present results, we do not recommend using the magnetic system for both group and individual analyses in this population.

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Football; team sports; speed; acceleration; performance

Introduction

Sprinting is considered a key component of overall performance in soccer (Faude et al. 2012; Martínez-Hernández et al. 2022). During match play, players commonly reach peak sprinting speeds or maximal sprinting speeds (MSS), respectively, of 31 to 34 km/h on average (Barnes et al. 2014; Altmann et al. 2023) with the fastest players ranging from 35 to 37 km/h, depending on playing position and tactical context (Andrzejewski et al. 2015; Oliva-Lozano et al. 2022). Knowing the MSS of players conveys several practical benefits as it facilitates i) the locomotor profiling of players (e.g., establishing the anaerobic speed reserve when knowing the maximal aerobic speed (Buchheit et al. 2012), ii) the individualization of speed thresholds in external load monitoring (Gualtieri et al. 2023,) and iii) the evaluation of MSS exposures during training and matches in relation to injury mitigation (Buchheit et al. 2021).

MSS of soccer players can be assessed in a standardized way using a variety of technologies including radar, (photoelectric) timing gates, global navigation satellite systems (GNSS), or high-speed videos through linear sprints of distances of 30 or 40 m[10–13] Altmann et al., (2019). For both researchers and practitioners, adequate validity is of utmost importance for confidently drawing conclusions from test results (Robertson et al. 2017). In this context, radar is considered the gold-standard technology for assessing MSS in various sports and has been used to validate other technologies. While high-speed video recordings and timing gates are generally supported for measuring MSS, the validity of GNSS seems to greatly vary depending on sampling frequency and filter algorithms used (Zabaloy et al. 2023; Thron et al. 2024).

Nevertheless, existing technologies are constantly evolving and new technologies are being developed. For example, timing gates employing error correction processing such as the Smartspeed Pro system (Vald Performance, Albion, Australia; formerly distributed by Fusion Sport, Cooper Plains, Australia) are being increasingly used as

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they reduce measurement errors, thereby improving measurement accuracy compared to conventional timing gates (Haugen and Buchheit 2016; Altmann et al. 2018; Multhuaptff et al. 2024). In relation to GNSS, companies are constantly developing new algorithms and better sensors to improve the accuracy of their products (Beato et al. 2018). One such example is Kinexon Perform GPS Pro (Kinexon Precision Technologies, Munich, Germany) which is supposed to offer increased accuracy compared to previous versions due to changes in the sensor hardware (Schmidt et al. 2022). Lastly, new technologies such as magnetic timing systems (e.g., Freelap, Freelap USA, Pleasanton, USA; SmarTracks, Humotion, Münster, Germany) are entering the market and are being used in both sports practice and research (Machulik et al. 2020; Thompson et al. 2021; Hallam et al. 2022) while their validity for MSS assessments is yet to be established.

Given the lack of validation studies for the abovementioned devices, this study aimed to investigate the criterion validity of timing gates using error correction processing, a 10-Hz GNSS, and a magnetic system to assess MSS in soccer. Based on previous research (Zabaloy et al. 2023; Thron et al. 2024) we hypothesized that both the timing gates and the GNSS would yield valid results compared to the criterion measure of a radar gun, while no hypothesis regarding the magnetic system could be formulated.

Methods

Experimental approach to the problem

In the present cross-sectional study, elite youth soccer players completed a linear-sprint test over 30 m to assess MSS. All trials were simultaneously captured via a radar gun as a criterion measure, a GNSS system, timing gates, and a magnetic timing system. The trial with the highest sprinting speed (i.e., MSS) as measured by the radar gun (i.e., criterion system) and the corresponding values of the other devices were analyzed. All tests were conducted at the end of the competitive season on an artificial-grass soccer pitch.

Subjects

Thirty elite youth male players from a professional German soccer club (age, 15.7 ± 0.5 years; height, 176.5 ± 6.6 cm; mass, 65.9 ± 8.8 kg; four to five training sessions and one official match per week) classified as tier 3 athletes (McKay et al. 2022) participated in this study. All players were free from injuries at the time of testing. The study was approved by the local ethics committee. All athletes or their legal guardians, respectively, gave their written informed consent before participation.

Procedures

After performing a standardized 15-minute warm-up consisting of jogging, short accelerations, and movement-preparation exercises, players completed three trials of the 30-m linear sprint test from a split-stance standing start. A 3-minute rest between the trials was provided to ensure sufficient recovery. Four different devices were used to assess the players' MSS.

Radar gun

A radar gun (Stalker ATS II, Richardson, USA) was used as a criterion system (Thron et al. 2023). The radar gun was placed on a waist-high tripod 2 m behind the start and tracked the players' running speed continuously at 46.875 hz. The data were processed with the manufacturer's software using the dig medium filter.

GNSS

The GNSS (Kinexon Perform GPS Pro, Kinexon Precision Technologies, Munich, Germany) was housed in a vest positioned between the shoulder blades in the upper-back region and tracked the players' running speed continuously at 10 hz. The data were processed with the manufacturer's software using unfiltered doppler speed data.

Timing gates

Single-beam timing gates using error correction processing (Smartspeed Pro, Fusion Sport, Coopers Plains, Australia) operating at 1,000 hz were placed at the start, 5 m, 20 m, 25 m, and 30 m. All gates were mounted at a height of 0.95 m matching approximately hip height of the players and the players' starting distance from the start timing gate was set at 1.00 m.

Magnetic system

The magnetic timing system (SmarTracks, Humotion, Münster, Germany) consists of two bars per unit (length 60 cm, diameter 2.5 cm) which were arranged 1.20 m apart and in parallel to each other, thereby creating a magnetic field. The players wore a sensor placed between the fourth and fifth lumbar vertebrae in one line with the spine which is capable of detecting the strength of magnetic fields at 500 hz. The peak value of the magnetic field detected by the sensor is assumed to reflect the moment a player passes the two bars and hence was registered (Machulik et al. 2020). As with the timing gates, the magnetic system was placed at the start, 5 m, 20 m, 25 m, and 30 m with a starting distance of the players of 1.00 m.

The intra-session reliability (intraclass correlation coefficient 3,1 absolute agreement, single measures, ICC; coefficient of variation, CV) for MSS in this study was 0.89 (95% confidence interval [95% CI] 0.78–0.95) and 1.37% (1.01%–1.77%) for the radar gun, 0.90 (0.80–0.95) and 1.43% (1.11%–1.79%) for the GNSS, 0.87 (0.76–0.93) and 1.61% (1.18%–2.05%) for the timing gates, and 0.88 (0.72–0.95) and 1.86% (1.44%–2.31%) for the magnetic system, respectively.

Data analysis

MSS of the radar gun and GNSS was provided by the respective manufacturers' software, while the fastest split time was used to calculate MSS of the timing gates and the magnetic system (Zabaloy et al. 2021). The trial with the highest sprinting speed (i.e., MSS) as measured by the radar gun (i.e., criterion system)

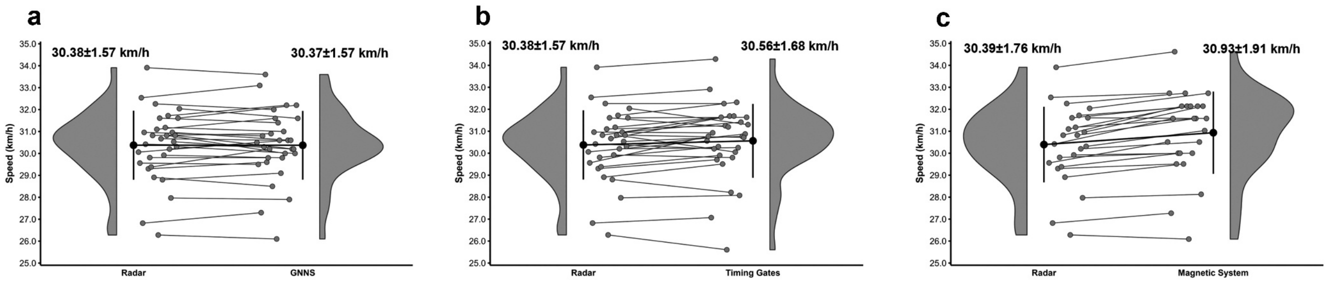

Figure 1. Descriptive statistics of MSS (mean ± SD) and individual values for each player for all comparisons. a: Radar vs GNSS, b: Radar vs Timing Gates, c: Radar vs Magnetic System. MSS – Maximal sprinting speed; GNSS – Global navigation satellite system; SD – Standard deviation.

and the corresponding values of the other devices were used for analysis. For the timing gates and the GNSS, data from all 30 players were analyzed. Conversely, only data from 24 players could be examined for the magnetic system as the last split (i.e., 25 to 30 m) was not recorded for the remaining 6 players.

Statistical analysis

The data were analyzed using SPSS statistical software version 29.0 (SPSS, Inc., Chicago, IL) and Rstudio (version 1.3.1056 R Foundation for Statistical Computing, Vienna, Austria). Mean values and standard deviations (SD) were calculated for each test outcome.

Equivalence testing (TOSTER package version 0.34) was performed to assess the statistical equivalence of MSS between the radar gun and the three other devices against a difference value of ±0.36 km/h. This value described a practically important difference as suggested by Kyprianou et al. (Kyprianou et al. 2019) and was therefore used to specify the upper and lower equivalence bounds (Lakens 2017; Caldwell 2022).

In addition, Bland & Altman's 95% limits of agreement (LoA) (BlandAltmanLeh package version 0.3.1) were computed to investigate the agreement between MSS results. For all statistical tests, 95% CIs were calculated to account for uncertainty in measures, and the significance level was set to 0.05.

Additionally, ICCs (3,1; absolute agreement, single measures) were computed to explore the association and paired t-tests to examine differences in MSS between the radar gun and the three other devices.

Results

Descriptive statistics of MSS (mean ± SD) and individual values for each player for all comparisons are illustrated in Figure 1. Bland-Altman plots including LoA are displayed in Figure 2.

MSS between the radar gun and the GNSS as well as the timing gates were deemed equivalent on a group level. The magnetic system overestimated MSS compared to the radar gun with mean differences being non-equivalent. The LoA for

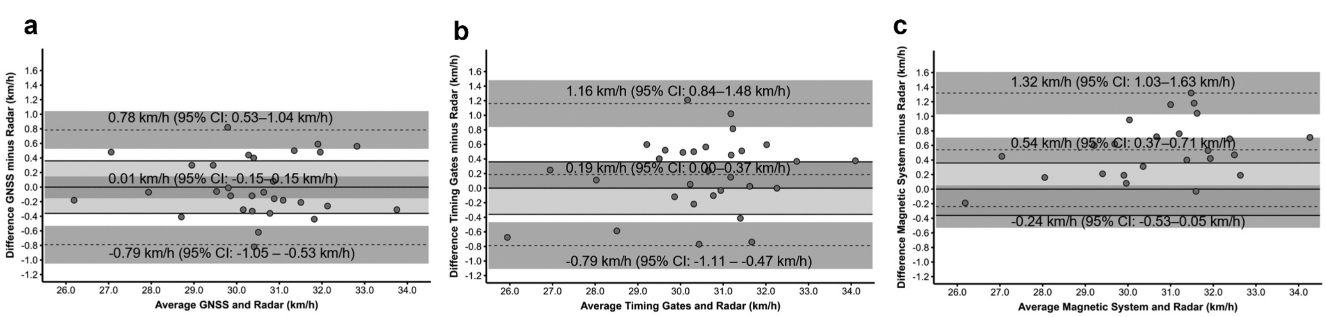

Figure 2. Bland-Altman plots of MSS including mean difference with 95% CI (dark grey), practically important difference bounds (light grey), and LoA with 95% CI (dark grey) for all comparisons. a: Radar vs GNSS, b: Radar vs Timing Gates, c: Radar vs Magnetic System. MSS – Maximal sprinting speed; GNSS – Global navigation satellite system; LoA – Limits of agreement; 95% CI – 95% Confidence interval

Table 1. Mean difference (95% CI), equivalence test, and 95% LoA for all comparisons regarding MSS.

	Mean difference (95% CI)	Equivalence test p-value	95% LoA
Radar vs GNSS	−0.01 km/h (−0.15 to 0.15 km/h)	Lower: < 0.01 Upper: < 0.01	−0.79 to 0.78 km/h
Radar vs Timing Gates	−0.19 km/h (−0.37 to 0.00 km/h)	Lower: < 0.01 Upper: 0.03	−0.79 to 1.16 km/h
Radar vs Magnetic System	−0.54 km/h (−0.71 to −0.37 km/h)	Lower: <0.01 Upper: 0.98	−0.24 to 1.32 km/h

95% CI – 95% Confidence interval; 95% LoA – 95% Limits of agreement; MSS – Maximal sprinting speed all three systems were outside the practically important difference bounds (see Table 1).

Discussion

The purpose of this study was to investigate the criterion validity of GNSS, timing gates, and a magnetic system compared to a radar gun for assessing MSS over 30 m in elite youth soccer players.

High levels of criterion validity on a group level relating to MSS were found for the GNSS and the timing gates as indicated by equivalent mean differences given the predefined region of equivalence of ±0.36 km/h, still, the timing gates were prone to larger uncertainty compared to the criterion method. LoA for both systems were outside the practically important difference bounds of ±0.36 km/h, suggesting a lack of reasonable measurement interchangeability on an individual level. The magnetic system overestimated MSS and mean differences were non-equivalent with LoA also being outside the practically important difference bounds. Hence validity could not be confirmed on both a group and an individual level.

The validity of GNSS to capture MSS seems to be largely affected by the sensors (e.g., sampling frequency) and filter algorithms used. Although not consistently evident through the literature, it seems that higher sampling frequencies of the sensors and smoothing of the data increase the agreement of GNSS with the criterion measures (Zabaloy et al. 2021; Cormier et al. 2023; Thron et al. 2024). The 10-Hz GNSS in our study showed highly accurate results for MSS on a group level, comparable to or more accurate than other 10-Hz GNSS (Roe et al. 2017; Kyprianou et al. 2019; Fornasier-Santos et al. 2022; Cormier et al. 2023) in relation to radar as a criterion. This is indicated by almost identical mean values and 95% CIs narrower than the practically important difference. The GNSS in this study also revealed an increased accuracy compared to a previous version of the same manufacturer (Schmidt et al. 2022) possibly due to changes in the sensor hardware, and given the lack of systematic bias, can therefore be recommended for MSS assessments in the present population at least on a group level. Nevertheless, the present GNSS revealed a lack of reasonable measurement interchangeability to radar measurements for individual players as LoA were outside the practically important difference bounds.

The timing gates yielded a similar high validity for MSS compared to other timing gate systems as reported in the literature (Thron et al. 2024,) although timing gates-based MSS assessments in our study were prone to larger uncertainty compared to the criterion method as for the GNSS. Research has shown that the type of timing gates affects the measurement accuracy at the sprint start and over short sprinting distances (e.g., 5 m and 10 m). Conventional single-beam systems are more prone to measurement errors caused by swinging limbs or a forward lean by the athletes that prematurely trigger the light beam compared to single-beam systems using error-correcting processing or dual-beam systems (Haugen and Buchheit 2016; Altmann et al. 2018; Multhuaptff et al. 2024). However, the differences in accuracy between the types of timing gates diminish with increasing sprinting distance (Haugen and Buchheit 2016; Altmann et al. 2018). This is due to athletes adopting a more upright running posture at longer distances, as well as swinging limbs causing only marginal measurement errors because of high running speeds, which is especially true for MSS assessments. Therefore, along with other timing-gate types, the device employing error-correction processing investigated in the current study can be considered valid for assessing MSS in soccer on a group level given the lack of systematic bias. Importantly, and in line with the GNSS, the timing gates used in the current study lacked validity on an individual level.

The magnetic system overestimated MSS compared to the radar gun, supported by non-equivalent mean differences, and LoA were outside the practically important difference. To the best of the authors' knowledge, no study so far compared a magnetic timing system to an accepted criterion measure (e.g., radar gun) in relation to MSS. Nevertheless, Machulik et al. (2020) compared the same device as in the current study with an optical measurement system as a criterion measure at various running speeds ranging from jogging to high-speed running. Authors also reported increased mean differences and LoA at higher running speeds as compared to lower running speeds for the magnetic system. Therefore, it seems that peak value of the magnetic field cannot be accurately captured by the sensor on the players' lower back, especially at higher running speeds. However, the reason for this remains unclear and needs further investigation. In addition, Thompson et al. (2021) compared another commercially available magnetic timing system (Freelap) to a robotic sprint resistance device. While the authors reported very large correlations (Pearson's r), no data about the magnitude of the mean and individual differences between the devices were provided (i.e., LoA), making comparisons to the present study impossible. In summary, given the systematic bias and the lack of reasonable agreement between devices, the current magnetic timing system cannot be recommended for assessing MSS on both a group and an individual level.

The main strengths of this study are the use of a radar gun as a widely-accepted criterion measure and the high performance level of the players which is representative of team-sport populations in which assessments of MSS commonly take place. However, all measurements were conducted in a controlled environment using standardized procedures. This represents a possible limitation in particular regarding GNSS which are most often used during training and matches characterized by abrupt changes in movement patterns and speeds as well as not always optimal environmental conditions. In this regard, research has shown that the validity of MSS measures is strongly compromised in such situations (Zabaloy et al. 2023).

Practical applications

Coaches and researchers can confidentially use the GNSS and timing gates applied in the current study to assess MSS in youth soccer players on a team level as indicated by the results of equivalence testing. Practical examples for using MSS results on a group level may be i) to look at general (team) trends in MSS to inform programming, e.g., the evaluation of MSS exposures during training and matches in relation to injury mitigation, or ii) to conduct research (inhouse or for a formal investigation) where MSS is an outcome measure. Nevertheless, one should also acknowledge a considerable degree of variability in accuracy on an individual level as highlighted by LoA outside the practically important difference bounds between the radar gun (criterion measure) and both devices, suggesting a lack of reasonable agreement for MSS assessment. Hence, the devices should not be used interchangeably for individual players. Conversely, MSS was both overestimated by the magnetic system and showed LoA larger than the practically important difference bounds. Therefore, we do not recommend using this device as this might lead to inaccurate calculations of player profiles or individualized speed thresholds in external load monitoring potentially leading to false training prescription and regeneration measures, at least in the population investigated. Lastly, as a very high intertrial reliability was evident for all devices, coaches and researchers might use them for tracking changes in MSS over time (Zabaloy et al. 2023). However, sensitivity analysis would be necessary for such purposes which was beyond the scope of this study.

Conclusions

While our results suggested a lack of systematic bias for the investigated GNSS and the timing gates when compared against the radar gun for MSS assessment over 30 m in elite youth soccer players on a team level, the width of the 95% LoAs did not indicate reasonable measurement interchangeability on an individual level. Based on the present results, we do not recommend using the magnetic system for both group and individual analyses in this population.

Disclosure statement

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Data availability statement

All individual data supporting the findings of this study are available within the article (igures 1 and 2). The data are also available as an Excel file from the corresponding author, SA, upon request.

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