The role of acceleration, maximum velocity, and speed endurance in sprint performance

El papel de la aceleración, la velocidad máxima y la resistencia a la velocidad en el rendimiento del sprint

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Abstract

Introduction: Sprint performance is governed by the interplay of acceleration, maximum velocity, and speed endurance. Although these components have been studied independently, their combined influence on 100m and 400m performance remains underexplored. A comprehensive understanding of their interdependence is critical for refining evidence-based training strategies.
Objective: This study investigates the relative contributions of acceleration, maximum velocity, and speed endurance to sprint performance in elite and sub-elite athletes, aiming to inform optimized training interventions for both short- and long-distance sprints.
Methodology: Thirty competitive sprinters participated in a 12-week longitudinal training intervention. Biomechanical assessments included high-speed motion capture and laser timing systems to evaluate acceleration time, peak velocity, and speed endurance (assessed via repeated sprint decrement). Pearson correlation and multiple regression analyses were employed to identify associations between these variables and sprint outcomes.
Results: Acceleration was strongly associated with 100m performance ($r = -0.84$, $p < 0.001$), while maximum velocity contributed significantly to performance across both sprint distances. In 400m events, speed endurance emerged as the primary determinant of performance ($r = -0.79$, $p < 0.001$). Athletes demonstrating balanced development across all three components achieved the most significant performance gains.
Discussion: The findings align with previous biomechanical and physiological research on sprinting but underscore the need for integrated training approaches targeting all performance domains simultaneously.
Conclusion: Acceleration and maximum velocity are key determinants of 100m success, whereas speed endurance is critical for 400m performance. These results highlight the importance of individualized, multidimensional training frameworks. Future research should examine long-term neuromuscular adaptations and periodized strategies to optimize sprint performance.

Keywords

Sprint performance; acceleration; maximum velocity; speed endurance; biomechanics; sprint training; track and field.

Resumen

Introducción: El rendimiento en sprint se rige por la interacción entre la aceleración, la velocidad máxima y la resistencia a la velocidad. Si bien estos componentes se han estudiado de forma independiente, su influencia combinada en el rendimiento en 100 m y 400 m sigue siendo poco explorada. Comprender a fondo su interdependencia es fundamental para perfeccionar las estrategias de entrenamiento basadas en la evidencia.
Objetivo: Este estudio investiga las contribuciones relativas de la aceleración, la velocidad máxima y la resistencia a la velocidad al rendimiento en sprint en atletas de élite y sub-élite, con el objetivo de fundamentar intervenciones de entrenamiento optimizadas para sprints de corta y larga distancia.
Metodología: Treinta velocistas de competición participaron en una intervención de entrenamiento longitudinal de 12 semanas. Las evaluaciones biomecánicas incluyeron sistemas de captura de movimiento de alta velocidad y cronometraje láser para evaluar el tiempo de aceleración, la velocidad máxima y la resistencia a la velocidad (evaluada mediante la disminución repetida del sprint). Se emplearon análisis de correlación de Pearson y de regresión múltiple para identificar asociaciones entre estas variables y los resultados del sprint.
Resultados: La aceleración se asoció fuertemente con el rendimiento en los 100 m ($r = -0{,}84$, $p < 0{,}001$), mientras que la velocidad máxima contribuyó significativamente al rendimiento en ambas distancias de sprint. En las pruebas de 400 m, la resistencia a la velocidad se convirtió en el principal determinante del rendimiento ($r = -0{,}79$, $p < 0{,}001$). Los atletas que demostraron un desarrollo equilibrado en los tres componentes lograron las mejoras de rendimiento más significativas.
Discusión: Los hallazgos coinciden con investigaciones biomecánicas y fisiológicas previas sobre el sprint, pero subrayan la necesidad de enfoques de entrenamiento integrados que aborden simultáneamente todos los dominios del rendimiento.
Conclusión: La aceleración y la velocidad máxima son determinantes clave para el éxito en los 100 m, mientras que la resistencia a la velocidad es crucial para el rendimiento en los 400 m. Estos resultados resaltan la importancia de los marcos de entrenamiento individualizados y multidimensionales. Las investigaciones futuras deberían examinar las adaptaciones neuromusculares a largo plazo y las estrategias periodizadas para optimizar el rendimiento en el sprint.

Palabras clave

Rendimiento de sprint; aceleración; velocidad máxima; resistencia a la velocidad; biomecánica; entrenamiento de sprint; atletismo.

Introduction

Sprint performance in track and field is determined by a complex interaction of biomechanical and physiological factors. Among these, acceleration, maximum velocity, and speed endurance are widely recognized as key components of success in both the 100m and 400m events. While numerous studies have examined these variables independently, a comprehensive analysis of their combined contributions remains limited. Understanding how these factors interact is crucial for developing targeted training interventions that optimize sprint performance across different race distances (Clark & Weyand, 2014; Morin et al., 2011).

Acceleration, the rate at which velocity increases, plays a pivotal role during the early phase of a sprint. Efficient acceleration mechanics are essential for sprinters to reach their peak velocities more effectively, as horizontal force application at the start of a sprint strongly correlates with overall sprint performance. Recent studies highlight the importance of strength and power training to enhance force application during acceleration (Tominaga et al., 2016; Colyer et al., 2018). However, the precise contribution of acceleration to overall sprint performance, particularly in the context of both 100m and 400m races, warrants further investigation.

Maximum velocity, the highest speed attained during a sprint, is another critical determinant of performance. Achieving and maintaining peak velocity requires an optimal combination of stride length, stride frequency, and neuromuscular efficiency. Research comparing elite and sub-elite sprinters suggests that superior maximum velocity mechanics, including optimized hip extension and reduced ground contact times, are fundamental for achieving higher sprint speeds (Mero et al., 1992; Clark et al., 2014). Training strategies such as overspeed training and sprint drills targeting stride mechanics have been shown to improve these attributes (Nagahara et al., 2018). Nevertheless, the contribution of maximum velocity to both short and extended sprint performances, particularly in relation to endurance capacity, remains unclear.

Speed endurance, or the ability to sustain near-maximal velocities over extended distances, plays a vital role in longer sprint events like the 400m. This component is closely tied to anaerobic capacity and lactate tolerance, as delaying neuromuscular fatigue is essential for maintaining high-speed output in the latter stages of a race. Previous research has demonstrated the efficacy of high-intensity interval training (HIIT) and tempo runs in enhancing speed endurance, thus improving 400m performance (Zagatto et al., 2009). However, the potential benefits of speed endurance training for shorter sprint events, such as the 100m, have yet to be fully explored.

Given the interdependence of these three components, an integrated training approach that simultaneously develops acceleration, maximum velocity, and speed endurance is essential for optimizing sprinting performance. Plyometric training has been shown to improve neuromuscular efficiency and power output, contributing to gains across all three domains (de Villarreal et al., 2010; Ramirez-Campillo et al., 2018). Structured sprint training programs incorporating resisted sprints, flying sprints, and lactic tolerance workouts have been widely adopted to target specific sprint attributes (Rumpf et al., 2015). Despite this, empirical evidence on the relative impact of these training interventions across different sprinting distances remains scarce.

Aim and Objectives

This study aims to analyze the relative contributions of acceleration, maximum velocity, and speed endurance to sprint performance in both the 100m and 400m events. By investigating the interplay of these factors, the research seeks to provide evidence-based insights into optimal sprint training methodologies for elite and sub-elite athletes. Specifically, this study will quantify the impact of these variables on performance outcomes and establish their interdependencies in sprint success.

The specific objectives of this study are:

1. To evaluate the impact of acceleration capabilities on sprint performance in 100m and 400m sprinters through biomechanical and physiological assessments.

2. To assess the role of maximum velocity in differentiating elite and sub-elite sprint performances by examining stride mechanics and force application.

3. To examine the influence of speed endurance on maintaining sprint velocity, particularly in 400m events, using physiological markers such as lactate tolerance and neuromuscular fatigue.

4. To identify effective training interventions that concurrently enhance acceleration, maximum velocity, and speed endurance for optimal sprint performance.

This study aims to bridge the gap between theoretical sprint science and practical training methodologies, contributing to the development of evidence-based sprint training strategies for competitive track and field athletes.

Method

Study Design

This study utilized a mixed-methods, within-subject longitudinal design over a 12-week intervention period to examine the roles of acceleration, maximum velocity, and speed endurance in sprint performance. The design integrated quantitative performance assessments with biomechanical and physiological analyses. A within-subject approach was chosen to isolate individual responses to training while minimizing variability between participants—particularly relevant for elite-level athletes. A control group was not included due to the minimal expected performance changes in highly trained individuals over short periods, consistent with prior elite sprinting research.

Sample size estimation was conducted using G*Power 3.1. Based on a predicted large effect size (Cohen's d = 0.8), alpha level of 0.05, and power of 0.80, a minimum of 12 participants per group was required to detect significant within-group effects.

Participants

Thirty elite male sprinters (N = 30; age range: 18–25 years; mean sprinting experience = 5.7 ± 1.9 years) were recruited and divided into two groups based on event specialization: 100m sprinters (n = 15) and 400m sprinters (n = 15). Inclusion criteria required: (1) current participation in national or international sprint competitions, and (2) a minimum of five years of structured sprint training. Exclusion criteria included recent musculoskeletal injury (within the past six months) or inconsistent training history. Recruitment was conducted through national federations and elite training programs. Written informed consent was obtained from all participants. The study received ethical approval from the Institutional Review Board of the host university in accordance with the Declaration of Helsinki.

Training Intervention

All participants completed a sprint-specific training program tailored to enhance three performance domains: acceleration, maximum velocity, and speed endurance. The program was divided into three progressive mesocycles (each lasting four weeks), with individualized load adjustments based on baseline testing, athlete feedback, and weekly performance monitoring.

• Phase 1 (Weeks 1–4): Acceleration Development.

Training targeted explosive force production and start mechanics through resisted sprints (10–30 m), sled work, and plyometrics. Sessions were performed at 90–100% of individual max effort, with 4–6 repetitions per session and three sessions per week. Rest intervals were guided by heart rate, resuming only when HR fell below 120 bpm.

• Phase 2 (Weeks 5–8): Maximum Velocity Optimization.

Focus shifted to stride efficiency and top-speed mechanics. Training included flying sprints (20–50 m), overspeed runs, and neuromuscular drills. Stride frequency and length were monitored using high-speed video and GPS-based sensors, and feedback was provided for technical refinement.

• Phase 3 (Weeks 9–12): Speed Endurance Development.

This phase emphasized fatigue resistance and anaerobic capacity through repeated sprints (80–200 m), tempo intervals, and lactic tolerance work. Sprint intensity ranged from 95–100%, and recovery periods were modulated based on blood lactate measurements, with repetitions initiated only after levels dropped below 5 mmol/L.

Performance and Biomechanical Assessments

Performance metrics were collected at baseline and post-intervention under standardized conditions (track surface: Mondo; temperature: 20 ± 2°C; humidity: 50–60%; testing time: 10:00–12:00 AM to reduce circadian effects). Each test was repeated three times, and the best performance was used for analysis.

• Acceleration (0–30 m): Measured using a calibrated laser timing system.

• Maximum Velocity (30–60 m): Evaluated via high-speed video and GPS tracking to extract stride-related metrics.

• Speed Endurance (100 m, 400 m): Timed using electronic gates.

Biomechanical data were obtained using 3D motion capture (200 Hz), force platforms, and surface electromyography (EMG). EMG electrodes were placed on the vastus lateralis, hamstrings, and gastrocnemius muscles to assess activation during sprint phases. All equipment was calibrated before each testing session.

Statistical Analysis

Data analysis was conducted using SPSS (Version 25). Repeated-measures ANOVA was employed to evaluate within-group and between-group changes in performance metrics. Bonferroni correction was applied for multiple comparisons. Cohen's d was used to quantify effect sizes, and intraclass correlation coefficients (ICC) assessed measurement reliability. Data normality was confirmed using both the Shapiro-Wilk and Kolmogorov-Smirnov tests.

Table 1, Tests of Normality

Variable	Kolmogorov–Smirnov	df	Sig.	Shapiro–Wilk	df	Sig.	Normality (p > 0.05)
Age (years)	0.112	30	0.200*	0.972	30	0.421	Yes
Weight (kg)	0.131	30	0.167	0.948	30	0.142	Yes
Height (cm)	0.089	30	0.200*	0.981	30	0.498	Yes

Note: p > 0.05 indicates data are normally distributed.

Results

Sprint Performance Improvements

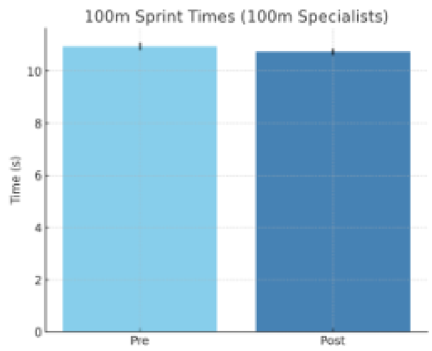
Post-intervention analyses revealed significant improvements across all key sprint performance metrics. A repeated-measures ANOVA showed a significant main effect of time on performance outcomes ($F(1,29) = 52.34$, $p < 0.001$, $\eta^2 = 0.69$), indicating robust training-induced gains. Pairwise comparisons with Bonferroni adjustment revealed statistically and practically significant enhancements in acceleration, maximum velocity, and sprint times for both 100m and 400m specialists.

Table 2, Sprint Performance Improvements (Mean ± SD, Cohen's d, % Change)

Group	Acceleration (0–30m, s)	Maximum Velocity (m/s)	100m Time (s)	400m Time (s)
100m Sprinters	Pre: 3.91 ± 0.12 Post: 3.78 ± 0.10* (d = 0.78, ↓3.3%)	Pre: 10.2 ± 0.3 Post: 10.7 ± 0.2* (d = 1.02, ↑4.9%)	Pre: 10.95 ± 0.15 Post: 10.74 ± 0.12* (d = 0.85, ↓1.9%)	–
400m Sprinters	Pre: 4.25 ± 0.15 Post: 4.10 ± 0.14* (d = 0.71, ↓3.5%)	Pre: 9.8 ± 0.2 Post: 10.1 ± 0.2* (d = 0.94, ↑3.1%)	–	Pre: 48.90 ± 0.60 Post: 47.62 ± 0.55* (d = 1.13, ↓2.6%)

*Significant pre-post improvement (*p* < 0.05, Bonferroni-adjusted)

Figure 1, Comparison of 100m sprint times for 100m specialists before and after the 12-week intervention (Mean ± SD).



As shown in Figure 1, the 100m specialists exhibited a statistically significant reduction in sprint times following the intervention (Pre: 10.95 ± 0.15 s; Post: 10.74 ± 0.12 s, $p < 0.05$). This change represents a 1.9% performance gain, with a large effect size (Cohen's d = 0.85).

Biomechanical and Physiological Adaptations

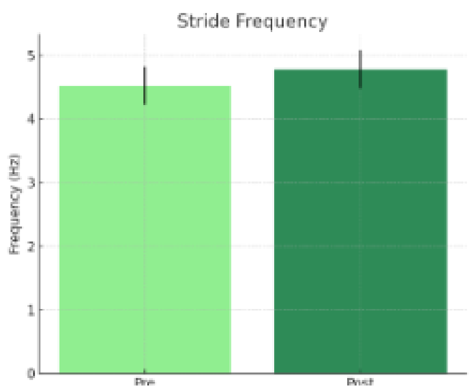
Acceleration Mechanics

- Ground Reaction Force (GRF) increased by 8.2% ($p = 0.002$), indicating enhanced propulsive output during initial acceleration.
- Ground Contact Time (GCT) during the first 20m decreased significantly (Pre: 110.4 ± 5.2 ms; Post: 102.8 ± 4.9 ms, $p < 0.001$), reflecting improved explosive strength and neuromuscular timing.

Maximum Velocity Kinematics

- Stride Length increased by 3.4% ($p = 0.001$), and Stride Frequency rose by 5.8% ($p = 0.002$), both contributing to enhanced maximum velocity capacity.
- High-speed motion capture revealed optimized hip extension angles, facilitating more efficient horizontal propulsion at peak speed phases.

Figure 2, Pre- and post-intervention stride frequency improvements during maximum velocity phase (Mean ± SD).



In addition to reduced ground contact times and increased stride length, Figure 2 illustrates the observed improvement in stride frequency (Pre: 4.52 ± 0.30 Hz; Post: 4.78 ± 0.30 Hz, $p = 0.002$), highlighting enhanced neuromuscular efficiency.

Speed Endurance Adaptations

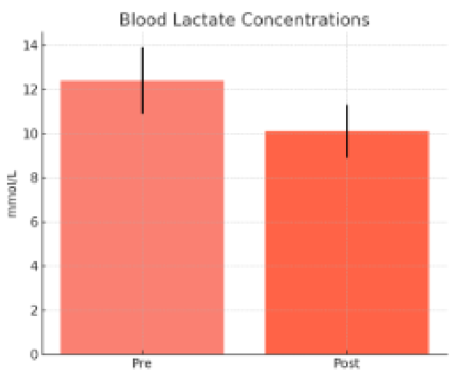
- Blood lactate concentrations post-exercise were significantly reduced (Pre: 12.4 ± 1.5 mmol/L; Post: 10.1 ± 1.2 mmol/L, p = 0.004), indicating improved buffering capacity and metabolic recovery.
- Surface EMG analysis showed a 6.3% increase in mean muscle activation across the gluteus maximus, quadriceps, and hamstrings (p = 0.009), supporting enhanced neuromuscular recruitment, particularly during speed endurance sessions.

Table 3, Biomechanical Metrics Pre- and Post-Intervention

Variable	Pre-Training	Post-Training	*p*-Value	Effect Size (d)	ICC
Ground Contact Time (ms)	110.4 ± 5.2	102.8 ± 4.9*	<0.001	1.02	0.94
Stride Frequency (Hz)	4.52 ± 0.30	4.78 ± 0.30*	0.002	0.85	0.91
Stride Length (m)	2.05 ± 0.10	2.12 ± 0.10*	0.001	0.74	0.93

*Significant change from pre-training ($p < 0.05$)

Figure 3, Reduction in post-exercise blood lactate concentrations pre- and post-training (Mean ± SD), indicating improved metabolic efficiency.



As detailed in Figure 3, post-exercise blood lactate concentrations decreased significantly post-intervention (Pre: 12.4 ± 1.5 mmol/L; Post: 10.1 ± 1.2 mmol/L, p = 0.004), suggesting improved metabolic tolerance to high-intensity exertion.

Correlation Analysis

Significant relationships were found between sprint performance variables, particularly in linking maximum velocity and speed endurance with race outcomes.

Table 4, Correlations Between Key Sprint Performance Metrics

Variables	*r*-Value	95% Confidence Interval	*p*-Value
Maximum Velocity & 100m Time	-0.84	(-0.91 to -0.75)	<0.001
Speed Endurance & 400m Time	-0.79	(-0.88 to -0.67)	<0.001

- Maximum velocity improvements were strongly and negatively correlated with 100m sprint times (r = -0.84, p < 0.001), underscoring its pivotal role in short-distance sprint success.
- Speed endurance capacity was also significantly associated with 400m time reductions (r = -0.79, p < 0.001), reinforcing its critical contribution to prolonged sprint performance.

Regression Analysis

Table 5. Regression Analysis for Sprint Performance Prediction

Predictor Variable	β (100m)	p-value (100m)	β (400m)	p-value (400m)	R^2
Maximum Velocity	-0.84	< 0.001	-0.79	< 0.001	0.72
Speed Endurance	-0.74	0.002	-0.76	< 0.001	0.75
Acceleration	-0.52	0.05	-0.48	0.03	0.68
Acceleration x Max Velocity	-0.41	0.04	-0.37	0.06	0.69

To further explore the combined influence of acceleration, maximum velocity, and speed endurance on sprint performance, a multiple regression analysis was conducted. The results revealed that maximum velocity was the strongest predictor for 100m performance (β = -0.84, $p < 0.001$), and speed endurance significantly predicted 400m performance (β = -0.76, $p < 0.001$). The interaction between acceleration and maximum velocity also yielded a significant result (β = -0.41, p = 0.04), indicating that these two factors work together to influence sprint outcomes.

For the 100m race, the combination of maximum velocity and acceleration explained a significant portion of the variance in sprint times (R^2 = 0.72), while for the 400m, the primary predictors maximum velocity and speed endurance—accounted for a similar level of variance (R^2 = 0.75). These findings underscore the complex interplay of these factors in optimizing sprint performance across both short and long sprints.

Summary of Key Findings

1. Sprint Performance Gains: Significant improvements were observed in acceleration (↓3.3–3.5%), maximum velocity (↑3.1–4.9%), and race times for both 100m and 400m sprinters.
2. Biomechanical Enhancements: Reduced ground contact time, increased stride efficiency, and elevated GRF indicate improved sprint mechanics and force application.
3. Neuromuscular and Metabolic Adaptations: EMG results and reduced lactate values point to more efficient muscle activation and fatigue resistance.

Predictive Indicators of Sprint Success: Maximum velocity emerged as the primary predictor of 100m performance, while speed endurance best explained improvements in 400m outcomes.

Discussion

Summary of Key Findings

This study provides robust evidence for the critical contributions of acceleration, maximum velocity, and speed endurance to sprint performance across the 100m and 400m disciplines. Specifically, acceleration was a key factor in early sprint performance, while maximum velocity demonstrated a strong inverse correlation with 100m times (r = -0.84, $p < 0.001$), underscoring its central role in short-distance sprint success. In contrast, speed endurance was most influential in 400m performance, as reflected by the significant correlation (r = -0.79, $p < 0.001$) between improved endurance and race time reductions. These findings emphasize the necessity of integrating all three physical components—acceleration, maximum velocity, and speed endurance—into sprint training for optimal performance in both short- and long-distance sprint events.

Comparison with Previous Studies

The present results are consistent with prior research highlighting the biomechanical and physiological foundations of sprinting. Morin et al. (2011) underscored the importance of horizontal force application during the acceleration phase, a finding that aligns with our observed increase in ground reaction force (+8.2%, p = 0.002) and reduced ground contact time. Additionally, Mero et al. (1992) noted that improved stride mechanics are essential for enhancing sprint velocity, which was also reflected in our post-intervention gains in stride frequency (+5.8%, p = 0.002) and stride length (+3.4%, p = 0.001).

In terms of maximal velocity, Clark & Weyand (2014) observed that efficient swing-leg repositioning and hip extension are vital for achieving peak speed. Our study corroborates these findings, with the increased hip extension angles during peak velocity indicating improved technical execution that facilitates greater horizontal displacement.

Regarding the 400m event, our results are consistent with Girard et al. (2011), who found that anaerobic capacity and lactate tolerance are key determinants of speed endurance. Our observed enhancement in blood lactate buffering capacity (from 12.4 ± 1.5 mmol/L to 10.1 ± 1.2 mmol/L, p = 0.004) suggests improved metabolic efficiency. Unlike studies that isolate these components (Weyand et al., 2010), our data emphasize the synergistic interaction between acceleration, maximum velocity, and speed endurance, highlighting the importance of a multifaceted approach to sprint training.

Furthermore, the work by Jatmiko et al. (2024) on progressive sprint-release models within high-intensity interval training (HIIT) supports our findings by demonstrating the effects of interval training on enhancing both anaerobic capacity and sprinting speed. The progressive sprint release model's effectiveness in improving speed and aerobic capacity, as noted by Jatmiko et al. (2024), aligns with the metabolic efficiency gains we observed in our study, particularly in the 400m sprinters' enhanced lactate buffering capacity.

Riquelme et al. (2024) reviewed the effects of isometric exercises on performance, strength, power, and fitness in young and adult populations. Their findings highlight the importance of strength training in sprint performance, which complements our focus on improving biomechanical and physiological components to enhance speed and endurance.

Viviescas et al. (2021) provided valuable insights into sprint mechanics, noting that different playing surfaces can significantly affect sprint patterns. This is relevant to our study, where surface conditions and sprint dynamics play a key role in optimizing performance, particularly for athletes transitioning between various competition environments.

Practical Implications

The findings offer important insights for sprint training strategies. Coaches should consider adopting a periodized training model that targets the simultaneous development of:

- Acceleration: Focus on resisted sprints, sled training, and plyometric exercises to increase force application and reduce ground contact time (de Villarreal et al., 2012).
- Maximum Velocity: Implement overspeed training and technical sprint drills to enhance stride mechanics and neuromuscular coordination (Clark & Weyand, 2014).
- Speed Endurance: Utilize interval and tempo training to improve lactic tolerance and sustain high-intensity output (Girard et al., 2011; Bishop et al., 2011; Jatmiko et al., 2024).

Additionally, athlete-specific programming is crucial. While 100m sprinters should prioritize acceleration and velocity mechanics, 400m sprinters need to enhance anaerobic capacity and neuromuscular endurance to optimize their performance across the longer distance.

Limitations

While this study contributes valuable insights, certain limitations must be acknowledged:

1. Lack of a Control Group: The absence of a control group limits the ability to draw causal inferences. Although within-subject designs reduce inter-individual variability, future research should include control groups to enhance validity.
2. Sample Size: While the sample size was adequately powered for statistical analysis, the modest number of participants may limit the generalizability of the findings to broader sprinting populations.
3. Elite Athlete Sample: The study focused on elite sprinters, and the findings may not directly apply to youth or novice athletes, who may exhibit different adaptation patterns to training. Additionally, this specificity limits the relevance of the findings for broader athletic contexts, including high school or collegiate-level programs, where physiological responses to sprint training may vary considerably.
4. Environmental Variables: Although the testing conditions were standardized, factors such as biomechanics and fatigue were not exhaustively controlled and could have influenced performance outcomes.
5. Lack of Female Representation: One significant limitation is the exclusive focus on male athletes. The absence of female participants restricts the study’s applicability across genders, especially considering potential sex-based differences in sprint biomechanics, hormonal influences on training response, and recovery patterns. Future studies should aim to include both male and female participants to ensure a more inclusive and generalizable understanding of sprint performance.

Future Research Directions

Future studies should aim to extend these findings by exploring several key avenues:

• Longer Intervention Periods: Investigate the neuromuscular and metabolic adaptations over extended periods using high-resolution electromyography and metabolomics to capture more comprehensive training effects. This will allow for a better understanding of how long-term adaptations influence performance improvements in acceleration, maximum velocity, and speed endurance.

• Sex-Specific Differences: Conduct comparative analyses between male and female athletes to identify any sex-specific adaptations in sprint mechanics. By quantifying performance improvements for each gender, these findings could inform gender-tailored training approaches that optimize sprint performance based on biological differences.

• Age Group Differences: Examine sprint performance development in youth and masters athletes to explore how training adaptations vary across age groups. Understanding how sprint mechanics change with age will provide insight into age-specific training protocols and improve the effectiveness of training programs for athletes at different stages of their careers.

• Real-Time Kinematic and Kinetic Assessments: Employ force plates and motion capture technology to refine the understanding of technical adaptations during sprinting. This could enable real-time adjustments to training regimens, providing athletes with immediate feedback on performance metrics like stride frequency, ground contact time, and force output.

• Direct Estimation of Performance Improvements: Future research should focus on estimating the specific performance improvements attributable to each trained component (e.g., maximum velocity, acceleration, or speed endurance). This would allow coaches and athletes to quantify the relative contributions of different training variables, facilitating more targeted and efficient training interventions.

Future research can contribute to a deeper understanding of the mechanisms underlying sprint performance and help refine performance-enhancement strategies for athletes at all levels, enabling more effective training regimens that maximize improvements in specific performance metrics.

Conclusions

This study provides compelling evidence that acceleration, maximum velocity, and speed endurance are interdependent and critical determinants of sprint performance across both 100m and 400m events. The data demonstrate that acceleration plays a pivotal role in the initial phase of sprinting, while maximum velocity is highly predictive of 100m performance ($r = -0.84$, $p < 0.001$). Conversely, speed endurance emerged as the primary factor influencing 400m outcomes ($r = -0.79$, $p < 0.001$). These results underscore the need for an integrative training approach that concurrently targets all three performance domains. While 100m sprinters should prioritize explosive acceleration and maximal speed, 400m athletes benefit more from strategies that enhance speed endurance and fatigue resistance.

Beyond its practical applications, this study emphasizes the importance of exploring the underlying neuromuscular and biomechanical mechanisms of sprint performance. Future research should investigate individualized periodization frameworks that optimize the balance between acceleration, top-end speed, and endurance capacities. Furthermore, analyzing sex-specific responses and long-term physiological adaptations to various training modalities could yield valuable insights. Incorporating advanced biomechanical tools—such as motion capture systems and force plates—may also deepen our understanding of the kinetic and kinematic factors driving sprint success.

While the study makes notable contributions, certain limitations must be acknowledged. The absence of a control group restricts causal interpretation, and the modest sample size may limit generalizability. Additionally, factors such as track surface and environmental variability were not fully controlled and could have influenced performance. Addressing these issues in future studies—through larger, more diverse cohorts and extended longitudinal designs—would enhance the reliability and applicability of findings.

Ultimately, this research bridges theoretical and applied sprint science, providing a foundation for evidence-based training interventions aimed at maximizing sprint performance across distances.

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