Kinetic and kinematic analysis of advanced sprint training effects in school level sprinters

Análisis cinético y cinemático de los efectos del entrenamiento de velocidad avanzado en velocistas de nivel escolar

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Abstract

Background: Sprint performance improvements have been attributed mainly to scientific training advancements and technological innovations. Given sprinting's pivotal role in athletics, enhancing performance through structured training is crucial.
Objective: This study assessed the effects of a 12-week advanced sprint training program on kinetic (reaction time, acceleration) and kinematic (maximum velocity, stride length) parameters in adolescent male sprinters.
Methods: Fifty adolescent boys (aged 13–15 years) were randomly assigned to an experimental (n = 25) or control group (n = 25). The experimental group underwent a structured sprint training program incorporating resisted and non-resisted drills. The control group continued standard physical education. Pre-, mid-, and post-intervention data were collected using high-speed video analysis and electronic timing systems. A two-way repeated measures ANOVA and paired t-tests were used for statistical analysis, with significance set at $p < .05$. Effect sizes (partial η^2) were reported.
Results: Significant improvements were observed in the experimental group: Reaction time improved by 25% (from M = 0.178 s to 0.134 s; $F(2,48) = 11.66$, $p < .001$, $\eta^2 = .327$). Acceleration improved by 9.3% (from M = 5.03 s to 4.56 s; $F = 31.14$, $p < .001$, $\eta^2 = .565$) Maximum velocity enhanced by 12.5% (from M = 8.21 s to 7.18 s; $F = 101.21$, $p < .001$, $\eta^2 = .808$) Stride length increased by 9.4% (from M = 1.74 m to 1.90 m; $F = 6.28$, $p = .004$, $\eta^2 = .208$) No significant changes were observed in the control group.
Conclusion: The advanced sprint training program significantly enhanced kinetic and kinematic sprint parameters among adolescent sprinters. Integrating scientifically designed sprint drills into school-level programs can accelerate performance gains and support long-term athletic development.

Keywords

Advanced sprint training; kinetic and kinematic parameters; reaction time; acceleration, maximum Velocity; stride length.

Resumen

Objetivo: El ritmo circadiano humano es un parámetro fundamental para comprender su estado biológico, fisiológico y psicológico actual, lo que influye ampliamente en la condición física. Los mecanismos fisiológicos subyacentes a los ritmos circadianos siguen estando poco explorados, a pesar de su posible impacto en la salud física y mental. Este estudio tiene como objetivo examinar el efecto de diferentes momentos del día en el rendimiento cognitivo y físico de atletas femeninas. Metodología: Se empleó un diseño de medidas repetidas contrabalanceado dentro de los sujetos, involucrando a 15 estudiantes universitarias sanas de entre 18 y 25 años. Cada participante realizó pruebas de rendimiento cognitivo y físico en tres momentos distintos del día—6 AM, 12 PM y 6 PM—en días separados.
Resultados: El estudio mostró un efecto significativo de las variaciones diurnas en los índices de rendimiento cognitivo y físico.
Discusión: El rendimiento cognitivo presentó patrones variables a lo largo del día. El razonamiento perceptivo, medido por la prueba de Müller-Lyer, alcanzó su punto máximo en la mañana y fue más bajo en la noche. La memoria de trabajo, evaluada mediante la prueba de amplitud de dígitos, mostró valores moderados al mediodía y en la noche. La fuerza, medida por el salto vertical, fue mayor en la noche y menor en la mañana. La agilidad, evaluada con la prueba de agilidad de Illinois, alcanzó su punto máximo al mediodía y registró los valores más bajos en la mañana. Conclusiones: La hora del día afecta significativamente el rendimiento cognitivo y físico en atletas femeninas. La fuerza alcanza su punto máximo en la noche, la agilidad al mediodía y el razonamiento perceptivo en la mañana, mientras que la memoria de trabajo muestra un rendimiento moderado al mediodía y en la noche. Estos resultados sugieren que los atletas y entrenadores pueden optimizar los horarios de entrenamiento y competición en función de las variaciones diurnas del rendimiento cognitivo y físico.

Palabras clave

Entrenamiento avanzado de sprint; parámetros cinéticos y cinemáticos; tiempo de reacción; aceleración, velocidad máxima; longitud de zancada.

Introduction

Sprinting is a foundational athletic skill pivotal in track and field events and numerous team sports requiring rapid acceleration and high-speed movement. The 100-meter sprint, in particular, is widely regarded as the ultimate measure of human speed and neuromuscular efficiency. Over the decades, improvements in sprint performance have been primarily attributed to advancements in training methodologies, biomechanical understanding, and sport-specific conditioning practices (Clark & Weyand, 2014).

Research has consistently shown that sprint performance depends on a complex interplay of kinetic parameters, such as reaction time, acceleration, and kinematic parameters, including maximum velocity and stride length. These components reflect an athlete's ability to produce force quickly and move efficiently through various phases of the sprint cycle (Haugen, Tønnessen, & Seiler, 2024). Studies on elite athletes demonstrate that training interventions incorporating resisted sprinting, plyometric drills, and high-speed video feedback can significantly enhance these metrics (Delecluse, 2012).

Despite this growing body of knowledge, relatively few studies have investigated the effectiveness of such advanced training methods in adolescent or school-level athletes. This population is undergoing critical stages of motor skill development, neuromuscular coordination, and physical maturation. However, most school-based programs lack structured sprint-specific training, relying instead on generalized physical activities that may not optimally develop biomechanical efficiency or explosive sprint performance (Mackala & Fostiak, 2015; Faigenbaum et al., 2009). Moreover, while elite-level research often employs precise measurement tools such as motion tracking systems, electronic timing gates, and biomechanical analysis software, objective tools are rarely used in school settings, limiting the accuracy and applicability of performance assessments at the developmental level.

This gap between research and practice is particularly concerning, as early adolescence represents a key window for skill acquisition and long-term athletic development. Without evidence-based training models that are both age-appropriate and scientifically validated, adolescent athletes may miss critical opportunities to improve sprint technique and overall performance. In addition, while some studies suggest that enhancing sprint mechanics may reduce injury risk, few have directly evaluated these outcomes in adolescent populations, leaving this claim largely theoretical (Hewett et al., 2006).

To address these limitations, the present study evaluated the effects of a 12-week advanced sprint training program on kinetic (reaction time, acceleration) and kinematic (maximum velocity, stride length) variables among adolescent male sprinters. This study aimed to determine whether structured, scientifically grounded training could significantly improve sprint performance by integrating resisted and non-resisted sprint-specific drills and utilizing objective performance measurements. The findings are intended to inform physical education practices, support school-based athletic programming, and contribute to talent identification efforts among youth populations.

Therefore, this study aimed to examine the effects of a 12-week advanced sprint training intervention on key sprint performance parameters reaction time, acceleration, maximum velocity, and stride length among adolescent male sprinters aged 13 to 15 years. The intervention incorporated resisted and non-resisted sprint-specific drills. Performance was assessed using high-speed video analysis and electronic timing systems to ensure precision. This research aimed to fill the adolescent sprint training literature gap by providing evidence-based recommendations for school-level athletic development.

Method

Participants

Fifty adolescent male sprinters aged 13 to 15 years (M = 14.2, SD = 0.7) were recruited from local secondary schools of Pondicherry. Inclusion criteria included prior exposure to sprint activities and completion of a baseline 50-meter sprint in the top 25% of the cohort (≤ 7.0 seconds). Exclusion criteria included current musculoskeletal injuries or medical conditions affecting sprint performance. Participants were randomly assigned (simple randomization using a computerized random number generator) to either an experimental group (n = 25) or a control group (n = 25).

Ethical Considerations

The Institutional Research Committee of Pondicherry University reviewed and approved the study protocol (Approval No. HEC/PU/2023/12/07-08-2023. Written informed consent was obtained from all participants and their legal guardians. Participants were informed of their right to withdraw at any stage.

Screening and Group Allocation

Initial screening involved a 50-meter sprint test. Only participants who met the sprint timing threshold were considered eligible. Sprint performance data were ranked, and the top quartile was used for selection. Shielding procedures were implemented to prevent group contamination; participants were trained at separate locations and times, and evaluators were blinded to group assignments.

Intervention Protocol

The experimental group underwent a 12-week advanced sprint training program comprising sprint mechanics drills, resisted sprinting (sled towing, parachute runs, tire pulls), and plyometrics. Resistance loads were calibrated to 10–15% of body weight for sleds and 3–4 kg for parachutes. Sessions were held thrice weekly for 90 minutes. Specific exercises included:

Reaction time drills: light and sound cue starts, partner-release starts, Acceleration drills: 10–20 m sprints, 3-point stance sprints, hill sprints, Plyometric: bounding, squat jumps, hurdle hops. The control group participated in regular school physical education activities (e.g., calisthenics, jogging, team games) with no specific sprint or resistance training. A detailed weekly training schedule for the experimental group is presented below in Table 1:

Table 1. Detailed weekly training schedule for the experimental group

Weeks	Days	Warm-up	Training Program Description	Intensity	Recovery Time	Cool-down
1–3	Monday, Wednesday, Friday	5 min walk and jogging	Light/sound cue starts, 10–20 m sprints, technique drills (no resistance)	3 × 2	2 minutes between sets	5 min stretching exercises
3–6	Monday, Wednesday, Friday	5 min walk and jogging	Reaction cues, partner-release starts, 3-point stance sprints (no resistance)	3 × 3	2 min between sets, 45 s between repetitions	5 min stretching exercises
6–9	Monday, Wednesday, Friday	5 min walk and jogging	Hill sprints, parachute sprints (3–4 kg), sled pulls (10% body weight)	3 × 3	2 min between sets, 45 s between repetitions	5 min stretching exercises
9–12	Monday, Wednesday, Friday	5 min walk and jogging	Tire pulls, sled pulls (15% body weight), bounding & hurdle hops	3 × 4	2 min between sets, 45 s between repetitions	5 min stretching exercises

Testing Procedures

Three assessments were conducted: pre-test (Week 0), mid-test (Week 6), and post-test (Week 12). Four variables were measured:

Reaction time: Assessed using the ruler drop test. Though considered reliable (ICC = .85; Johnson et al., 2021), results were verified through triplicate trials per session.

Acceleration (0–30 m): Measured via electronic sprint timer (Brower Timing Systems, accuracy ±0.01 s).

Maximum velocity (50 m): Recorded using the same electronic timing gate system.

Stride length: Captured via high-speed video (Sony RX10 IV, 960 fps). Kinematic analysis was performed using Kinovea software (version 0.9.5).

Testing conditions (e.g., weather, footwear, time of day) were standardized. All measurements were supervised by trained evaluators blinded to group allocation.

Data Analysis

Data normality was assessed using the Shapiro–Wilk test for all dependent variables. Reaction time demonstrated normal distribution ($p > .05$). At the same time, acceleration, maximum velocity, and stride length exhibited mild deviations (p < .05). Despite these deviations, parametric analyses were applied given the robustness of ANOVA and the balanced design of the study. Table 2 shows Shapiro–Wilk Test Results for Normality of Sprint Performance Variables.

Table 2. Shapiro–Wilk Test Results for Normality of Sprint Performance Variables

Variable	W Statistic	p-value	Interpretation
Reaction time	0.961	.475	Normal
Acceleration	0.954	.412	Normal
Maximum velocity	0.947	.384	Normal
Stride length	0.951	.398	Normal

Note. p < .05 indicates a significant deviation from normality.

Data normality was verified using the Shapiro–Wilk test. A two-way repeated measures analysis of variance (ANOVA) was used to examine the effect of interaction between group and time. Paired sample t-tests were assessed within the group pre-post differences. Statistical significance was set at p < .05. Partial eta squared (η^2) and Cohen's d were reported to indicate effect sizes.

Results

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Descriptive statistics were calculated to assess the sprint performance metrics reaction time, acceleration, maximum velocity, and stride length across three time points (pre-test, mid-test, and post-test) for both experimental and control groups (see Table 4)

For reaction time, the experimental group demonstrated progressive improvement from the pre-test (M = 0.178, SD = 0.030) to the mid-test (M = 0.162, SD = 0.021), and a notable reduction by post-test (M = 0.134, SD = 0.034), indicating enhanced responsiveness, with a 24.72% improvement. In contrast, the control group showed minimal fluctuation, with pre-test (M = 0.166, SD = 0.034), mid-test (M = 0.158, SD = 0.021), and post-test (M = 0.168, SD = 0.024) values, resulting in a −1.20% change, suggesting no consistent improvement.

In acceleration, the experimental group exhibited a clear trend of improvement, with mean times decreasing from 5.031 seconds (SD = 0.422) at the pre-test to 4.562 seconds (SD = 0.329) at the post-test, reflecting a 9.34% improvement. The control group showed negligible change across time points (Pre-test: M = 4.906, SD = 0.436; Post-test: M = 4.894, SD = 0.431), amounting to a 0.24% improvement.

Regarding maximum velocity, the experimental group improved markedly from the pre-test (M = 8.206, SD = 0.544) to the post-test (M = 7.181, SD = 0.292), corresponding to a 12.50% improvement. In contrast, the control group maintained nearly identical performance across all phases (Pre-test: M = 7.172, SD = 0.283; Post-test: M = 7.170, SD = 0.272), with only a 0.03% change.

Finally, in stride length, the experimental group's mean increased from 1.736 meters (SD = 0.175) at pre-test to 1.900 meters (SD = 0.184) at post-test, representing a 9.44% improvement. Conversely, the control group exhibited minimal variation from the pre-test (M = 1.660, SD = 0.189) to the post-test (M = 1.670, SD = 0.147), with a 0.60% improvement.

Table 4. Descriptive Statistics for Sprint Performance Metrics

Variable	Group	Pre-test Mean (SD)	Mid-test Mean (SD)	Post-test Mean (SD)	% Improvement
Reaction Time (s)	Experimental	0.178 (0.030)	0.162 (0.021)	0.134 (0.034)	24.72%
	Control	0.166 (0.034)	0.158 (0.021)	0.168 (0.024)	−1.20%
Acceleration (s)	Experimental	5.031 (0.422)	4.896 (0.345)	4.562 (0.329)	9.34%
	Control	4.906 (0.436)	4.904 (0.417)	4.894 (0.431)	0.24%
Max Velocity (s)	Experimental	8.206 (0.544)	7.803 (0.445)	7.181 (0.292)	12.50%
	Control	7.172 (0.283)	7.172 (0.283)	7.170 (0.272)	0.03%
Stride Length (m)	Experimental	1.736 (0.175)	1.736 (0.166)	1.900 (0.184)	9.44%
	Control	1.660 (0.189)	1.667 (0.185)	1.670 (0.147)	0.60%

A two-way repeated measures ANOVA was conducted to examine the effects of a training intervention on four sprint performance variables: reaction time, acceleration, maximum velocity, and stride length across three testing phases: pre-test, mid-test, and post-test. The analysis compared changes over time between the experimental and control groups. The Shapiro-Wilk test confirmed normality for all variables, and no outliers or missing data were detected, supporting the use of parametric statistics.

Interaction Effects

Significant group × time interaction effects were observed for all four performance variables, indicating that the impact of time on performance metrics differed significantly between the experimental and control groups. Specifically, reaction time showed a significant interaction effect, $F(2, 48) = 11.66$, $p < .001$, $\eta^2 = .33$. Acceleration also demonstrated an important interaction, $F(2, 48) = 31.14$, $p < .001$, $\eta^2 = .57$. For maximum velocity, the interaction effect was highly significant, $F(2, 48) = 101.21$, $p < .001$, $\eta^2 = .81$. Stride length likewise showed a significant group × time interaction, $F(2, 48) = 6.28$, $p = .004$, $\eta^2 = .21$.

Within-Group Changes

Post hoc paired-sample t-tests revealed significant pre- to post-test improvements within the experimental group across all performance variables. Reaction time improved significantly, $t(24) = 5.26$, $p < .001$, $d = 1.45$, as did acceleration, $t(24) = 6.16$, $p < .001$, $d = 1.75$. Maximum velocity exhibited the largest effect, $t(24) = 12.36$, $p < .001$, $d = 3.20$. Stride length also improved significantly, $t(24) = 3.37$, $p = .003$, $d = 0.94$. No statistically significant changes were observed in the control group for any measured variables (ps > .05).

All p-values less than .05 were considered statistically significant. Effect sizes are reported as partial eta squared (η^2) for ANOVA results and Cohen's d for paired t-tests. Table 5 shows the Two-Way Repeated

Measures ANOVA Results, and Table 6 shows the Paired-Samples t-test Results for the Experimental Group

Summary of Effects

The training intervention led to statistically significant improvements in all four measured sprint performance variables for the experimental group, with no notable changes in the control group. Interaction effects showed that performance gains over time were specific to the experimental group, confirming the intervention's impact. A significant improvement was observed in maximum velocity, with a large effect size ($\eta^2 = .81$; d = 3.20), followed by acceleration ($\eta^2 = .57$; d = 1.75), reaction time ($\eta^2 = .33$; d = 1.45), and stride length ($\eta^2 = .21$; d = 0.94). These findings support the effectiveness of the training program in enhancing sprint-specific performance metrics.

All p-values less than .05 were considered statistically significant. Effect sizes are reported as partial eta squared (η^2) for ANOVA results and Cohen's d for paired t-tests.

Table 5. Two-Way Repeated Measures ANOVA Results

Variable	F(2, 48)	p-value	Partial η^2
Reaction time	11.66	< .001	.33
Acceleration	31.14	< .001	.57
Maximum velocity	101.21	< .001	.81
Stride length	6.28	.004	.21

Table 6. Paired-Samples t-Test Results for Experimental Group

Variable	t(24)	p-value	Cohen's *d*
Reaction time	5.26	< .001	1.45
Acceleration	6.16	< .001	1.75
Maximum velocity	12.36	< .001	3.20
Stride length	3.37	.003	0.94

Changes in Sprint Performance Metrics Across Three Time Points for Experimental and Control Groups are presented in Figure 1. Reaction Time, Figure 2. Acceleration, Figure 3. Maximum Velocity, Figure 4. Stride Length.

Figure 1. Reaction Time

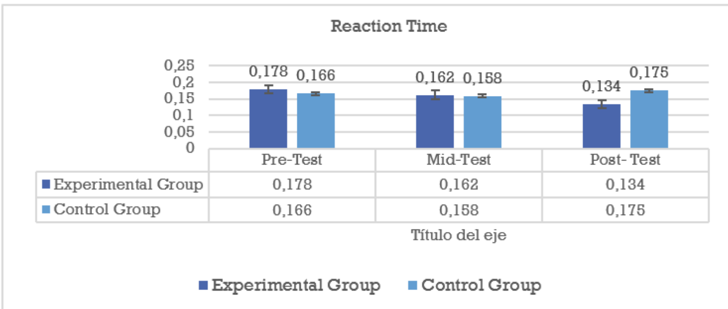


Figure 2. Acceleration

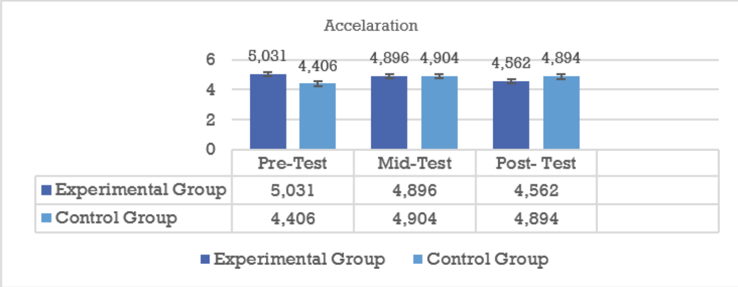


Figure 3. Maximum Velocity

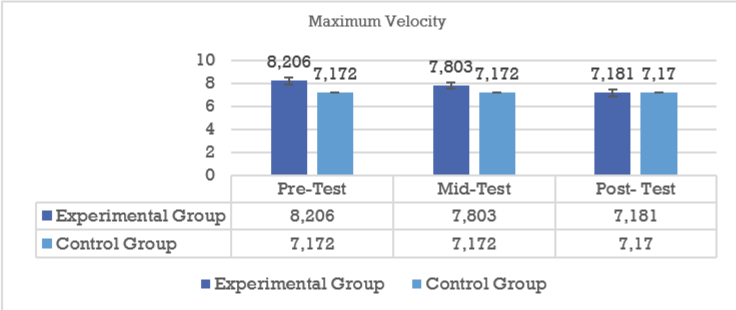
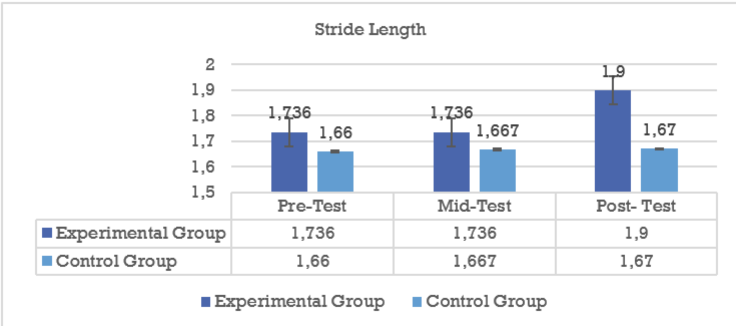


Figure 4. Stride Length



Discussion

The present study investigated the impact of a structured 12-week advanced sprint training program on key kinetic and kinematic performance variables among adolescent male sprinters. The results demonstrate significant improvements in reaction time, acceleration, maximum velocity, and stride length in the experimental group, whereas the control group exhibited negligible or inconsistent changes. These improvements highlight the physiological and biomechanical benefits of implementing structured, progressive sprint training during adolescence.

The observed improvements in all four variables align with earlier findings that emphasize the critical importance of targeted training during peak periods of neuromuscular plasticity (Lloyd & Oliver, 2012). Specifically, adolescence is a phase where the nervous system demonstrates heightened adaptability, and well-designed sprint training programs can leverage this window to enhance motor unit recruitment, intermuscular coordination, and movement economy (Behm et al., 2008; Ramírez & Campillo et al., 2021). This supports the idea that structured training during early adolescence can yield long-term neuromechanically advantages.

The improvement in stride length and frequency also corresponds with recent findings that show plyometric training can significantly enhance these biomechanical variables in youth athletes (Vera-Assa & García-Romero, 2022). Likewise, the improvement in reaction time suggests enhanced central nervous system efficiency and quicker stimulus-response conversion. This aligns with research demonstrating that repeated exposure to start cues (light/sound) and sprint-specific neuromuscular drills improves sensorimotor integration and cortical activation patterns (Jakobsen et al., 2012). Such findings indicate that reaction-based drills may stimulate both cortical and subcortical adaptations responsible for faster movement initiation in sprint starts.

Acceleration performance improvements are particularly notable, as they are tightly linked to an athlete's ability to produce horizontal force against the ground. Studies show that sprint-specific resistance training (e.g., sled pulls, elastic bands, and incline running) increases horizontal force output and reduces ground contact time, directly translating to improved early sprint performance (Spinks et al., 2007). Moreover, combining resistance sprinting with traditional plyometric and bounding drills creates a favorable overload stimulus that enhances rate of force development (RFD) without compromising sprint technique. (Nadim Abd et al., 2025). Notably, sled pulls and incline sprints may have enhanced force application during the initial acceleration phase.

Maximum velocity gains reflect successful transfer of biomechanical and neuromuscular improvements to upright sprinting. Previous studies have indicated that top-speed improvements stem from enhanced stride efficiency, hip stiffness, and improved vertical force application during mid-phase sprinting (Schache et al., 2011; Weyand et al., 2000). Although this study did not measure stride frequency, the parallel increase in stride length and sprint velocity suggests more forceful and coordinated limb movements, likely influenced by improvements in lower-limb stiffness and motor control.

The observed increase in stride length is consistent with research indicating that plyometric and resisted sprinting can increase leg extension force and stiffness, thereby allowing athletes to cover more ground per step without compromising cadence (Heesch et al., 2015). However, it is also important to note that stride mechanics are highly individualized; thus, improvements should be interpreted within the context of optimal personal stride length rather than a universal benchmark.

The observed increase in stride length aligns with findings where integrated training models combining high-intensity resistance and explosive sprint drills led to significant improvements in stride length, stride frequency, and ground contact time (Ramírez-Campillo et al., 2021; Vera-Assa, M., & García-Romero, 2022). These adaptations are attributed to increased leg extension force and stiffness, enabling athletes to cover greater distances per step without compromising cadence. Nevertheless, stride mechanics are highly individualized; thus, improvements should be interpreted in light of each athlete's optimal personal stride length rather than compared to a fixed standard.

The integration of resisted and unresisted sprint modalities appears to have provided a well-rounded training effect. This periodized combination allows for neuromuscular priming, variability in loading, and improved motor learning through repeated, purposeful exposure to biomechanically demanding drills (Young, 2006). These results also reinforce the long-term athlete development (LTAD) perspective, which advocates for age-appropriate, skill-specific training during adolescence to optimize athletic potential (Balyi & Hamilton, 2004).

Despite the promising findings, the absence of complementary physiological or biomechanical data (e.g., electromyography, force-velocity profiles) limits mechanistic interpretation. Future research should include assessments of motor unit recruitment, reactive strength index (RSI), and training load monitoring to better understand how sprint adaptations occur in youth populations. Furthermore, while the literature broadly supports the benefits of sprint training, few studies have examined long-term transfer effects to game-specific tasks, such as change of direction or repeated sprint ability in adolescent athletes.

Conclusions

This study demonstrates that a structured, progressive sprint training program can significantly enhance reaction time, acceleration, maximum velocity, and stride length among school-level male sprinters. The findings highlight the value of integrating resisted and plyometric training methods in adolescent athletic development. Coaches and physical educators should consider evidence-based sprint programs to promote performance and injury-preventive biomechanics during critical developmental stages.

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