

Affordable open-source system for measuring sprint-test times

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Abstract:

Introduction: Ultrasonic sensors integrated with open-source microcontrollers may represent a promising low-cost alternative for sprint assessment. However, evidence regarding their validity and reliability remains limited. **Objective:** The objective of this methodological study was to develop and valuate the validity and test-retest reliability of a low-cost sprint-timing system based on ultrasonic sensors and an open-source electronic prototyping platform incorporating open hardware and software. **Methods:** Ten physically active men (22.0 ± 2.6 years) participated in the study. Each participant completed two experimental sessions, with three maximal flying 30-m sprints performed per session. To assess concurrent validity, sprint times recorded by the prototype were compared with measurements obtained through video analysis using Kinovea software. The developed system consisted of two sensors. Each sensor included an HC-SR04 ultrasonic sensor to detect the runner's passage, an nRF24L01 wireless communication module to enable communication between the sensors, an Arduino Uno microcontroller responsible for executing commands programmed in C++, and, for Sensor 2, a 9-V battery to power the system. Test-retest reliability was evaluated by comparing the measurements recorded across the two experimental sessions. **Results:** The results demonstrated excellent agreement ($ICC = 0.96$), associated with low measurement errors. Bland-Altman analysis showed that most observations fell within the limits of agreement ($bias \pm 1.96 SD$), and the bias was close to zero (0.08 s). In the test-retest analysis, reliability was high ($ICC = 0.81$), with low typical error. Bland-Altman analysis showed a small bias between the test and retest measurements (0.08 s). **Conclusion:** It is concluded that the developed system represents an accessible alternative for real-time sprint time assessment, demonstrating satisfactory validity and reliability for 30-m sprint tests.

Key Words: Arduino; ultrasonic sensors; concurrent validity; test-retest reliability; sports technology; accuracy.

Introduction

Sprint speed is a key physical component for high-level athletic performance and sports success (Altmann et al., 2019), requiring accurate assessment. To objectively quantify sprint performance, electronic timing systems have become highly effective and versatile tools, enabling precise real-time measurements across a wide range of sporting contexts (Pérez-Chirinos Buxadé et al., 2021; Newton & Earp, 2012). Among these, photocell timing systems measure sprint time by detecting interruptions in a light beam (Cronin & Templeton, 2008; Multhaupt et al., 2023; Yeadon, Kato, & Kerwin, 1999). Despite their high accuracy, however, their relatively high cost may limit their adoption in settings with restricted financial resources (Pérez-Chirinos Buxadé et al., 2021; Uhlmann et al., 2023). Consequently, the search for reliable and cost-effective alternatives has become increasingly important to ensure the continuous assessment of sprint performance (Uhlmann et al., 2023). Among the available alternatives, video analysis using digital cameras combined with software such as Kinovea has demonstrated satisfactory validity and reliability for measuring sprint time and running speed, producing results comparable to those obtained with gold-standard systems (Haugen & Buchheit, 2016). Despite its accuracy, its practical applicability is limited by the need for post-processing, resulting in delayed feedback and making it less practical for routine training environments (Haugen & Buchheit, 2016). Furthermore, measurement accuracy depends on the technical specifications of the recording device, particularly the camera frame rate (Balsalobre-Fernández et al., 2014; Marco-Contreras et al., 2024). Therefore, technologies capable of providing immediate feedback while maintaining low implementation costs remain necessary.

To provide immediate feedback without increasing costs, systems based on open-source microcontrollers have emerged as a promising strategy for assessing motor performance (Moraes et al., 2026; Pousibet-Garrido et al., 2025; Robalino et al., 2025; Septiandi et al., 2018; Susuki et al., 2025; Uhlmann et al., 2023; Wibowo et al., 2021). For example, Robalino et al. (2025) validated a low-cost device integrating an

Arduino Uno microcontroller with contact mats to measure, in real time, kicking execution time in combat sports athletes. Extending this technological approach to sprint assessment, Morais et al. (2026) validated an affordable system based on an ESP-family microcontroller to measure 10- and 20-m sprint performance in soccer players. In addition, the development of portable devices and customized sensors has enabled accurate assessment of variables related to sprint starts. Microcontroller-based systems using ATmega and ESP32 platforms have been validated to measure neuromuscular reaction time (Pousibet-Garrido et al., 2025), block start performance (Septiandi et al., 2017), as well as foot contact time and force production (Wibowo et al., 2021), demonstrating that these technologies provide practical and affordable solutions for coaches and practitioners.

The accurate assessment of sprint time is relevant not only for performance analysis but also for monitoring training adaptations, evaluating the effects of training interventions, and supporting decisions regarding sprint training prescription. In these contexts, measurement systems should combine sufficient accuracy with practical feasibility, allowing repeated assessments under routine training conditions. Although commercially available timing systems provide reliable measurements, their acquisition costs may restrict access for coaches, researchers, and sports institutions with limited financial resources. Consequently, the development of affordable alternatives should consider not only measurement accuracy but also implementation costs, ease of assembly, portability, and the possibility of obtaining immediate results. These characteristics are particularly relevant in environments where access to specialized sports technology is limited.

Recent advances in open-source electronics have expanded the possibilities for developing customized measurement instruments using accessible microcontrollers and sensors. Unlike proprietary systems, open-source platforms allow users to modify hardware configurations and software according to specific assessment requirements, potentially reducing development and maintenance costs. However, the availability of inexpensive electronic components does not necessarily ensure adequate measurement performance. Sensor characteristics, signal acquisition, detection procedures, and system configuration may introduce measurement errors that affect the accuracy and reproducibility of the recorded times. Therefore, the practical advantages of open-source systems must be supported by empirical evidence demonstrating their validity and reliability under the conditions in which they are intended to be used. These previous studies indicate that the accuracy of low-cost devices is comparable to that of validated commercial systems (Morais et al., 2026; Pousibet-Garrido et al., 2025; Susuki et al., 2025; Uhlmann et al., 2023), suggesting that open-source hardware can democratize access to sports performance assessment without compromising data quality. Nevertheless, despite their considerable potential, the increasing use of devices that have not undergone appropriate validation against reference standards may lead to inaccurate interpretations and compromise decision-making (Mason et al., 2024). The development of new measurement instruments therefore requires rigorous validation and reliability protocols (Currell & Jeukendrup, 2008; Robertson et al., 2017) to ensure that the collected metrics accurately reflect athletes' performance rather than measurement noise or device-related errors (Haugen & Buchheit, 2016; Uhlmann et al., 2023). In this context, ultrasonic sensors offer a potential alternative for detecting an athlete's passage through predefined measurement points without requiring a conventional optical timing system. When integrated with a programmable microcontroller, these sensors may enable automated event detection and immediate calculation of elapsed time using relatively accessible components. Nevertheless, the suitability of this approach depends on its ability to produce measurements that agree with an established reference method and remain consistent across repeated testing sessions. In particular, the concurrent validity and test-retest reliability of the complete system need to be examined rather than inferred from the specifications of individual components. Addressing this methodological gap may provide researchers and practitioners with evidence on whether an ultrasonic sensor-based system represents a feasible alternative for sprint time assessment.

Therefore, the aim of this study was to develop and evaluate the validity and reliability of a low-cost open-source system for sprint time assessment using ultrasonic sensors integrated with an open-source hardware and software platform. Although several low-cost systems have been proposed for sprint assessment, evidence regarding the validity and reliability of ultrasonic sensor-based systems remains scarce. The development and validation of a low-cost, easy-to-assemble system capable of providing real-time feedback may expand access to objective sprint performance assessment in both sports practice and research settings.

Material & methods

This was a methodological study of test-retest reliability and concurrent validity, in which a low-cost system was tested on different occasions and compared with a reference method based on video analysis.

Participants and ethical considerations

Ten male volunteers aged between 18 and 30 years participated in this study. To be eligible, participants had to be physically active and present no contraindications to physical exercise. The sample had a mean age of 22.00 ± 2.62 years, a mean height of 1.76 ± 0.06 m, and a mean body mass of 78.90 ± 14.40 kg. The sample size was determined by convenience. All participants provided written informed consent before participation and were informed about the study objectives, the experimental procedures, and all potential risks. The study followed the recommendations of the 1964 Declaration of Helsinki.

Experimental design

Participants completed two experimental sessions on separate days. During Session 1, volunteers completed a health screening questionnaire and underwent an anthropometric assessment. Height was measured using a stadiometer (Caumaq®), and body mass was measured using a digital bioelectrical impedance scale (Omron HBF514C®). After these assessments, participants performed a self-selected warm-up consisting of jogging and dynamic stretching, followed by three maximal 30-m sprints, with a five-minute recovery interval between trials. Session 2 was conducted after a minimum interval of 48 hours and consisted of a self-selected warm-up followed by three maximal 30-m sprints, with a five-minute recovery interval between trials. During both sessions, sprint time was measured simultaneously using the developed prototype and a video recording system.

Sprint test

The experimental protocol was conducted on the straight section of an official synthetic athletics track. Flying sprints were performed, with participants starting 10 m before the first sensor. The sensors were positioned at 10 m and 40 m from the starting point, allowing the measurement of sprint time over a 30-m distance (Figure 1). Participants were allowed to initiate the sprint freely at any time, without an external starting command, and no verbal encouragement was provided during the test. For statistical analysis, the fastest sprint time obtained by each participant in each experimental session was considered.

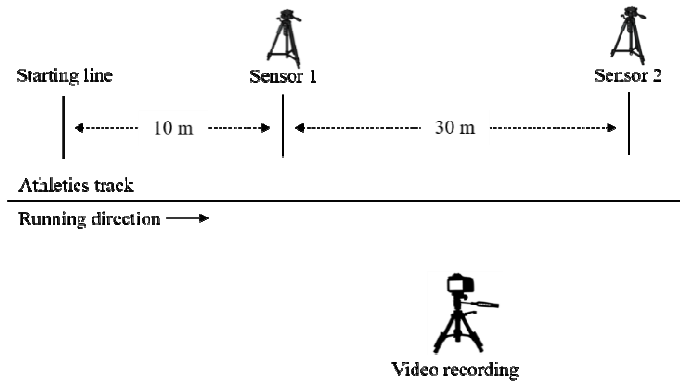


Figure 1: Schematic representation of the sprint test and the arrangement of the measurement systems.

Prototype

The developed system consisted of two sensors. Each sensor included an HC-SR04 ultrasonic sensor to detect the runner's passage, an nRF24L01 wireless communication module to enable communication between the sensors, an Arduino Uno microcontroller responsible for executing commands programmed in C++, and, for Sensor 2, a 9-V battery to power the system. Functionally, Sensor 2 detected the runner's passage and transmitted the detection time to Sensor 1. Sensor 1, which was connected to a notebook computer, also detected the runner's passage, received the information from Sensor 2, and displayed the sprint time instantaneously. Both sensors were positioned approximately 95 cm above the ground to detect the passage of the participants' trunk. The system operated with continuous data acquisition, automatically recording sprint times each time a runner was detected. Detailed technical specifications of the sensors (e.g., detection range, accuracy, and response time) are available in the manufacturer's datasheet. During data collection, sprint times recorded by the sensors were entered into a Microsoft Excel® spreadsheet by one evaluator, while a second evaluator simultaneously recorded the trials on video. A schematic representation of the prototype is shown in Figure 2.

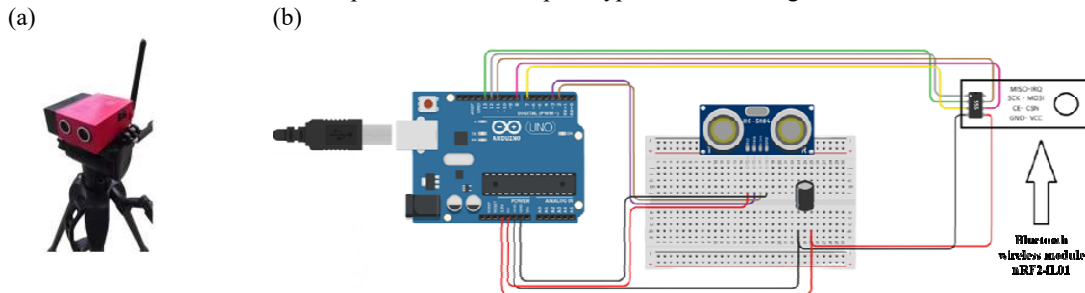


Figure 2. (a) Final prototype used during data collection; (b) Schematic diagram of the prototype showing all system components, including the USB cable, Arduino Uno, breadboard, ultrasonic sensor, capacitor, and Bluetooth wireless module.

Videography

Sprint time was measured simultaneously using the developed prototype and video recording. The camera (Samsung S23 Ultra or Poco X5 Pro) was configured to record at 60 frames per second (FPS) and positioned in the stands of the Olympic Training Center at an elevated location and at a sufficient distance to allow complete visualization of the sprint course. The videos were subsequently analyzed using Kinovea software (version 2023.1.2), which served as the reference method. After data collection, both evaluators independently analyzed the videos using Kinovea and recorded the results separately. This procedure was adopted to minimize observational bias and assess inter-rater reliability, allowing comparison between the measurements obtained by the sensor system and those obtained through video analysis. For subsequent comparisons with the prototype, the measurements from Evaluator 1 were used.

Statistical analysis

Initially, agreement between the evaluators responsible for video analysis was assessed using the Intraclass Correlation Coefficient (ICC), adopting the ICC (3,1) model to evaluate measurement consistency. Additionally, differences between evaluators were examined using an independent-samples t-test. The concurrent validity of the prototype was evaluated by comparing the sprint times recorded by the developed system with those obtained from video analysis, which was considered the reference method. For this purpose, the ICC was calculated to assess relative agreement between methods, the Root Mean Square Error (RMSE) was calculated as a measure of overall error, the Typical Error of Measurement (TEM) was calculated to quantify random measurement error, and bias was calculated as the mean difference between methods to identify possible systematic errors. Test-retest reliability was determined by comparing the results obtained from two assessments performed under identical experimental conditions. The ICC, RMSE, TEM, and bias between assessments were calculated to evaluate temporal stability, measurement error magnitude, and the presence of systematic differences between sessions. ICC values were interpreted according to the criteria proposed by Koo and Li (2016): values below 0.50 indicated poor reliability, values between 0.50 and 0.75 indicated moderate reliability, values between 0.75 and 0.90 indicated good reliability, and values above 0.90 indicated excellent reliability. Additionally, agreement between methods and between assessments was examined using Bland-Altman analysis, considering the mean difference (bias) and the 95% limits of agreement (mean difference $\pm$ 1.96 $\times$ standard deviation of the differences). Statistical significance was set at $p < 0.05$. All analyses were performed using SigmaStat version 3.5 and Microsoft Excel (Microsoft Office Professional Plus 2019).

Results

Agreement Between Evaluators for Video Analysis

Inter-rater reliability for the sprint times obtained from the video analysis was excellent, with an ICC of 1.00, indicating perfect agreement between evaluators. The mean sprint times obtained by the two evaluators were nearly identical (4.085 vs. 4.084 s), with no statistically significant difference between them ($p = 0.942$).

Concurrent Validity (Prototype vs. Video Analysis)

The results obtained from the prototype and the video analysis are presented in Table 1, and the scatter plot of the data is shown in Figure 3. The intraclass correlation coefficient was classified as excellent (ICC = 0.96), demonstrating high relative agreement between the prototype and the video analysis. The RMSE (0.106 s) and TEM (0.048 s) values, when considered relative to the mean sprint time, indicate relatively low measurement error, supporting the practical application of the system for sprint performance assessment. Bland-Altman analysis showed that most observations fell within the limits of agreement (bias $\pm$ 1.96 SD), and the bias was close to zero (0.08 s), indicating no relevant systematic error. Overall, the concurrent validity analyses indicate good agreement between the two methods.

Table 1. Results obtained from the prototype and the video analysis for the concurrent validity assessment, and from the prototype test and retest for the reliability analysis.

		Mean (s)	SD (s)	RMSE (s)	TEM (s)	Bias (s)	ICC (s)
Validity	Prototype	3.945	± 0.258	0.106	0.048	0.058	0.96
	Video recording	3.860	± 0.231				
Reliability	Prototype test	3.902	± 0.249	0.172	0.114	0.059	0.81
	Prototype retest	3.983	± 0.273				

SD = Standard deviation; RMSE = Root mean squared error; TEM = Typical error of measurement; ICC = Intraclass Coefficient Correlation.

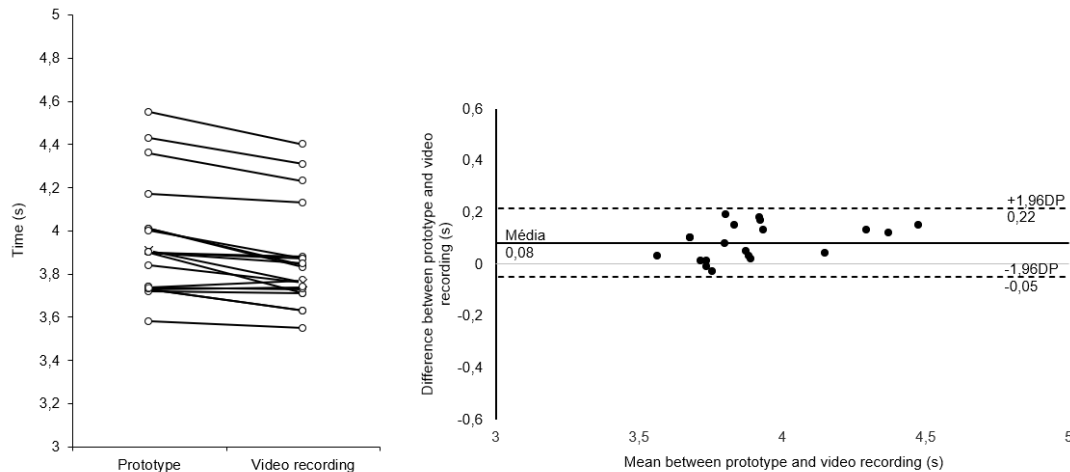


Figure 3: Scatter plot (left panel) and Bland-Altman plot (right panel) comparing measurements obtained with prototype and video recording.

Test-Retest Reliability of the Prototype

The results obtained with the prototype during the test and retest sessions are presented in Table 1, and the scatter plot of the data is shown in Figure 4. The test-retest intraclass correlation coefficient (ICC) was 0.81, indicating good reliability. The RMSE (0.172 s) and TEM (0.114 s) values indicate relatively low measurement error when compared with the mean sprint time, while the bias (0.059 s) confirms the absence of meaningful systematic differences between the test and retest sessions. Therefore, the prototype demonstrated satisfactory temporal stability for the assessment of 30-m sprint performance. Bland-Altman analysis showed a small bias between the test and retest measurements (0.08 s). The 95% limits of agreement ranged from -0.40 to 0.23 s. No evidence of proportional bias or heteroscedasticity was observed in the data.

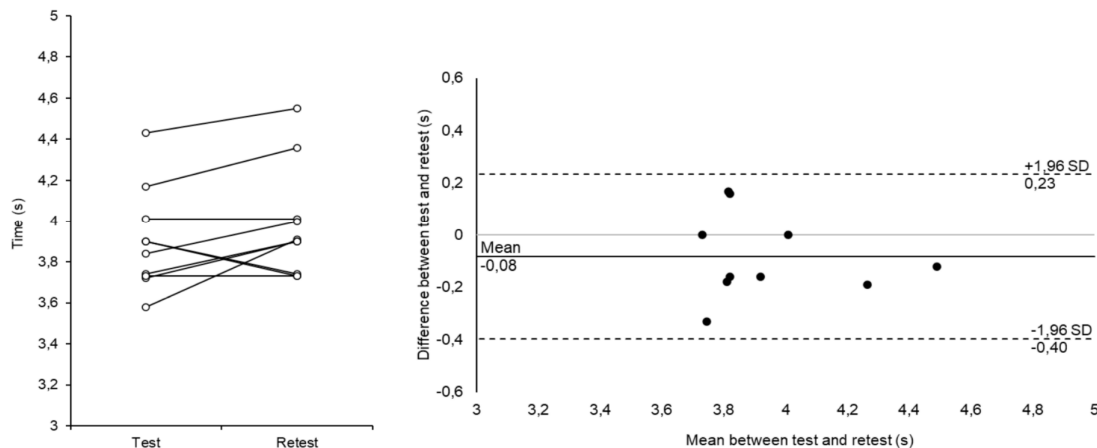


Figure 4: Scatter plot (left panel) and Bland-Altman plot (right panel) comparing measurements obtained with prototype between test and retest.

Dicussion

The present study aimed to develop and evaluate the validity and reliability of a low-cost timing system using ultrasonic sensors integrated into an open-source platform. Regarding validity, the sprint times recorded by the prototype showed high similarity to those obtained through video analysis, which was used as the reference method. Bland-Altman analysis demonstrated that most measurements fell within the limits of agreement, indicating good agreement between the two methods and the absence of relevant systematic bias. Furthermore, in the test-retest analysis, the measurement error remained relatively constant across assessments, suggesting good temporal stability and reliability of the system.

Sprint timing is strongly influenced by different triggering methods (Haugen, Tønnessen, & Seiler 2012) and detection mechanisms (Haugen & Buchheit, 2016; Multhaupt et al., 2023), which may result in differences of several tenths of a second in the final sprint time. Unlike linear-beam photocell systems, in which

the event is recorded when the light beam is interrupted, the ultrasonic sensor operates through a conical detection field, causing the athlete to be detected progressively as they enter the sensor's sensitive area. Despite these differences in operating principles, the prototype developed in the present study demonstrated high agreement with the video analysis, indicating that this detection mechanism did not compromise the validity of the measurements under the conditions evaluated.

The test–retest reliability analysis yielded an ICC of 0.81, which is classified as good reliability (Koo & Li, 2016). However, this result should be interpreted alongside other measurement error metrics, as the ICC is influenced by sample variability. In more homogeneous groups, such as the sample evaluated in the present study, the lower variability among participants may reduce ICC values even when the instrument demonstrates good stability. In this context, the low Typical Error of Measurement (TEM = 0.114 s), together with the Bland–Altman analysis showing a small bias and no evidence of systematic error, reinforces that the prototype exhibits good absolute consistency and high reproducibility of the measurements.

In addition to the quality of the measurements obtained, the findings highlight the practical applicability of the proposed system. The combination of HC-SR04 ultrasonic sensors with an Arduino Uno microcontroller enabled the development of a low-cost system based on open-source hardware and software, capable of automatically recording sprint times in real time. Ultrasonic sensors offer several advantages, including low cost, ease of integration with microcontrollers, and the ability to perform non-contact measurements (Priadi et al., 2025; Queiroz, Sousa Neto, & Queiroz, 2022). Likewise, the Arduino platform is widely used for electronic prototyping because of its programming simplicity, high flexibility, and low financial cost (McRoberts, 2011; Kondaveeti et al., 2021). Together, these characteristics make the proposed system a viable alternative for researchers, coaches, and institutions that do not have access to more expensive commercial timing systems, thereby expanding access to objective performance assessment in sprint tests.

Although the prototype demonstrated satisfactory performance for sprint time measurement, the findings should be interpreted in light of several methodological and operational limitations. Regarding the hardware, the accuracy of the HC-SR04 sensor may be affected by the shape and surface characteristics of the detected object, false triggering caused by surrounding obstacles, and environmental variations in temperature and humidity, as its operation depends on the speed of sound propagation (Arunglabi, Allu, & Patandianan, 2026; Priadi et al., 2025). In addition, although the video analysis used as the reference method allowed complete visualization of the sprint course, it was subject to parallax error due to the elevated camera position, which may have introduced small inaccuracies in identifying the exact moments at which participants crossed the measurement points (Moraes et al., 2026; Mullin & Taylor, 2002; Tian, Kyte, & Messer, 2002). Finally, the use of a small convenience sample composed exclusively of physically active men limits the generalizability of the findings. Therefore, future studies should evaluate the performance of the system under different environmental conditions, in larger and more diverse populations, and across different sporting contexts, as well as compare it directly with commercially available photocell timing systems.

Conclusions

The findings of the present study demonstrate that the proposed low-cost, open-source prototype provides satisfactory concurrent validity and good test–retest reliability for measuring 30-m sprint time. The agreement between the prototype and the video-based reference method supports its use as an objective tool for sprint performance assessment, while the test–retest results indicate that it can provide reasonably consistent measurements across repeated assessments. Together, these findings support the feasibility of using accessible electronic components to develop a practical system for sprint timing without relying on expensive commercial equipment.

From a practical perspective, the proposed system may be useful for researchers, coaches, and sports practitioners who require objective measurements of sprint performance in laboratory, field-based, and applied sports settings. Its low cost and open-source design may facilitate access to sprint monitoring technology in institutions and training environments with limited financial resources. Furthermore, the availability of an accessible and reproducible system may encourage the development and adaptation of similar tools for sports performance assessment, supporting innovation and the democratization of measurement technologies in sports science.

From a methodological and technological perspective, this study contributes to the field by providing empirical evidence regarding the measurement properties of a prototype developed using accessible electronic components. The findings support the potential of open-source hardware as an alternative for specific performance-monitoring applications, although its suitability should be established according to the measurement requirements of each context. In particular, the results should be interpreted in light of the characteristics of the present validation protocol and the sample studied, and the prototype should not be assumed to be interchangeable with commercial systems under all testing conditions.

Future studies should investigate the performance of the prototype in larger and more diverse samples, across different environmental conditions and sprint-testing protocols, and in comparison with additional

reference systems. Further development should also examine its long-term measurement stability, practical usability, and applicability to routine athlete monitoring. Overall, the proposed prototype represents a promising, accessible, and reproducible approach to sprint timing that may expand opportunities for objective performance assessment and support further technological development in sports science.

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Conflicts of interest: The authors declare that there is no conflict of interest.

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