ORIGINAL ARTICLE

Evaluation of integrated sprint and plyometric interventions for enhancing spatial performance of sprinters

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Abstract

Background and Study Aim Sprint performance is strongly influenced by neuromuscular coordination and spatial running mechanics. Sprint training commonly includes speed work together with strength and plyometric exercises. Although these approaches are used in practice, their relative effectiveness in improving key spatial sprint parameters remains of practical interest. Therefore, the present study sought to investigate the effects of a ten-week integrated sprint and plyometric training programme on selected key spatial sprint-related parameters in male sprinters.

Material and Methods The experimental group underwent sprint and plyometric training three times a week, while the control group followed their normal sprint training schedule. Ground contact time, step length, stride length, and 30 m sprint time were assessed at baseline and after the intervention. Data were analyzed using mixed analysis of variance (ANOVA) and analysis of covariance (ANCOVA), in which body mass index (BMI) was entered as a covariate.

Results The experimental group showed a statistically significant decrease in ground contact time and sprint time, while showing a significant increase in step length and stride length during the pre- to post-assessment period ($p < 0.001$). In contrast, no statistically significant changes in any spatial parameters were recorded for the control group over the same period ($p > 0.05$). Pronounced time × group interactions were observed for the examined spatial parameters ($p \leq 0.005$).

Conclusions Integrated sprint and plyometric training is associated with beneficial adaptations relevant to sprint performance in male sprinters. This approach reflects coordinated neuromuscular and mechanical responses during sprint execution and supports its practical application in training settings.

Keywords: plyometrics, ground contact time, stride mechanics, neuromuscular adaptations, sprinters

Introduction

Sprint performance represents a complex motor task that depends on the coordination of multiple biomechanical and physiological processes during high-speed running. Effective sprinting requires the precise interaction of force production, limb positioning, and temporal control of ground contact in order to maintain forward acceleration and running efficiency. Small variations in step and stride characteristics can substantially influence running velocity and movement economy, making spatial parameters an important component of performance evaluation. Consequently, training strategies that simultaneously address mechanical execution and neuromuscular control are of practical importance in sprint preparation and require detailed examination in applied training contexts.

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Sprint performance is fundamentally based on neuromuscular readiness and the efficiency of sprint biomechanics, through which small changes in spatial variables can cause substantial changes in competitive outcomes. Contemporary sprint research consistently emphasizes that speed development cannot be achieved only by sprinting but requires an integrated programming paradigm that aims to advance acceleration capacity, maximal velocity mechanics, and the neuromuscular determinants of force application [1, 2]. From an applied perspective, this premise is especially relevant in resource-constrained training settings in which coaches seek field-based measurements and practical interventions to monitor parameters such as ground contact time, step length, stride length, and total sprint time.

Within this applied context, warm-up interventions are an important and often under optimized element of sprint preparation. Beyond simply preventing injuries, warm-ups can acutely improve explosive capacity by increasing muscle temperature, improving nerve conduction velocity, and enhancing coordination of movement, leading to better sprint-specific movement execution. Conditioning activities incorporating sprint drills and explosive exercises have been demonstrated to create acute performance effects in sprinters, supporting the idea that the warm-up is a performance intervention rather than a procedural formality [3]. Because of the similarities in key mechanical characteristics between plyometric actions and sprinting (rapid stretch-shortening cycle function and a high rate of force development), warm-up practices using plyometric-type activation may be particularly relevant for improving sprint output immediately and over time [4].

Training theory further supports the incorporation of plyometric content into sprint development plans because both modalities focus on overlapping neuromuscular qualities. Long-term strength-oriented approaches have shown benefits in sprint-related tasks, such as change-of-direction speed and sprint performance, suggesting that increased force production capacity aids faster and more efficient sprinting patterns [5,6]. At the same time, elite sprint development frameworks emphasize that the "best practice" approach is integrated and periodized, progressing from technical learning and capacity development toward higher-intensity sprint-specific outputs as the athlete adapts [7]. This theoretical perspective provides a rationale for a combined sprint and plyometric program in which specific, systematic, and progressive attention is given to mechanics (step and stride characteristics) and neuromuscular function (ground contact behavior and acceleration capacity).

Empirical evidence related to plyometric training shows improvements in explosive performance across a range of sporting disciplines. Meta-analyses and systematic reviews suggest that plyometric-based interventions can produce gains in sprint performance along with increases in jumping ability [8, 9]. The benefits in sprinting resulting from plyometric practice are mediated by mechanisms related to spatial parameters: regulation of muscle contractility during movement, increased impulse generation over a short time period, and improved coordination of elastic energy storage and release during the stretch and relaxation phases of muscle action. These adaptations can reduce ground contact time while supporting greater step and stride lengths for a given velocity [10, 11]. Continuous improvement in sprint time is attractive to practitioners because it indicates a viable way to achieve performance enhancement through measurable alterations in the interaction between the athlete and the ground.

Assessing training effects requires the adoption of appropriate measurement approaches. Although sophisticated equipment, such as force plates, timing gates, and inertial measurement units, provides high-resolution data, many sprint programmes rely on more practical field methods. Empirical evidence suggests that meaningful changes in technique and performance can be assessed through step kinematic analyses and periodized monitoring schemes, supporting the use of structured pre- and post-measurements in applied settings [12, 13]. This aligns with the assessment of spatial parameters that can be quantified using practicable tools while remaining consistent with established constructs of sprint performance.

From a performance-oriented standpoint, sprint and plyometric training are commonly associated with changes in ground contact time, step and stride characteristics, and overall sprint time. Previous syntheses indicate that plyometric training improves physical performance outcomes across populations, supporting the expectation of measurable change following structured training [14, 15]. Moreover, acute and post-activation approaches, particularly those combining resisted sprinting and explosive tasks, have received attention for improving acceleration and short-distance sprint outputs, suggesting an additional pathway through which integrated training may affect spatial parameters [16, 17].

Several aspects remain under discussion in applied sprint training research. Many studies examine sprint training, strength training, or plyometric training in isolation, whereas coaches frequently employ combined programmes in practical settings [18, 19]. In addition, even when improvements in sprint time are reported, spatial parameter responses, particularly contact-time behavior and step and stride adaptations, are not always presented in a way that supports applied coaching decisions. Ongoing investigations also address questions related to training dose, retention, and transfer of plyometric adaptations to sprint performance, highlighting the need for applied studies that include clear biomechanical indicators [20, 21].

Analysis of research findings has shown that sprint performance is influenced by the interaction of neuromuscular control and spatial running mechanics, and that training approaches frequently combine sprint and plyometric elements. Researchers emphasize that measurable changes in contact behavior and step–stride characteristics are central to understanding performance adaptations in applied settings. At the same time, the interpretation of these parameters in practical training contexts remains methodologically and practically complex. This situation highlights the relevance of further structured examination of spatial sprint characteristics within integrated training conditions.

Materials and Methods

Participants

A total of one hundred male sprinters volunteered to take part in the study. Participants came from university-level sprint training programmes and had already participated in structured sprint training.

The inclusion criteria were:

- age between 18 and 25 years;
- a minimum of 1 year of regular sprint training experience;
- active participation in sprint training at the time of recruitment;
- no musculoskeletal injuries or neurological disorders within the 6 months prior to the study.

Participants were excluded if they had:

- a history of lower limb surgery;
- a current injury;
- participation in additional structured strength or plyometric training programmes alongside regular sprint training during the study period.

Baseline demographic characteristics recorded were age, body height, body mass, and body mass index. All participants were classified as university-level competitive sprinters and regularly participated in organized training and competition. Prior to data collection, participants were familiarized with the testing procedures to reduce learning effects.

Ethical approval was obtained in accordance with the guidelines of the Research Performance Evaluation Committee (RPEC) of Gomal University, Dera Ismail Khan, Pakistan. The performance testing and training procedures consisted of non-invasive field-based assessments commonly used in routine sports practice. All participants were informed about the study objectives, procedures, and possible risks and benefits, and provided written informed consent prior to participation. The study was conducted in accordance with the principles of the Declaration of Helsinki.

Research Design

The study used a two-group pre-test–post-test controlled experimental design. Participants completed baseline (pre-test) measurements, followed by a 10-week training period and post-test measurements. The confirmatory inferential framework was the Group × Time interaction. This interaction was used to determine whether pre-to-post change differed between the experimental and control groups. The 10-week integrated sprint technique and plyometric training program is presented in Table 1. The training frequency was three sessions per week. Session duration was 45–

Table 1. 10-Week integrated sprint technique and plyometric training program (ISTPTP)

Weeks	Training Phase	Main Focus	Sprint Technique Drills (Volume)	Plyometric Exercises (Volume)	Sprint Work (Volume & Intensity)	Rest & Supervision
1–2	Adaptation	Technique learning & neuromuscular adaptation	Wall drills, A-skips, high knees; 2–3 sets × 20–30 m	Squat jumps, ankling; 2–3 sets × 8–10 reps	3 × 20 m @ 85–90%	Rest: 60–90 s (drills), 2–3 min (sprints); supervised by sprint coach
3–4	Technique Development	Improved sprint mechanics	Marching drills, skipping; 3 sets × 20–30 m	Bounding, CMJ; 3 sets × 6–8 reps	4 × 20 m @ 90%	Rest: 90 s (plyometrics), 3 min (sprints); coach monitored technique
5–6	Strength–Power	Force application & elastic energy use	Fast-leg drills; 3 sets × 30 m	Box jumps, pogo jumps; 3–4 sets × 6–8 reps	4 × 30 m @ 95%	Rest: 2 min (plyometrics), 3–4 min (sprints); verbal feedback provided
7–8	Reactive & Speed	Reduced ground contact time	Fast-leg drills; 3 sets × 30 m	Hurdle hops, drop jumps; 3–4 sets × 5–6 reps	Flying sprints (20 + 20 m) × 3	Rest: 2–3 min (plyometrics), 4 min (sprints); close supervision
9–10	Performance	Sprint performance optimization	Technique reinforcement; 2–3 sets × 30 m	Mixed plyometrics; 3 sets × 6 reps	3 × 30 m @ 95–100%	Rest: 3 min (plyometrics), 4–5 min (sprints); full supervision

60 minutes. The program applied the principles of specificity, progressive overload, recovery, and variation.

Group Assignment

Following baseline testing, participants were assigned to one of two groups: an experimental group (N = 60) or a control group (N = 40) using a matched-group allocation procedure based on baseline 30 m sprint time to ensure equivalence in initial sprint performance (Figure 1). The experimental group followed a ten-week integrated sprint and plyometric training programme, while the control group followed their usual sprint training programme without additional plyometric exercises.

After completing the intervention, complete post-test data were collected from 46 participants in the experimental group and all 40 participants in the control group. Attrition in the experimental group (n = 14) was attributed to non-training-related factors such as scheduling conflicts and inconsistent attendance. No training-associated injuries or adverse events were reported during the intervention period.

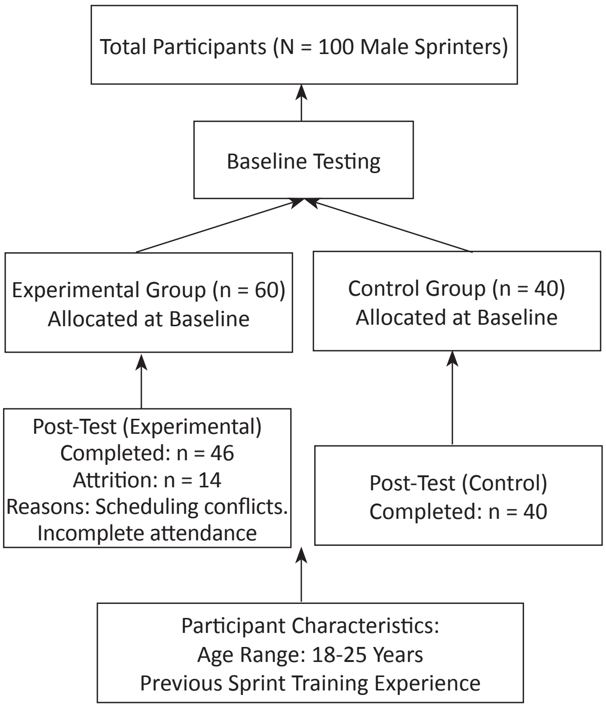

Figure1. ParticipantFlowDiagram

Procedure

All testing sessions and the intervention in the form of training were held at the Gomal Football Ground, Gomal University campus, Dera Ismail Khan, Khyber Pakhtunkhwa, Pakistan. The training and testing surface was a natural turf football pitch, which was consistent throughout the study period to ensure consistent ground conditions for sprinting assessments. A group of local and international researchers conducted the project. Participants reported to the field between 16:00 and 18:00 h to minimize the effects of circadian factors on performance. Weather conditions were monitored during testing and training sessions, and dry and warm conditions (around 22–28 °C) were maintained in most sessions. Sessions affected by adverse weather were rescheduled to maintain consistency.

Upon arrival, the participants were familiarized with the study procedures and underwent a standardized dynamic warm-up protocol lasting approximately 10–12 minutes. The warm-up consisted of light jogging, dynamic stretching, sprinting drills, and progressive acceleration runs. Immediately after the warm-up phase, the participants performed 3 maximal-effort 30-m sprints along a marked straight line on the football ground, with 3–5 min of passive recovery between trials to reduce fatigue. Participants wore sprint training footwear that they normally used during all sessions.

Sprint spatiotemporal parameters were obtained using high-speed video recorded with a smartphone camera (iPhone 12, Apple Inc., USA) positioned perpendicular to the sprint lane at a distance of about 8 m. Videos were captured at 240 frames per second (fps) and then analyzed frame-by-frame using Kinovea motion analysis software (version 0.9.5) to detect periods of ground contact and flight. Sprint time was also measured using a calibrated manual stopwatch. Step length and stride length were measured using visual footprint markers made on the turf and a standardized measuring tape. All assessments were carried out by the same experienced investigator to ensure procedural consistency and reliability.

Statistical Analysis

Statistical analyses were conducted using IBM SPSS Statistics (version 27). Data were screened prior to inferential analysis. Univariate outliers were examined using standardized z-scores, and multivariate outliers were assessed using Mahalanobis distance. No influential cases requiring removal were identified. Missing data occurred only at post-test due to participant attrition (14%). Little's MCAR test indicated that missingness was not systematic. Analyses were therefore conducted using a complete-case (per-protocol) approach including participants with both pre- and post-test measurements. No imputation procedures were applied. The primary outcome variable was 30-m sprint time, and secondary outcomes included ground contact time, step length, and stride length. Descriptive statistics (mean ± standard deviation) were calculated for each variable by group and time point. The study hypothesis was tested using a two-way mixed-design analysis of variance (ANOVA), with (1) Group (experimental vs control) as the between-subject factor and (2) Time (pre-test vs post-test) as the within-subject factor. The primary confirmatory test was the Group × Time interaction term, and a statistically significant interaction ($p < .05$) was interpreted as evidence that pre-to-post change differed between groups. To adjust for baseline differences and improve precision of estimates, a mixed-design analysis of covariance (ANCOVA) was additionally performed for each outcome, with baseline sprint time and body mass index (BMI) included as covariates. Confirmatory inference remained based exclusively on the Group × Time interaction in the ANCOVA model. Model assumptions were evaluated prior to interpretation, including normality of residuals (Shapiro–Wilk test) and homogeneity of variance (Levene's test), and for ANCOVA models homogeneity of regression slopes was assessed. Effect sizes were reported as partial eta-squared (ηp^2) for ANOVA and ANCOVA effects. Statistical significance was set at $p < .05$ (two-tailed). Within-group paired comparisons were not used as primary inferential evidence and were not considered confirmatory tests of the study hypothesis.

Results

The results of missing data screening and univariate characteristics of the study variables are presented in Table 2. Complete baseline data were available for all variables. Post-test data were missing for 14 participants (14%) due to attrition. Little's MCAR test indicated that missingness was not systematic. Analyses were therefore conducted using a complete-case approach.

The univariate descriptive statistics of demographic and spatial parameters are presented in Table 3. Residual and influence diagnostics were examined prior to inferential testing. No cases exceeded commonly accepted thresholds for exclusion, and all observations were retained for analysis.

Prior to inferential analysis, model assumptions were evaluated (Table 4). Normality of residuals

Table 2. Little MCAR test

Variable Name	N	Mean	SD	Missing (n)	Missing (%)	Outliers (Low)	Outliers (High)
Age (years)	100	21.10	1.80	0	0.0	0	5
Height (cm)	100	175.09	6.09	0	0.0	0	0
Body Mass (kg)	100	68.23	6.57	0	0.0	0	0
Ground Contact Time – Pre (ms)	100	142.74	11.56	0	0.0	0	0
Step Length – Pre (m)	100	1.85	0.12	0	0.0	0	1
Stride Length – Pre (m)	100	3.70	0.26	0	0.0	0	1
Sprint Time – Pre (s)	100	4.92	0.40	0	0.0	0	0
Ground Contact Time – Post (ms)	86	139.67	11.81	14	14.0	1	2
Step Length – Post (m)	86	1.89	0.13	14	14.0	0	1
Stride Length – Post (m)	86	3.80	0.27	14	14.0	0	1
Sprint Time – Post (s)	86	4.79	0.43	14	14.0	0	0
Group (1 = experimental, 2 = control)	100	—	—	0	0.0	—	—

Table 3. Univariate descriptive statistics of demographic and spatial parameters

Statistic	Minimum	Maximum	Mean	Std. Deviation	N
Predicted Value	0.72	2.04	1.48	0.491	84
Standardized Predicted Value	−1.534	1.138	0.000	1.000	84
Standard Error of Predicted Value	0.021	0.054	0.035	0.009	84
Adjusted Predicted Value	0.67	2.04	1.48	0.495	84
Residual	−0.238	0.278	0.000	0.105	84
Standardized Residual	−2.162	2.519	0.000	0.951	84
Studentized Residual	−2.311	2.740	0.004	1.027	84
Deleted Residual	−0.272	0.328	0.001	0.122	84
Studentized Deleted Residual	−2.382	2.869	0.005	1.041	84
Mahalanobis Distance	2.082	18.848	7.905	4.363	84
Cook's Distance	0.000	0.152	0.020	0.031	84
Centered Leverage Value	0.025	0.227	0.095	0.053	84

was assessed using the Shapiro–Wilk test. Although minor deviations from normality were observed for selected variables within the control group, the mixed-design ANOVA and ANCOVA procedures are considered robust to moderate violations of normality, particularly with comparable group sizes. Homogeneity of variance was assessed using Levene's test, and no substantial violations were detected. Where appropriate, the Greenhouse–Geisser correction was applied to adjust for violations of sphericity. Overall, model assumptions were considered adequately satisfied for parametric analysis.

Table 5 presents the overall pre- and post-test descriptive statistics for the spatial parameters. Ground contact time decreased, whereas step length and stride length increased. Sprint time decreased at post-test. Post-test sample size was reduced due to attrition (n = 84).

Table 6 presents the pre- and post-test descriptive statistics for the experimental group. Ground contact time decreased, whereas step length and stride length increased. Sprint time decreased at post-test. Post-test sample size was reduced to n = 44 due to attrition.

Table 7 presents the pre- and post-test descriptive statistics for the control group. No meaningful changes were observed between pre- and post-test values across the measured variables.

Baseline equivalence between the experimental

Table 4. Results of Kolmogorov–Smirnov and Shapiro–Wilk tests

Variable	Group	Kolmogorov–Smirnov			Shapiro–Wilk		
		Statistic	df	Sig.	Statistic	df	Sig.
Ground Contact Time (Estimated) – Pre (ms)	Experimental	.156	46	.009	.957	46	.105
	Control	.150	40	.023	.948	40	.065
Step Length – Pre (m)	Experimental	.094	46	.200*	.981	46	.654
	Control	.122	40	.134	.950	40	.077
Stride Length – Pre (m)	Experimental	.071	46	.200*	.980	46	.646
	Control	.145	40	.034	.932	40	.018
Sprint Time (30 m) – Pre (s)	Experimental	.100	46	.200*	.968	46	.256
	Control	.070	40	.200*	.983	40	.801
Ground Contact Time (Estimated) – Post (ms)	Experimental	.079	46	.200*	.976	46	.476
	Control	.150	40	.023	.948	40	.066
Step Length – Post (m)	Experimental	.089	46	.200*	.982	46	.705
	Control	.121	40	.140	.949	40	.073
Stride Length – Post (m)	Experimental	.089	46	.200*	.974	46	.401
	Control	.146	40	.035	.932	40	.018
Sprint Time (30 m) – Post (s)	Experimental	.100	46	.200*	.975	46	.433
	Control	.070	40	.200*	.983	40	.804

Note. * This is a lower bound of the true significance; a. Lilliefors significance correction.

Table 5. Descriptive statistics of spatial parameters

Variable	Pre-test			Post-test		
	N	Mean	SD	N	Mean	SD
Ground Contact Time (ms)	100	142.80	11.67	86	139.80	11.86
Step Length (m)	100	1.85	0.12	86	1.89	0.13
Stride Length (m)	100	3.69	0.26	86	3.79	0.27
Sprint Time (30 m) (s)	100	4.91	0.39	86	4.79	0.43

Table 6. Descriptive statistics of spatial parameters in the experimental group

Variable	Pre-test			Post-test		
	N	Mean	SD	N	Mean	SD
Ground Contact Time (ms)	60	141.47	12.21	46	135.32	11.15
Step Length (m)	60	1.85	0.13	46	1.93	0.14
Stride Length (m)	60	3.69	0.28	46	3.88	0.27
Sprint Time (30 m) (s)	60	4.84	0.36	46	4.60	0.32

and control groups at pre-test was examined using independent-samples t-tests (Table 8). H0: There is no statistically significant difference between the experimental and control groups at pre-test for the measured spatial sprint parameters. No statistically significant differences were observed for ground contact time, step length, or stride length ($p > .05$). However, a statistically significant baseline difference was detected for 30-m sprint time ($p = .030$), with the experimental group demonstrating a modestly faster pre-test time (Cohen's d = −0.45). Therefore, baseline sprint time was included as a covariate in subsequent ANCOVA analyses.

Descriptive statistics for both groups at pre- and post-test are presented in Table 9. The effect of the intervention on 30-m sprint performance was examined using a two-way mixed-design analysis of variance (ANOVA) (Table 10). H1: It was hypothesized that pre-to-post changes in 30-m sprint performance would differ between the experimental and control groups (i.e., a significant Group × Time interaction would be observed). The analysis was conducted with Group (experimental vs control) as the between-subject factor and Time (pre-test vs post-test) as the within-subject factor. The analysis revealed a significant main effect of Time, $F(1.06, 86.60) = 12717.04$, $p < .001$, $\eta p^2 = .994$, and a significant main effect of Group, $F(1, 82) = 5.00$, $p = .028$, $\eta p^2 = .057$. A statistically significant Group × Time interaction was observed, $F(1.06, 86.60) = 8.31$, $p = .004$, $\eta p^2 = .092$. The study hypothesis was tested using the Group × Time interaction term. Because

Table 7. Descriptive statistics of spatial parameters in the control group

Variable	Pre-test			Post-test		
	N	Mean	SD	N	Mean	SD
Ground Contact Time (ms)	40	144.73	10.71	40	144.72	10.72
Step Length (m)	40	1.85	0.10	40	1.85	0.10
Stride Length (m)	40	3.70	0.24	40	3.70	0.24
Sprint Time (30 m) (s)	40	5.02	0.43	40	5.02	0.43

Table 8. Results of independent samples t-test

Variable	Experimental group (n = 60) Mean ± SD	Control group (n = 40) Mean ± SD	t (df)	p-value	Cohen's d
Ground Contact Time – Pre (ms)	141.47 ± 12.21	144.73 ± 10.71	−1.36 (96)	.176	−0.28
Step Length – Pre (m)	1.85 ± 0.13	1.85 ± 0.10	0.06 (96)	.951	0.01
Stride Length – Pre (m)	3.69 ± 0.28	3.70 ± 0.24	−0.14 (96)	.886	−0.03
Sprint Time (30 m) – Pre (s)	4.84 ± 0.36	5.02 ± 0.43	−2.20 (96)	.030	−0.45

Table 9. Descriptive statistics of spatial parameters

Variable	Experimental group (n = 44)	Control (group n = 40)
Ground Contact Time – Pre (ms)	143.61 ± 12.04	144.73 ± 10.71
Ground Contact Time – Post (ms)	135.32 ± 11.15	144.72 ± 10.72
Step Length – Pre (m)	1.87 ± 0.13	1.85 ± 0.10
Step Length – Post (m)	1.93 ± 0.14	1.85 ± 0.10
Stride Length – Pre (m)	3.74 ± 0.27	3.70 ± 0.24
Stride Length – Post (m)	3.88 ± 0.27	3.70 ± 0.24
Sprint Time (30 m) – Pre (s)	4.86 ± 0.34	5.02 ± 0.43
Sprint Time (30 m) – Post (s)	4.58 ± 0.32	5.02 ± 0.43

Table 10. Mixed ANOVA results for spatial parameters

Effect	F	df	p	Partial η^2
Time	12717.04	1.06, 86.60	< .001	.994
Group	5.00	1, 82	.028	.057
Time × Group	8.31	1.06, 86.60	.004	.092

Note. Greenhouse–Geisser correction applied due to violation of sphericity.

the interaction effect was statistically significant, the null hypothesis was rejected, indicating that the pre-to-post change differed between the experimental and control groups.

To facilitate interpretation of the interaction effect, the estimated marginal means across time for both groups are presented in Figure 2. The figure visually reflects the statistically significant Group × Time interaction.

To control for baseline differences and improve precision of estimates, a mixed-design analysis of covariance (ANCOVA) was performed with Group (experimental vs control) as the between-subject factor and Time (pre-test vs post-test) as the within-subject factor. Baseline sprint time and body mass index (BMI) were included as covariates. H1: It was hypothesized that, after controlling baseline sprint time and BMI, pre-to-post changes in 30-m sprint performance would differ between the experimental and control groups. Descriptive statistics for both groups are presented in Table 11, and the ANCOVA results are presented in Table 12.

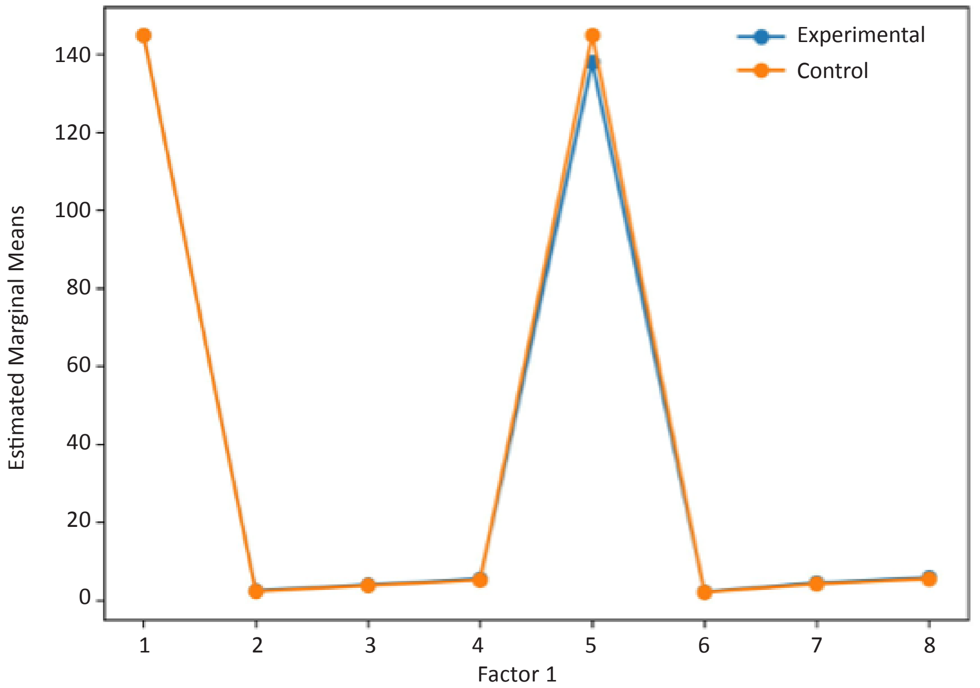

Figure 2. Estimated marginal means of spatial parameters across time (pre- and post-test) for experimental and control groups.

Table 11. Descriptive statistics of spatial parameters (Adjusted analysis sample)

Variable	Experimental group (n = 44)	Control group (n = 40)
Ground Contact Time – Pre (ms)	143.61 ± 12.04	144.73 ± 10.71
Ground Contact Time – Post (ms)	135.32 ± 11.15	144.72 ± 10.72
Step Length – Pre (m)	1.87 ± 0.13	1.85 ± 0.10
Step Length – Post (m)	1.93 ± 0.14	1.85 ± 0.10
Stride Length – Pre (m)	3.74 ± 0.27	3.70 ± 0.24
Stride Length – Post (m)	3.88 ± 0.27	3.70 ± 0.24
Sprint Time (30 m) – Pre (s)	4.86 ± 0.34	5.02 ± 0.43
Sprint Time (30 m) – Post (s)	4.58 ± 0.32	5.02 ± 0.43

Table 12. Mixed ANCOVA results for spatial parameters

Effect	F	df	p	Partial η^2
Time	117.11	1.06, 85.51	< .001	.591
BMI (covariate)	0.02	1, 81	.967	.000
Group	4.93	1, 81	.029	.057
Time × Group	8.23	1.06, 85.51	.005	.092

Note. Greenhouse–Geisser correction applied due to violation of sphericity.

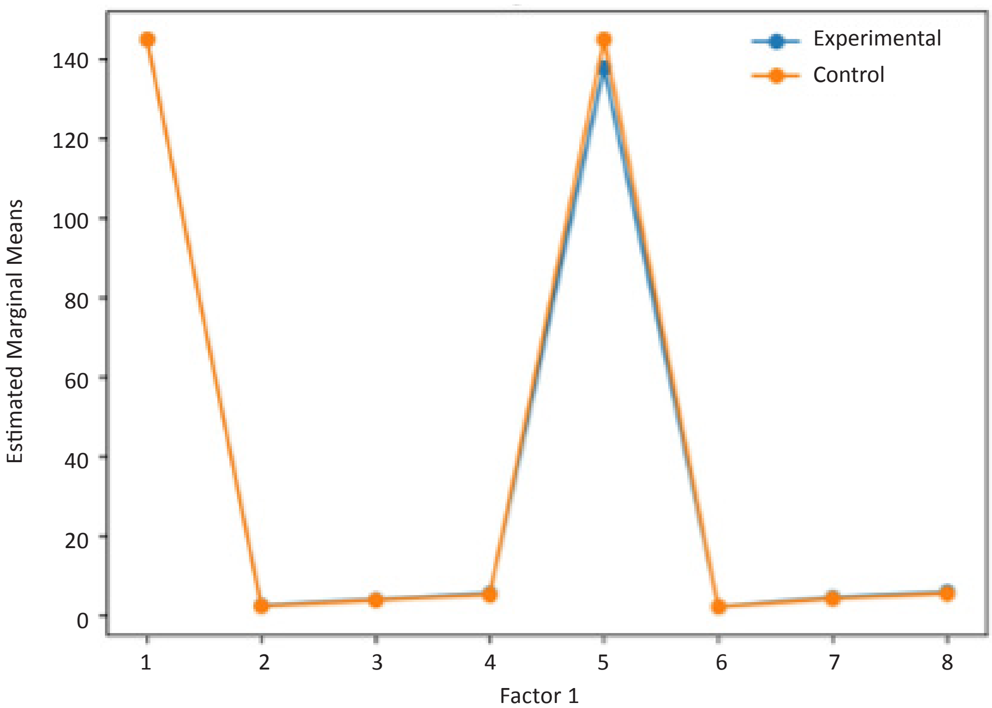

Figure 3. Estimated marginal means of spatial parameters adjusted for body mass index (BMI). Note. Covariates appearing in the model are evaluated at the following values: Body mass of participant (kg) = 67.937

To adjust for minor baseline differences and improve precision of estimates, a mixed-design analysis of covariance (ANCOVA) was conducted with Group (experimental vs control) as the between-subject factor and Time (pre-test vs post-test) as the within-subject factor, while baseline sprint time and body mass index (BMI) were included as covariates. Descriptive statistics corresponding to this analysis are presented in Table 11. The ANCOVA results are presented in Table 12. The analysis revealed a significant main effect of Time, $F(1.06, 85.51) = 117.11$, $p < .001$, $\eta p^2 = .591$, and a significant main effect of Group, $F(1, 81) = 4.93$, $p = .029$, $\eta p^2 = .057$. The covariate BMI was not statistically significant, $F(1, 81) = 0.02$, $p = .967$, $\eta p^2 = .000$. A statistically significant Group × Time interaction was observed, $F(1.06, 85.51) = 8.23$, $p = .005$, $\eta p^2 = .092$. The study hypothesis was tested using the Group × Time interaction term in the mixed ANCOVA model. Because the interaction effect was statistically significant, the null hypothesis was rejected, indicating that the adjusted pre-to-post change differed between the experimental and control groups after controlling for baseline sprint time and BMI.

To illustrate the adjusted model results, the estimated marginal means are presented in Figure 3. Figure presents the estimated marginal means adjusted for BMI and reflects the statistically significant Group × Time interaction.

Discussion

The present study examined the effects of a 10-week integrated sprint and plyometric training program on selected spatiotemporal parameters of sprint performance in male university-level sprinters. The primary finding was a statistically significant Group × Time interaction for 30-m sprint time, ground contact time, step length, and stride length, indicating that pre-to-post changes differed between the experimental and control groups. These results indicate that the integrated intervention produced performance adaptations that exceeded those observed in athletes who continued usual sprint training alone.

The experimental group demonstrated reductions in ground contact time and sprint time, along with increases in step and stride length, whereas the control group showed minimal change across the same period. These findings suggest that the integrated training program was associated with measurable alterations in sprint spatiotemporal characteristics beyond those observed with usual sprint training alone. From a performance perspective, sprint velocity over short distances is determined by the interaction between step length and step frequency, with ground contact time representing a critical determinant of effective horizontal force production. The reduction in ground contact time observed in the experimental group, combined with concurrent increases in step and stride length, suggests improved mechanical efficiency during the stance phase.

The reduction in ground contact time and the concurrent increases in step and stride length are consistent with patterns reported in previous sprint and plyometric training studies [4, 11, 22]. Prior literature has proposed that such changes may reflect improvements in sprint mechanics and lower-limb power characteristics. Although the present study did not directly measure neuromuscular variables or force production, the observed spatiotemporal modifications align with adaptations previously documented following plyometric interventions. Similar kinematic patterns have been reported following speed-oriented interventions in which enhanced stretch–shortening cycle function and rate of force development contributed to shorter contact phases without compromising step amplitude [4, 10, 11, 22, 23].

Similarly, the observed reduction in 30-m sprint time in the experimental group is consistent with meta-analytic evidence indicating performance improvements following plyometric or combined sprint training programs in athletic populations [4, 24]. The present findings therefore extend previous work by demonstrating comparable adaptations within a university-level sprint cohort under field-based conditions. The magnitude of the interaction effect indicates practically meaningful change rather than trivial statistical variation, and supports the effectiveness of systematic integration of sprint drills and progressive plyometric content within the same microcycle.

Baseline analyses indicated general equivalence between groups, except for a modest difference in pre-test sprint time. This difference was statistically controlled in subsequent ANCOVA models. The persistence of significant Group × Time interactions after covariate adjustment supports the robustness of the observed group differences over time. Although regression to the mean cannot be completely excluded, the adjusted results strengthen confidence that the improvements were primarily attributable to the intervention. Similar statistical adjustment procedures have been recommended in training-intervention research where baseline performance asymmetry is present [7, 12].

Attrition during the intervention period was limited and unrelated to injury. Diagnostic analyses indicated no influential outliers affecting model stability. Additionally, the relative stability of performance in the control group strengthens the internal validity of the comparison by reducing the likelihood that changes in the experimental group were attributable to repeated testing or natural performance fluctuation. Comparable stability of sprint performance in non-intervention conditions has been reported in longitudinal training studies when no additional neuromuscular stimulus is introduced beyond habitual practice [5, 6].

Study Limitations and Future Directions

Several limitations should be acknowledged. First, neuromuscular activation, force production, musculotendinous stiffness, and other biomechanical determinants were not directly measured; therefore, mechanistic explanations for the observed changes remain speculative. Sprint time was measured using manual timing and spatiotemporal parameters were derived from smartphone-based high-speed video analysis, which may introduce observer-related variability compared with automated systems. The sample consisted of male university-level sprinters, which may limit generalizability to other populations and surface conditions.

Future research should incorporate direct biomechanical and neuromuscular measurements, examine longer intervention durations, include retention testing, and evaluate similar training models across different competitive levels and female athletes to further clarify mechanisms and external validity.

Conclusions

The present study evaluated the effects of a 10-week integrated sprint and plyometric training program on selected spatiotemporal parameters of sprint performance in male university-level sprinters. Statistically significant Group × Time interactions were observed for 30-m sprint time, ground contact time, step length, and stride length, indicating that pre-to-post changes differed between the experimental and control groups. Participants in the experimental group demonstrated greater changes in sprint time and associated spatiotemporal variables compared with those following usual sprint training. These findings suggest that the integrated training program was associated with measurable alterations in sprint performance characteristics under the conditions examined in this study. The conclusions are based solely on the measured spatiotemporal outcomes. Mechanistic factors such as neuromuscular activation, force production, or musculotendinous properties were not directly assessed and therefore cannot be inferred from the present data. Within the limitations of this sample and study design, the results indicate that combining sprint and plyometric exercises over a 10-week period may be associated with greater improvements in sprint-related spatiotemporal parameters than usual sprint training alone. Further research incorporating direct biomechanical measurements, alternative training comparators, and diverse athletic populations is warranted to clarify underlying mechanisms and generalizability.

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Conflict of Interest

The authors declare no conflict of interest.

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