

60-m sprint time and late-segment stride measures during horizontal plyometric training in youth athletes: A single-group field study

Carlos Francisco Hernández García. *University Institute of Physical Education and Sport. University of Antioquia (UdeA). Medellín, Colombia.*

 **Wilder Geovanny Valencia-Sánchez**  . *University Institute of Physical Education and Sport. University of Antioquia (UdeA). Medellín, Colombia.*

 **Samuel José Gaviria-Alzate.** *Faculty of Education and Social Sciences. Antioquia Institute of Technology – University Institution (TdeA). Medellín, Colombia.*

ABSTRACT

This exploratory single-group study examined changes in 60-m sprint time and late-segment stride measures during six weeks of horizontal plyometric training. Nine male track-and-field athletes aged 12-13 years were assessed before and after a programme of 12 planned sessions. Sprint time was recorded with a smartphone application, and stride length, stride time and ground contact time were assessed from 120-Hz video over 40-48 m. Pre-test-post-test changes were analysed at the athlete level. Mean 60-m sprint time decreased from 10.46 ± 0.39 to 10.18 ± 0.28 s (mean change -0.282 s, 95% CI -0.479 to -0.085 s; $p = .011$; $d_z = -1.10$). Changes in stride length, stride time and ground contact time within the 40-48-m segment were inconclusive, with all confidence intervals including zero. Lower whole-sprint time was therefore accompanied by uncertain late-segment estimates, leaving the phase and mechanical basis of the change unresolved. The uncontrolled design and measurement uncertainty preclude attribution to the training programme. For youth sprint monitoring, total timing, phase-specific assessment and mechanical analysis provide complementary information; a change in overall performance does not, by itself, establish where or how that change occurred.

Keywords: biomechanics; measurement uncertainty; adolescence; field assessment; kinematics.

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 **Corresponding author.** *Instituto Universitario de Educación Física y Deporte, Universidad de Antioquia (UdeA), Calle 70 No. 52-21, Medellín, Colombia.*

E-mail: Wilder.valencia@udea.edu.co

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INTRODUCTION

Sprint performance is an important component of youth track-and-field and contributes to performance across many sports. Sprint velocity emerges from the interaction between stride length and stride frequency, which in turn reflects the magnitude, orientation, and timing of force application during ground contact (Buchheit et al., 2014; Haugen et al., 2019; Hunter et al., 2004; Morin et al., 2012). However, sprinting is not mechanically uniform across the race. Early acceleration depends strongly on the ability to produce and orient force horizontally, whereas maximum-velocity running requires high force production within progressively shorter ground-contact times (Buchheit et al., 2014; Haugen et al., 2019; Morin et al., 2012). Consequently, an improvement in total sprint time does not necessarily indicate that acceleration and maximum-velocity mechanics changed to the same extent.

Plyometric training uses rapid stretch-shortening-cycle actions to develop neuromuscular power and can improve sprint and jump performance (Cormie et al., 2011; Markovic & Mikulic, 2010; Sáez de Villarreal et al., 2012). When progressively prescribed and appropriately supervised, plyometric training is considered suitable for children and adolescents (Lloyd & Oliver, 2012; Lloyd et al., 2016; Ramirez-Campillo et al., 2023). Evidence from young athletes indicates that sprint adaptations may depend on age, maturation status, training dose, and exercise orientation (Norgeot & Fouré, 2024; Ramírez-Campillo et al., 2015; Ramirez-Campillo et al., 2023; Tottori & Fujita, 2019). In pre-adolescent boys, plyometric training has been associated with improvements in sprint velocity and step length during the maximum-velocity phase (Tottori & Fujita, 2019). Moreover, horizontally oriented plyometric exercises may have particular relevance to sprint acceleration because of the importance of horizontally directed force production during the early stages of sprinting (Kossow et al., 2018; Loturco et al., 2015; Moran et al., 2021; Samozino et al., 2022). Nevertheless, comparisons of vertical, horizontal, and combined plyometric programmes suggest that transfer is outcome-specific rather than determined solely by exercise direction (Moran et al., 2021; Norgeot & Fouré, 2024; Ramírez-Campillo et al., 2015).

Biological maturation is an additional consideration in youth training research. Athletes of the same chronological age may differ substantially in growth and maturational status, which can influence physical performance and responsiveness to training (Lloyd et al., 2016; Malina et al., 2015). This is especially relevant in athletes aged 12-13 years, who may be positioned before, near, or after peak height velocity. Studies comparing maturity groups indicate that sprint and jump adaptations to plyometric or combined training may differ between pre- and post-peak-height-velocity athletes (Lloyd et al., 2016). Therefore, findings from small chronological-age groups should be interpreted cautiously when biological maturation has not been assessed.

For coaches, an important question is whether a change in total sprint time is accompanied by a change in the running pattern being monitored. Total time integrates performance across the entire distance, whereas video from one segment describes only the strides sampled there. The two measurements are complementary, but neither identifies the information supplied by the other. Their interpretation is especially consequential in small youth squads, where accessible equipment may provide whole-sprint timing and a limited view of stride mechanics without a continuous velocity profile.

This study examined paired changes in 60-m sprint time and stride measures from the 40-48-m segment during a six-week period of training that included horizontal plyometrics. The aim was to describe whole-sprint and late-segment changes together, without assuming that a change in total time identified its location

or mechanism. The analysis was exploratory, with 60-m sprint time as the principal outcome and stride length, stride time and ground contact time as secondary outcomes.

MATERIAL AND METHODS

Participants

Nine male track-and-field athletes aged 12-13 years from a municipal squad in the Urabá subregion of Antioquia, Colombia, were included in the analysis. All nine had paired pre-test and post-test values for the four outcomes. Eligibility required at least two months of athletics practice. Biological maturation was not assessed, and individual anthropometric data and detailed training histories were unavailable.

Study design

The study used a single-group pre-test-post-test design within the squad's regular training programme. The investigator was the athletes' usual coach, and the plyometric sessions and sprint/video assessments took place during scheduled club training, without additional study-specific visits. There was no control group or random allocation.

Measures

60-m sprint assessment

Athletes performed three maximal 60-m sprints at each assessment, with approximately five minutes of recovery between attempts. They started without blocks, from a semi-erect position with one foot advanced and the opposite hand on the ground.

Sprint time was recorded using the Photo Finish application on a Xiaomi Mi 10 Pro smartphone. Timing began with an acoustic start signal, and the camera identified the finish. The same device and procedure were used at both assessments, and times were transferred to a spreadsheet.

Photo Finish has been evaluated against photocells over shorter sprint protocols (Marco-Contreras et al., 2024). This evidence does not provide a protocol-specific typical error or smallest detectable change for the present 60-m assessment in early-adolescent athletes.

Video recording and stride analysis

Sagittal-plane video was recorded at 1920×1080 pixels and $120 \text{ frames} \cdot \text{s}^{-1}$ using a Xiaomi Mi 10 Pro smartphone. The camera was mounted on a tripod approximately 7 m perpendicular to the running lane, at around half the athlete's standing height and centred on the 40–48-m analysis zone. This zone was treated as a late-sprint segment because individual maximum velocity within it was not verified.

Videos were analysed in Kinovea version 0.9.5. Spatial calibration used each athlete's greater-trochanter-to-lateral-femoral-condyle distance when the runner was perpendicular to the camera. The calibration was not validated against a fixed reference in the movement plane. Original calibration images were unavailable, preventing assessment of landmark visibility, plane alignment and perspective error.

A stride was defined as one complete cycle of the same limb. Stride length was the horizontal displacement between successive ground contacts of that limb; ground contact time was the interval from initial contact to toe-off; and stride time was the interval between successive initial contacts. The recording frequency corresponded to 8.33 ms between frames. Temporal summaries are presented to whole milliseconds for readability.

One complete stride of the self-reported dominant limb was assessed in each of the three runs by the same analyst. Independent verification and intra- and inter-rater reliability were not established for the video-derived measures; analyst blinding could not be confirmed.

Validation studies of smartphone-based running and sprint measurements demonstrate the importance of evaluating a specific recording and analysis procedure (Balsalobre-Fernández et al., 2017; Romero-Franco et al., 2017). The present combination of camera placement, anatomical calibration and temporal extraction was not validated against a criterion system.

Procedures

Both assessments were conducted on the same outdoor athletics track in the Urabá subregion of north-western Colombia, an area characterised by a warm, humid tropical climate.

The warm-up comprised general activation, general and exercise-specific dynamic stretching, and short runs. Its duration and repetition counts were not recorded.

Plyometric training programme

The programme prescribed two horizontal-jumping sessions per week for six weeks, on Tuesdays and Thursdays at approximately 15:00, with around 48 h between sessions. The 12 sessions were scheduled within regular club training on a concrete athletics surface.

Sessions 1-6 prescribed bilateral jumps and sessions 7-12 unilateral jumps. The planned volume was 1,209 jump repetitions, comprising 420 bilateral and 789 unilateral repetitions. Target distances were expressed as percentages of each athlete's baseline maximum horizontal jump distance and marked with cones. Approximately 15 s separated repetitions, with 100 m of walking recovery between series. Higher distance targets involved fewer consecutive jumps and lower targets more consecutive jumps; the exact allocation into sets and repetitions was unavailable. The percentages describe distance targets rather than measured mechanical intensity. Table 1 presents the session plan.

Table 1. Six-week horizontal plyometric training plan.

Session	Planned jump repetitions	Target distance (% MHJD)	Orientation
1	50	100	Bilateral
2	50	100	Bilateral
3	70	90	Bilateral
4	70	90	Bilateral
5	90	80	Bilateral
6	90	80	Bilateral
7	110	70	Unilateral
8	110	70	Unilateral
9	160	80	Unilateral
10	160	80	Unilateral
11	120	90	Unilateral
12	129	90	Unilateral
Total	1,209	-	420 bilateral; 789 unilateral

Note. MHJD = baseline maximum horizontal jump distance. Counts denote jump repetitions, not individually verified foot contacts. The planned total is 1,209 repetitions: 420 bilateral and 789 unilateral. Distance targets were marked with cones; the documented recovery was approximately 15 s between repetitions and 100 m of walking between series. Exact sets achieved target distances, attendance, limb allocation, completed dose and adverse events were not recoverable. The plan is a historical exposure description, not a validated safe or effective prescription.

An attendance criterion of at least 80% was specified in the programme. Session-level attendance, completed repetitions, limb allocation, achieved distances, technical quality, concurrent training and exertion ratings were unavailable. Pain, injury and other adverse-event records were also unavailable; actual exposure, adherence and safety could therefore not be evaluated.

Ethical safeguards

Field activities and data collection were completed in 2022 within the athletes' regular club training programme. The project was subsequently reviewed and approved by the Research Ethics Committee of Tecnológico de Antioquia - Institución Universitaria, Medellín, Colombia, on 27 May 2026 (Acta No. 04, semester 2026-01), which classified the reviewed project as research without risk under Article 11 of Colombian Resolution 8430 of 1993. Because the review occurred after completion of the field activities, it was retrospective and did not constitute prospective ethical oversight of the 2022 data collection. Because the participants were minors, the surviving consent documentation and its limitations are reported explicitly under Consent to participate. The present report is restricted to retrospective analysis of pre-existing, de-identified records; no additional participant contact, intervention or data collection was undertaken for this analysis, and no directly identifying information is reported.

Analysis

The original analyses were conducted in IBM SPSS Statistics version 25; the reported calculations were reproduced in Python.

The athlete was the unit of analysis. For each outcome, one pre-test and one post-test athlete-level value were included in the paired analyses. Three attempts were completed at each assessment, although separately identifiable trial-level values were not retained in the archived dataset. No imputation was performed, and change was calculated as post-test minus pre-test.

Sprint split times and adverse events were listed in the retrospective registry. Horizontal-jump outcomes were excluded from inferential analysis because paired values were available for only three athletes. Means and standard deviations summarised each assessment. Two-sided paired-samples *t* tests were used for sprint time, stride length and stride time. Ground contact time was analysed using an exact Wilcoxon signed-rank test, excluding zero differences and assigning mid-ranks to tied absolute differences. The exact probability was obtained by enumerating the possible sign allocations of the non-zero pairs.

For each outcome, the 95% confidence interval (CI) for mean paired change was calculated as the mean difference $\pm t(0.975, 8) \times \text{SD of the differences}/\sqrt{9}$. The ground-contact-time interval was descriptive and *t*-based, rather than derived from the signed-rank test. Cohen's *d_z* was calculated as the mean paired difference divided by its standard deviation. Rank-biserial correlation (*r_{tb}*) for ground contact time used non-zero pairs only. Relative change was $100 \times \text{mean paired change}/\text{group pre-test mean}$; the same scaling was applied to the confidence limits. These intervals describe sampling uncertainty conditional on the analysed values and do not account for their provenance or measurement error.

Sprint time was the principal descriptive outcome and the stride measures were exploratory. No adjustment for multiple comparisons was applied. Interpretation prioritised the direction, magnitude and confidence interval of each estimate over statistical significance alone. Sample size was determined by the availability of paired data for nine athletes, without a prospective sample-size calculation. No equivalence margin or threshold for a practically meaningful individual change was specified.

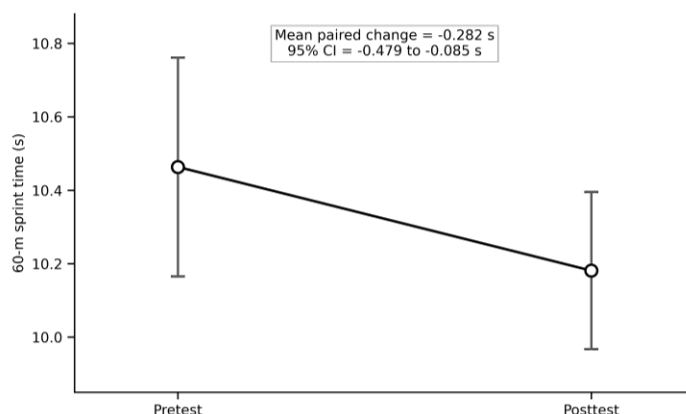
RESULTS

Table 2 presents the pre-test and post-test values and paired changes for the nine athletes. Figure 1 shows the group sprint-time means, and Figure 2 places relative changes across the four outcomes on a common scale.

Table 2. Paired changes in 60-m sprint time and late-segment stride measures (nine archived pairs).

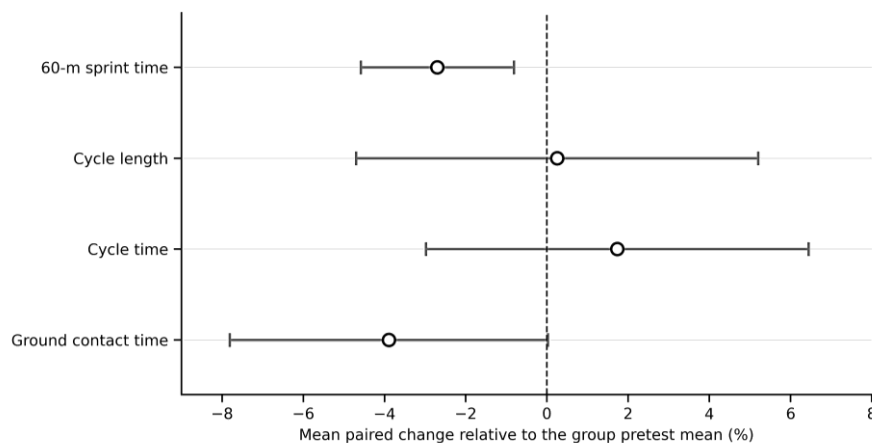
Outcome	Pre, M $\pm$ SD	Post, M $\pm$ SD	Mean paired change [95% CI]	Test statistic; <i>p</i>	Standardised change
60-m sprint time (s)	10.46 $\pm$ 0.39	10.18 $\pm$ 0.28	-0.282 [-0.479, -0.085]	<i>t</i> (8) = -3.30; <i>p</i> = .011	<i>dz</i> = -1.10
Stride length (cm)	381.6 $\pm$ 21.4	382.6 $\pm$ 30.8	+1.0 [-17.9, +19.9]	<i>t</i> (8) = 0.12; <i>p</i> = .909	<i>dz</i> = 0.04
Stride time (ms)	519 $\pm$ 33	528 $\pm$ 47	+9 [-15, +33]	<i>t</i> (8) = 0.85; <i>p</i> = .421	<i>dz</i> = 0.28
Ground contact time (ms)	140 $\pm$ 14	134 $\pm$ 16	-5 [-11, 0] ¹	<i>W</i> = 0; <i>p</i> = .125 ²	<i>rrb</i> = -1.00 ²

Note. Analyses use one retained entry per athlete, outcome and occasion (*n* = 9), not verified three-attempt means. Changes are post-test minus pre-test. Confidence intervals condition on the retained entries and do not include measurement or source-record uncertainty. ¹ Temporal summaries are rounded to whole milliseconds; acquisition was specified at 120 Hz (8.33 ms per frame). The contact-time interval is descriptive and *t*-based, rather than an inversion of the signed-rank test; its upper bound is slightly positive before rounding. ² The exact signed-rank test excludes five zero differences and enumerates the 16 possible sign allocations of the four non-zero mid-ranks. The rank-biserial coefficient applies only to those four pairs. *dz* = Cohen's standardised paired change; *rrb* = rank-biserial correlation.



Note. Values are means with 95% confidence intervals for each occasion mean (*n* = 9).

Figure 1. Recorded sprint time across the training period.



Note. Points are mean paired changes and horizontal bars are 95% confidence intervals (*n* = 9).

Figure 2. Whole-sprint and late-segment changes.

Mean 60-m sprint time decreased from 10.46 ± 0.39 s to 10.18 ± 0.28 s. The mean paired change was -0.282 s (95% CI -0.479 to -0.085), equivalent to -2.7% ($t(8) = -3.30$, $p = .011$, $d_z = -1.10$). All nine athletes had lower post-test values; individual changes ranged from -0.86 to -0.02 s.

Mean stride length was 381.6 ± 21.4 cm at pre-test and 382.6 ± 30.8 cm at post-test, a paired change of $+1.0$ cm (95% CI -17.9 to $+19.9$), or approximately $+0.3\%$ ($t(8) = 0.12$, $p = .909$, $d_z = 0.04$).

Mean stride time was 519 ± 33 ms at pre-test and 528 ± 47 ms at post-test, a paired change of $+9$ ms (95% CI -15 to $+33$), or approximately $+1.7\%$ ($t(8) = 0.85$, $p = .421$, $d_z = 0.28$).

Mean ground contact time was 140 ± 14 ms at pre-test and 134 ± 16 ms at post-test. The mean paired change was approximately -5 ms (-3.9%), with a descriptive 95% CI of approximately -11 to 0 ms; the unrounded upper limit was slightly positive. Five athletes had identical pre-test and post-test values and four had lower post-test values. The exact signed-rank test gave $W = 0$ and $p = .125$; $r_b = -1.00$ among the four non-zero pairs.

DISCUSSION

Mean 60-m sprint time was approximately 0.28 s lower at the end of the training period, while estimates of change in the 40-48-m stride measures remained imprecise. The central finding is therefore a difference in whole-sprint time with inconclusive information about the accompanying late-segment running pattern. Total sprint time and measurements from one short segment describe different aspects of performance; interpreting them together requires distinguishing the magnitude of a change from its location and mechanical basis.

The direction of the sprint-time change is consistent with reports of improved sprint performance following plyometric training (Cormie et al., 2011; Lloyd & Oliver, 2012; Lloyd et al., 2016; Markovic & Mikulic, 2010; Ramirez-Campillo et al., 2023; Sáez de Villarreal et al., 2012). Horizontally directed exercises provide a plausible stimulus for the force-production demands of sprint acceleration (Kossow et al., 2018; Loturco et al., 2015, 2018; Moran et al., 2021; Samozino et al., 2022), but comparisons of exercise orientations indicate that transfer depends on the performance outcome and training context (Moran et al., 2021, 2024; Norgeot & Fouré, 2024; Ramírez-Campillo et al., 2015). The present study adds an exploratory description from a municipal youth squad, rather than evidence that horizontal exercises are superior or that they caused the difference in sprint time.

Interpreting the late-segment measures

Stride length and stride time must be interpreted jointly; a longer stride does not by itself imply greater running speed if its duration also increases. Their mean changes were approximately $+0.3\%$ and $+1.7\%$, respectively, but both confidence intervals included changes in either direction. These estimates are insufficient to establish a change in segment velocity, which was not measured directly. Equally, they do not establish that mechanics were unchanged. A contrast between the statistical results for total sprint time and a stride measure is not evidence of a physiological dissociation.

An earlier-phase change is one hypothesis that could explain lower total time without a clear difference in the sampled strides. It remains untested here because sprint splits, continuous velocity, acceleration kinematics and force measurements were unavailable. Cross-sectional evidence also indicates age-related differences in sprint-phase distribution (Bleeker & Siener, 2025), cautioning against assigning the same 40–48-m zone

to every athlete's maximum-velocity phase. Validated split timing at 5, 10, 20, 30, 40 and 60 m, or continuous velocity measurement, would distinguish a change in acceleration from one later in the sprint.

Ground contact time showed a different descriptive pattern: five athletes had identical recorded values across assessments and four had reductions. The rank-biserial coefficient of -1.00 reflects the consistent direction of only those four non-zero differences, not a uniformly large response across the group. Its magnitude must therefore be read alongside the small number of contributing pairs, the descriptive confidence interval and the temporal resolution. Similarly, variation in sprint-time changes does not separate training responsiveness from ordinary fluctuation or measurement error; responder classifications are not supported.

Training exposure and monitoring

The programme combined an individualised distance prescription with a bilateral-to-unilateral progression. Controlled research in youth athletes has examined the consequences of different plyometric volumes (Azarain-Cardiel et al., 2024). In the present study, however, 1,209 repetitions describe the prescription, not the dose completed. The relationship between exposure and performance change cannot be estimated without attendance, completed work and concurrent-training records. The programme, including its concrete-surface setting, should therefore be understood as the training context rather than a validated prescription or evidence of safety.

A practical monitoring strategy should begin with the coaching question (Table 3). Whole-sprint timing describes total performance; split timing or continuous velocity locates changes within the sprint; calibrated video characterises selected stride measures; and suitable mechanical profiling addresses force-velocity determinants. These are complementary levels of assessment, not interchangeable indicators. The framework is a proposal for organising measurements, not a validated tool from this study. In resource-limited programmes, the priority is a small, reproducible set of measures that answers the intended question, with preserved trial records and an established error range.

Table 3. A question-led monitoring framework for resource-limited youth programmes.

Question	Minimum measurement layer	Record and quality check to preserve	Inference not supported by that layer alone
Did recorded whole-sprint performance change?	Standardised total sprint timing with clearly defined start and finish.	Original time-stamped export or video; authentic repeated attempts; aggregation rule; device, start protocol, recovery and testing conditions; exact-protocol test-retest error.	Causation by the training block, location of a phase change, or an individual response beyond error.
Where within the sprint did a difference occur?	Validated split timing or a suitable continuous velocity measure.	Segment distances; synchronisation and event definitions; segment-specific reliability. Future studies may use 5-, 10-, 20-, 30-, 40- and 60-m splits.	Which force or stride mechanism produced the segment difference.
Which segment-specific stride quantity differed?	Video with an appropriate frame rate, fixed spatial calibration and operational event definitions.	Original recordings; frame indices for contact and toe-off; calibration in the movement plane; repeated digitisation and, where feasible, blinded independent analysis.	A validated maximum-velocity phase without individual verification, whole-race mechanics, or direct force measurement.
Which mechanical determinant is implicated?	Appropriate validated velocity-based modelling or direct force instrumentation.	Model inputs, equations and assumptions; reference validation; uncertainty estimates; separation of model-derived quantities from directly measured forces.	A force-velocity profile from a single total time, a stride length or exercise orientation alone.

Note. This proposed framework was not tested or validated in the present study. Each approach requires protocol-specific validation, preserved source records and appropriate research oversight, consent and data governance when used for research.

Limitations and future research

Measurement error is particularly important when interpreting a change of approximately 0.28 s in total time or approximately 5 ms in ground contact time. External Photo Finish validation (Marco-Contreras et al., 2024) does not establish test–retest error for the present 60-m procedure, so the sprint-time difference cannot be compared with a protocol-specific detectable-change threshold. At 120 Hz, the interval between frames is 8.33 ms. Averaging can yield a mean change smaller than one frame but cannot improve the acquisition resolution. Missing event annotations and the unvalidated anatomical calibration further limit confidence in the temporal and spatial estimates.

The small male sample from a single squad limits precision and generalisability. Incomplete recruitment records prevent reconstruction of the full enrolment process and assessment of selection into the analytical sample. Without a comparison group, the sprint-time change remains compatible with familiarisation, regular training, maturation, motivation, environmental variation, regression to the mean and measurement error. The unavailable trial-level records and aggregation rule also prevent independent verification of the analysed values. Biological maturation was not assessed, so developmental status could not be considered when interpreting group or individual changes. Training exposure, adherence and safety could not be quantified, and protocol-specific timing and analyst reliability were not established.

Future studies should use randomised or appropriately matched comparisons with equivalent usual-training exposure and a sample size justified by a practically meaningful change and measurement error. Developmental assessment should use repeated anthropometry or another suitable maturation measure (Malina et al., 2015). Comparison with electronic timing gates and between-day repeat assessments in similar youth athletes would establish protocol-specific validity and reliability. Video analysis should include a fixed calibration reference and repeat or blinded independent digitisation. Session records should capture completed work, technical quality, pain and adverse events alongside concurrent training. These measures would allow performance change, developmental variation and measurement uncertainty to be considered separately.

CONCLUSION

The six-week training period coincided with lower recorded 60-m sprint time, while changes in late-segment stride measures remained uncertain. The study does not establish a plyometric training effect or identify the phase or mechanism of the total-time difference. For coaches, the main implication is to match the measurement to the question: total timing describes performance, whereas phase localisation and mechanical explanation require additional, appropriately validated assessments.

AUTHOR CONTRIBUTIONS

All authors meet the criteria for authorship in accordance with established ethical guidelines. Contributions are specified according to the CRediT (Contributor Roles Taxonomy) as follows:

Conceptualisation: Carlos Francisco Hernández García. Methodology: Carlos Francisco Hernández García. Formal analysis: Samuel José Gaviria-Alzate. Investigation: Carlos Francisco Hernández García. Data curation: Carlos Francisco Hernández García. Writing – original draft: Carlos Francisco Hernández García. Writing – review & editing: Wilder Geovanny Valencia-Sánchez, Samuel José Gaviria-Alzate. Supervision: Wilder Geovanny Valencia-Sánchez.

All authors have critically reviewed and approved the final version of the manuscript and agree to be accountable for all aspects of the work.

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CONFLICT OF INTEREST

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this manuscript.

ETHICS APPROVAL

Field activities and data collection were completed in 2022. The project was subsequently reviewed and approved by the Research Ethics Committee of Tecnológico de Antioquia - Institución Universitaria, Medellín, Colombia, on 27 May 2026 (Acta No. 04, semester 2026-01), which classified the reviewed project as research without risk under Article 11 of Colombian Resolution 8430 of 1993. Because this review occurred after data collection, the approval was retrospective and did not constitute prospective ethical oversight of the 2022 field activities.

CONSENT TO PARTICIPATE

The original 2022 academic project included a research-specific informed-consent form describing the study, its procedures, voluntary participation, use of participant data and the right to withdraw, with separate signature fields for a parent or legal guardian and the athlete. Completed signed forms are not available in the surviving project archive; therefore, research-specific parental consent and participant assent cannot now be retrospectively verified, and the authors do not claim otherwise. Parents or legal guardians had authorised participation in the athletes' regular club training programme and associated assessments. The present secondary analysis is limited to pre-existing, de-identified records. The subsequent institutional review classified the project as research without risk under Article 11 of Colombian Resolution 8430 of 1993; no waiver of consent or prospective ethical oversight is claimed. No participant re-contact was undertaken and no directly identifying information is reported.

DATA AVAILABILITY

Aggregate outputs and de-identified analytical materials that do not permit participant identification are available from the corresponding author upon reasonable request, subject to appropriate confidentiality safeguards. Original source records and participant-level materials are not publicly available.

TRIAL REGISTRATION

The study was retrospectively registered at ClinicalTrials.gov in 2026 (NCT07571083).

AI USE DISCLOSURE

In accordance with current publishing ethics and transparency recommendations, ChatGPT assisted with language editing, source checking, statistical verification through code preparation and execution, and

revision of methodological and interpretative text. Claude also assisted with manuscript preparation. The authors critically reviewed and verified all AI-assisted material, made the final decisions concerning the study design, analysis, interpretation and conclusions, and retain full responsibility for the originality, integrity and accuracy of the manuscript.

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