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Agreement and Repeatability of a Time-Interval Measurement Prototype for Controlled Horizontal-Displacement Tasks

Concordancia y Repetibilidad de un Prototipo de Medición de Intervalos en Tareas de Desplazamiento Horizontal Controlado

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Abstract

The development of locally engineered technology for human movement assessment offers an alternative to costly imported instruments. This instrumental method-comparison study evaluated the repeatability of Prototype II, a photocell-based electronic device for measuring time intervals during controlled horizontal-displacement tasks, and its agreement with Newtest Powertimer and Chronojump Boscosystem in indoor and outdoor environments. Repeatability was assessed at 1.5, 6, and 15 s in sessions separated by 24 hours. Agreement was assessed at 2, 5, and 12 s using 35 paired technical repetitions for each interval-by-environment condition, with simultaneous measurements from Prototype II and both comparison systems. Relative reliability was summarized with ICC(2,1), while absolute repeatability was prioritized using CV% and SEM; agreement was summarized with Lin's CCC. ICCs for repeated Prototype II measurements were low or negative under restricted between-trial variance, whereas CV% ranged from 0.49% to 1.92% and SEM from 0.019 to 0.042 s. CCC ranged from 0.94 to 0.99 outdoors, from 0.809 to 0.915 indoors at 2 and 5 s, and from 0.623 to 0.636 at 12 s indoors. These results support repeatable technical performance and substantial agreement in several tested conditions, particularly outdoors, but do not establish practical interchangeability because no a priori acceptable-difference threshold was defined. Prototype II is a promising locally developed timing system that warrants further validation against traceable standards and during real movement tasks.

Keywords: agreement; repeatability; instrumental measurement; photocells; horizontal displacement.

Resumen

El desarrollo de tecnología local para evaluar el movimiento humano puede reducir la dependencia de instrumentos importados. Este estudio instrumental de comparación de métodos evaluó la repetibilidad del Prototipo II, un dispositivo electrónico basado en fotoceldas para medir intervalos temporales durante tareas controladas de desplazamiento horizontal, y su concordancia con Newtest Powertimer y Chronojump Boscosystem en ambientes interior y exterior. La repetibilidad se evaluó en intervalos de 1.5, 6 y 15 s en sesiones separadas por 24 h. La concordancia se evaluó a 2, 5 y 12 s mediante 35 repeticiones técnicas pareadas por condición intervalo-ambiente, con mediciones simultáneas de los tres sistemas. La confiabilidad relativa se resumió mediante ICC(2,1), mientras que la repetibilidad absoluta se priorizó mediante CV% y SEM; la concordancia se resumió mediante el CCC de Lin. Los ICC de las mediciones repetidas del Prototipo II fueron bajos o negativos bajo variabilidad entre ensayos restringida; el CV% osciló entre 0.49% y 1.92% y el SEM entre 0.019 y 0.042 s. El CCC osciló entre 0.94 y 0.99 en exteriores, entre 0.809 y 0.915 en interiores a 2 y 5 s, y entre 0.623 y 0.636 a 12 s en interiores. Estos resultados respaldan una repetibilidad técnica cuantificable y concordancia variable según la condición, pero no establecen intercambiabilidad práctica porque no se definió un umbral a priori de diferencia aceptable. Se requiere validación adicional frente a estándares trazables y durante tareas reales de movimiento.

Keywords: concordancia; repetibilidad; medición instrumental; fotoceldas; desplazamiento horizontal.

Introduction

Technological development has progressively transformed how human movement is evaluated, monitored, and optimized in sport, physical education, and health-related exercise settings. Within this field, objective time measurement during horizontal-displacement tasks such as sprinting and agility testing is widely used, and electronic timing systems based on photocells reduce the reaction-time error associated with manual timing (Haugen & Buchheit, 2016). The present protocol, however, did not evaluate sprint or agility performance; controlled horizontal displacements were used only to interrupt the photocell beams at standardized time signals.

Despite the growing use of electronic timing systems, most validated devices available for human-movement research and sport training are manufactured abroad, which entails high acquisition and maintenance costs and fosters technological dependency in countries with limited access to specialized equipment (Earp & Newton, 2012; Pino-Ortega & Rico-González, 2021). This constraint is particularly relevant in Latin American contexts such as Costa Rica, where accessible, locally developed, and scientifically validated instrumentation for human-movement assessment remains scarce.

In response to this gap, a first-generation device (Prototype I) was previously designed and evaluated, showing adequate reliability and concordance under controlled conditions (Gutiérrez Vargas, 2023). Prototype II represents an evolution of this line of technological development, incorporating structural and functional improvements to its housing and control algorithm. Because these modifications may alter measurement behavior, Prototype II cannot be assumed to be equivalent to its predecessor and therefore requires an independent metrological evaluation.

The literature on photocell-based timing systems emphasizes that temporal precision and agreement between instruments are essential criteria for measurement quality, especially for short time intervals and across different testing environments (Altmann et al., 2017; Altmann et al., 2018; Bond et al., 2017). A recent systematic review of photocells in sport also highlights the need to complement relative reliability indices such as the intraclass correlation coefficient (ICC) with absolute-error estimators and dedicated agreement procedures, particularly when repeated instrumental trials have restricted between-unit variability (Multhauptt et al., 2024; Koo & Li, 2016).

Accordingly, the general objective of this study was to evaluate the repeatability of Prototype II for measuring fixed time intervals during controlled horizontal-displacement tasks and its agreement with two commercially available timing systems across indoor and outdoor conditions. The specific objectives were: (a) to replicate, for Prototype II, the experimental protocol previously used for Prototype I in indoor and outdoor settings; (b) to describe repeatability using ICC together with absolute-error indices (CV% and SEM), giving greater interpretive weight to the latter under restricted variance; (c) to quantify agreement with the comparison systems using Lin's concordance correlation coefficient (CCC); (d) to use Bland-Altman and Deming procedures as supplementary method-comparison diagnostics without inferring interchangeability in the absence of an a priori acceptable-difference threshold; and (e) to compare the descriptive measurement behavior of Prototype II between indoor and outdoor environments.

Materials and Methods

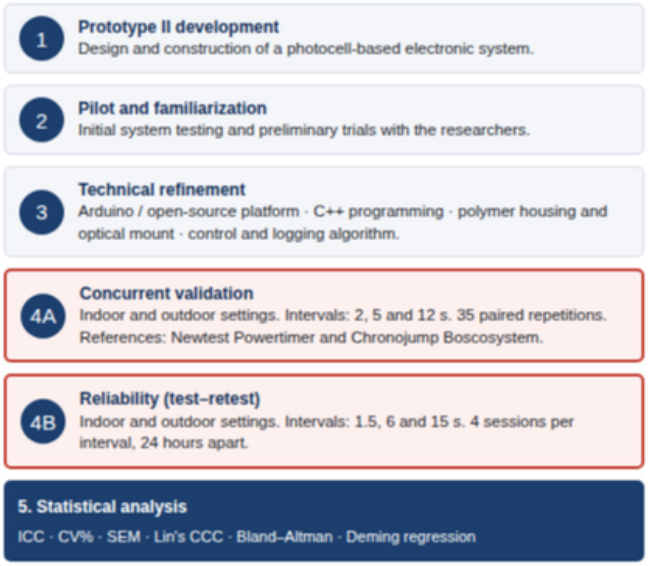
Design

This was a quantitative, non-experimental, repeated-measures instrumental method-comparison study. No independent variables were manipulated. The analytic

units were repeated time measurements generated by Prototype II and the comparison systems; human collaborators were used only to trigger the photocell beams and were not treated as a performance sample. The study therefore focused on repeatability and agreement rather than participant-level validity (see Figure 1).

Figure 1

Schematic study design and procedures



ICC: Intraclass correlation coefficient; CV%: Coefficient of variation; SEM: Standard error of measurement; CCC: Lin's concordance correlation coefficient.

Participants

Teaching staff and students served in a purely operational role. The study record did not retain a count of unique collaborators because no participant-level dataset was created; consequently, a human sample size cannot be reported and this is acknowledged as a reporting limitation. The operational task consisted of a controlled horizontal displacement between the start and finish photocells to interrupt the beams in response to externally indicated signals; it was not a standardized sprint, agility, or fitness test. No personal or sensitive data were collected, and no physiological, biomechanical, or performance variables of the collaborators were assessed.

Instruments

The primary instrument evaluated was Prototype II, an electronic device designed and built to record the interval between two consecutive photocell interruptions. Two commercially available timing systems were used as comparators: the wireless Newtest Powertimer (Newtest, Oulu, Finland) and the wireless Chronojump Boscosystem (Barcelona, Spain). These systems were treated as reference comparators for operational method comparison rather than as metrological gold standards. The study documentation available for this analysis did not include an independent traceable calibration against a primary time standard or manufacturer accuracy/resolution information sufficient to define an a priori allowable error; consequently, the present results are described as agreement with reference systems rather than criterion or concurrent validity. A programmable wireless light system, FitLight (Miami, FL, USA), was used to standardize the generation of fixed time intervals during the repeatability trials. Prototype I was not used for data collection; comparisons with Prototype I were made only at the documentary level, using previously reported results (Gutiérrez Vargas, 2023).

Measurement environments

Indoor measurements were carried out in the gymnasium of the School of Human Movement Sciences and Quality of Life (CIEMHCAVI) at Universidad Nacional, Costa Rica, under controlled lighting, temperature, and wind-free conditions. Outdoor measurements were carried out on an International Association of Athletics Federations (IAAF)-certified synthetic track at the same institution, where solar light, wind, and temperature could not be fully controlled, thereby contributing to the external validity of the results.

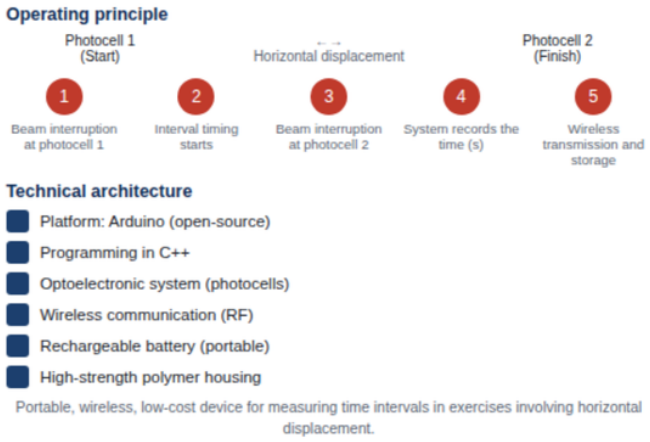
Experimental protocol and procedures

The protocol replicated the procedure previously used to evaluate Prototype I (Gutiérrez Vargas, 2023) and was implemented in five sequential phases: (1) a targeted literature search and narrative synthesis to update the theoretical framework; this was not conducted or reported as a systematic review; (2) familiarization pilot trials with Prototype II; (3) technical refinement, in which the developer implemented the control algorithm in C++ on an open-source Arduino platform and replaced the provisional housing with a more rigid polymer casing to improve durability and reduce interference; (4) evaluation of repeatability and agreement; and (5) documentary comparison with Prototype I.

For the agreement assessment, 35 simultaneous technical repetitions were obtained for each fixed interval (2, 5, and 12 s) in each environment (indoor and outdoor). In every repetition, Prototype II, Newtest Powertimer, and Chronojump Boscosystem recorded the same interval, generating 35 Prototype II-Newtest pairs and 35 Prototype II-Chronojump pairs for each interval-by-environment condition. The count of 35 repetitions was retained from the Prototype I protocol to preserve methodological comparability and represents a technical-replication target rather than a participant-based sample-size calculation. Because these were repeated technical observations rather than independent participant observations, confidence intervals should be interpreted as describing precision within the measurement series rather than population-level inference. Repeatability was evaluated with Prototype II at 1.5, 6, and 15 s across two indoor and two outdoor sessions, with 24 hours between repeated sessions.

Figure 2

Architecture and operation of Prototype II.



Statistical analysis

Data were analyzed with Jamovi (version 2.3.26.0). The Shapiro-Wilk test was used to assess distributional assumptions. Relative repeatability was described with a two-way random-effects intraclass correlation coefficient for absolute agreement (ICC(2,1)); however, because the fixed-interval design restricts true between-trial variability, interpretation prioritized absolute-error measures. The standard error of measurement (SEM) was reported in seconds as an absolute-error indicator, while the coefficient of variation (CV%) provided a complementary relative-error index (Hopkins, 2000; Koo & Li, 2016; Weir, 2005). The retained statistical documentation does not identify the exact computational expression originally used to derive SEM; therefore, no formula was assigned retrospectively, and the reported SEM values are interpreted descriptively rather than as a newly recalculated estimate. Agreement between Prototype II and the comparison systems was primarily summarized using Lin's concordance correlation coefficient (CCC), which incorporates both precision and accuracy (Lin, 1989). Bland-Altman and Deming procedures were retained as supplementary graphical method-comparison diagnostics (Bland & Altman, 1986; Giavarina, 2015; Linnet, 1993; Zou, 2013). Practical interchangeability was not inferred from a regression slope near 1 or an intercept confidence interval including 0 in isolation. No a priori maximum acceptable

difference was specified. In addition, the retained analytical output did not preserve interval-specific numerical Bland-Altman mean bias and limits of agreement or complete Deming slope/intercept confidence intervals and error-ratio settings; these values were therefore not reconstructed from the figures and were not used for inferential conclusions. The previously applied weighted Deming model for the 12 s indoor condition is interpreted only as an exploratory response to heteroscedasticity because its error-ratio specification was not documented in the retained output.

Ethical considerations

This was an instrumental study in which the measurement device, rather than the human collaborator, was the analytic unit. Collaborators participated voluntarily in non-invasive operational tasks limited to interrupting photocell beams; no participant-level outcome dataset, personal or sensitive information, physiological measures, or biomechanical measures were collected. Anonymity and confidentiality were preserved throughout.

Results

Analyses were organized into two complementary components: (a) repeatability and absolute measurement error of Prototype II at 1.5, 6, and 15 s across indoor and outdoor sessions, and (b) agreement between Prototype II and the two comparison systems at 2, 5, and 12 s.

Descriptive statistics and repeatability

Table 1 summarizes the descriptive statistics of Prototype II by session and environment. Mean values remained close to the nominal interval values across the three durations, absolute dispersion increased with interval length, and proportional stability was greatest at the 6 s and 15 s intervals, with no marked descriptive differences between environments.

Table 1

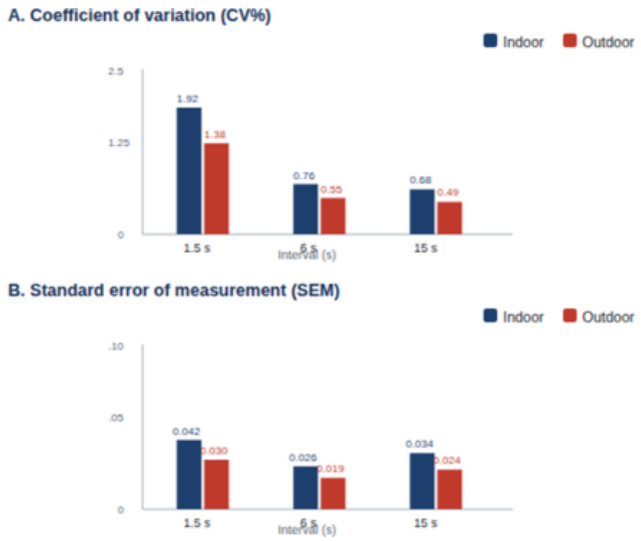
Descriptive statistics of Prototype II by session and environment.

Interval	Session	Environment	M (ms)	SD	Mdn	Min	Max
1.5 s	2	Outdoor	1510.6	34.2	1510	1450	1580
1.5 s	6	Outdoor	1508.3	36.8	1507	1449	1575
1.5 s	4	Indoor	1515.1	31.4	1513	1460	1568
1.5 s	5	Indoor	1512.7	33.0	1511	1458	1562
6 s	2	Outdoor	6015.4	97.3	6012	5841	6220
6 s	6	Outdoor	6018.6	102.8	6014	5845	6215
6 s	4	Indoor	6024.1	99.1	6016	5852	6228
6 s	5	Indoor	6020.7	95.4	6019	5849	6205
15 s	2	Outdoor	15018.3	224.9	15022	14525	15342
15 s	6	Outdoor	15011.6	219.8	15008	14538	15315
15 s	4	Indoor	15024.9	230.4	15020	14511	15348
15 s	5	Indoor	15008.1	227.2	15006	14534	15323

The Shapiro-Wilk test indicated distributions compatible with normality for the 1.5 s and 6 s intervals; the 15 s interval showed deviations from normality in two of the four sessions. ICC values for repeated Prototype II measurements were low or negative across intervals and environments (e.g., ICC = -0.176, 95% CI [-0.483, 0.099] for the outdoor 1.5 s comparison; ICC = 0.0037, 95% CI [-0.191, 0.211] for 6 s; ICC = 0.061, 95% CI [-0.123, 0.254] for 15 s). Given the restricted true variance produced by fixed-time technical trials, these ICCs were not used as the primary evidence of repeatability (Koo & Li, 2016). Absolute-error indices were more informative: CV% values were 1.92%, 0.70%, and 0.68% indoors and 1.38%, 0.55%, and 0.49% outdoors at 1.5, 6, and 15 s, respectively; corresponding SEM values were 0.042, 0.026, and 0.034 s indoors and 0.030, 0.019, and 0.024 s outdoors. Thus, relative error was greatest at 1.5 s and lower at 6 and 15 s. These values are reported descriptively because no a priori acceptable-error threshold was defined.

Figure 3

Absolute repeatability indicators (CV% and SEM) by interval and environment.



Agreement with reference systems

Table 2 reports Lin's CCC for Prototype II against each comparison system. Outdoors, CCC values ranged from 0.94 to 0.99 across intervals; at 5 s the point estimates were 0.96 for Newtest Powertimer and 0.99 for Chronojump Boscosystem. Indoors, CCC values ranged from 0.809 to 0.915 at 2 and 5 s and decreased to 0.623 and 0.636 at 12 s for Newtest and Chronojump, respectively. The 95% confidence interval for the 5 s outdoor Newtest comparison was not retained in the available analytical output and is therefore reported as NR rather than estimated. Because no a priori allowable difference was defined and interval-specific numerical Bland-Altman bias/limits of agreement and complete Deming coefficients were not available in the retained output, the CCC values and scatterplots are interpreted as evidence of agreement within the tested series, not as proof of absence of bias or practical interchangeability. Weighted Deming had previously been applied to the 12 s indoor condition in response to heteroscedasticity, but its error-ratio specification was not documented; no quantitative conclusion is therefore based on that model.

Table 2

Lin's concordance correlation coefficient (CCC) between Prototype II and each reference instrument.

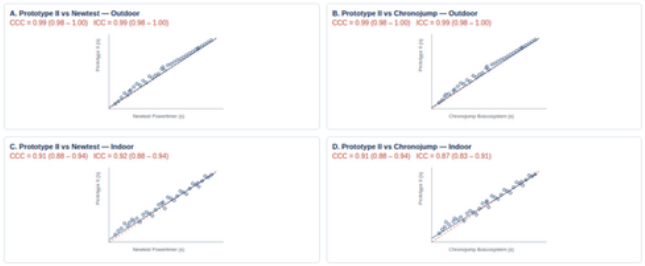
Interval	Environment	Reference instrument	CCC	95% CI
2 s	Outdoor	Newtest Powertimer	0.94	[0.90, 0.96]
2 s	Outdoor	Chronojump Boscosystem	0.98	[0.96, 0.99]
5 s	Outdoor	Newtest Powertimer	0.96	NR
5 s	Outdoor	Chronojump Boscosystem	0.99	[0.97, 0.99]
12 s	Outdoor	Newtest Powertimer	0.97	[0.94, 0.99]
12 s	Outdoor	Chronojump Boscosystem	0.98	[0.95, 0.99]
2 s	Indoor	Newtest Powertimer	0.814	[0.721, 0.878]
2 s	Indoor	Chronojump Boscosystem	0.915	[0.864, 0.947]
5 s	Indoor	Newtest Powertimer	0.809	[0.705, 0.880]
5 s	Indoor	Chronojump Boscosystem	0.915	[0.864, 0.947]
12 s	Indoor	Newtest Powertimer	0.623	[0.401, 0.766]
12 s	Indoor	Chronojump Boscosystem	0.636	[0.414, 0.775]

Note. NR = not retained in the available analytical output. The 5 s outdoor Newtest CCC point estimate (0.96) was available in the original summary output, but its 95% confidence interval was not available and was not reconstructed.

Two-way random-effects ICC values for the same method-comparison observations followed a similar descriptive pattern: 0.942-0.987 outdoors, 0.814-0.935 indoors at 2 and 5 s, and 0.630-0.643 at 12 s indoors. These values are supplementary because the observations are repeated technical measurements rather than independent participant measurements and because ICC remains sensitive to the variance structure of the sample. Figure 4 displays the method-comparison scatterplots, the line of identity, and exploratory Deming fits; it should not be interpreted as establishing interchangeability in the absence of numerical limits of agreement and a predefined acceptable-difference criterion.

Figure 4

Agreement between Prototype II and the two reference systems.



Discussion

The main objective of this study was to evaluate the repeatability of Prototype II and its agreement with two commercially available timing systems when measuring fixed intervals during controlled horizontal-displacement tasks. The analytical unit was the measurement itself, not human performance; collaborators only triggered the photocells in response to standardized signals. Consequently, the findings describe instrumental behavior under the tested protocol and should not be interpreted as evidence about sprint, agility, or other athletic performance outcomes.

The low or near-zero ICC values for repeated Prototype II measurements should not be interpreted in isolation. In designs based on fixed technical intervals, restricted between-trial variance can destabilize the ICC because the coefficient depends on the ratio between between-unit and residual variance (Koo & Li, 2016; Shrout & Fleiss, 1979). For this reason, the revised interpretation gives greater weight to absolute repeatability. CV% ranged from 0.49% to 1.92% and SEM from 0.019 to 0.042 s, with lower relative error at 6 and 15 s than at 1.5 s. These values quantify the magnitude of repeatability error, but they are not labeled as clinically or practically acceptable because the study did not prespecify an acceptance threshold (Atkinson & Nevill, 1998; Hopkins, 2000; Weir, 2005).

Agreement with the comparison systems was strongest outdoors (CCC = 0.94-0.99), remained higher at 2 and 5 s indoors (CCC = 0.809-0.915), and was lower at 12 s indoors (CCC = 0.623-0.636). These coefficients indicate the degree of concordance observed in the tested measurement series, but CCC alone does not establish that two methods are interchangeable. Likewise, a Deming slope visually close to the line of identity or an intercept compatible with zero is insufficient to demonstrate absence of practically relevant bias. Demonstrating interchangeability would require a prespecified maximum acceptable difference and explicit Bland-Altman bias and limits of agreement evaluated against that threshold (Bland & Altman, 1986; Giavarina, 2015; Lin, 1989; Linnet, 1993). Because those interval-specific numerical outputs were not retained in the available analytical record, the revised manuscript deliberately avoids claims of no bias, equivalence, or interchangeability.

Interval duration and testing environment were descriptively associated with measurement behavior. The 1.5 s condition showed the largest relative error, whereas the 6 and 15 s conditions showed lower CV% values. In the method-comparison analyses, the 12 s indoor condition showed the lowest CCC values. These patterns may reflect the greater influence of small absolute timing differences at shorter intervals and condition-specific variance at longer intervals, but the present design does not support a causal explanation. The 12 s indoor finding should therefore be regarded as a condition requiring targeted replication and full reanalysis of the paired raw data rather than as evidence of a definitive environment-by-duration interaction.

From a technological-development perspective, Prototype II can be regarded as a consistent evolution of the line of work initiated with Prototype I (Gutiérrez Vargas, 2023), expanding the evaluation to outdoor conditions and to a broader multimethod

statistical approach. This continuity is especially relevant in contexts where access to specialized equipment depends largely on imported commercial technology, since it favors local innovation and scientific autonomy in human-movement measurement (Pino-Ortega & Rico-González, 2021).

This study has several limitations. Controlled photocell interruptions isolated technical behavior but did not reproduce the biomechanical and functional conditions of real human displacement such as acceleration, deceleration, technique, or fatigue. Some outdoor environmental factors could not be fully controlled. The number of unique human collaborators was not retained because no participant-level dataset was created. The 35 observations per condition were technical repetitions retained for comparability with the Prototype I protocol rather than a participant-based sample justified by an inferential sample-size calculation, and repeated technical observations may not be statistically equivalent to independent observations. The comparison systems were not established within this study as traceable metrological gold standards, and no a priori maximum acceptable difference was defined. Most importantly, the retained analytical output did not include the interval-specific numerical Bland-Altman mean bias and limits of agreement, the complete Deming slopes/intercepts with confidence intervals, or the error-ratio specification used for weighted Deming; the 95% CI for the 5 s outdoor Newtest CCC was also unavailable. These quantities were not reconstructed from graphical displays. Accordingly, the present data support a cautious description of repeatability and agreement but cannot establish criterion validity, absence of bias, or practical interchangeability. Reanalysis of the original paired raw data and future validation against traceable timing standards are required before stronger metrological claims are made (Portney & Watkins, 2015; Zou, 2013).

Conclusions

Prototype II showed quantifiable repeatability error when measuring fixed time intervals under the tested indoor and outdoor conditions: CV% ranged from 0.49% to 1.92% and SEM from 0.019 to 0.042 s. Agreement with Newtest Powertimer and Chronojump Boscosystem varied by condition, with CCC values of 0.94-0.99 outdoors, 0.809-0.915 indoors at 2 and 5 s, and 0.623-0.636 at 12 s indoors. Low or negative ICC values for repeated fixed-interval measurements should be interpreted cautiously because the restricted between-trial variance limits the usefulness of relative reliability coefficients in this design. The present results do not establish criterion validity or practical interchangeability, because the study did not define an a priori acceptable-difference threshold and the interval-specific numerical Bland-Altman limits of agreement and complete Deming outputs were not available for the present report.

Taken together, the findings identify Prototype II as a promising locally developed timing system whose technical performance warrants further study rather than as a demonstrated replacement for the commercial systems. Future work should include traceable calibration or verification, prospective definition of acceptable measurement error, complete reporting of Bland-Altman and Deming estimates from the paired raw data, and testing during real sprinting, change-of-direction, agility, and other movement tasks in more ecologically valid settings. Such work is necessary to establish the practical relevance and external validity of the device for educational, sport-training, and research applications.

Statement on the use of artificial intelligence

During development of the theoretical background, Anthropic's Claude (large-language-model assistant; version not retained in the project record) was used to

with identification and shortlisting of candidate literature. During preparation of the revised manuscript, OpenAI ChatGPT (GPT-5.6 Sol; accessed October 2026) was used for language editing, organization of responses to peer review, and consistency checking. No artificial-intelligence tool generated or altered raw measurements or performed the statistical analyses reported in this manuscript. All AI-assisted text was critically reviewed by the authors against the original study records and cited sources; numerical values, interpretations, references, and final wording were verified by the authors, who assume full responsibility for the manuscript.

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