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# Physical and Physiological Responses to Training and Their Association with Performance Outcomes in Young Sub-Elite Sprinters

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**Abstract**

Sprinting requires great physical fitness and physiological qualities. This study aims to assess the impact of structured training on body composition, physical fitness, and physiological variables, as well as their correlations with performance outcomes in sub-elite sprinters. One hundred thirty boys (aged 18-20 years) were recruited and separated into two groups: control group (CG, n=65) and short-distance runner (SDR, n=65). The SDR group received supervised training (4 hours/day, 5 days/week, for 12 weeks), but the CG group did not receive any. Body composition, physical fitness, and physiological markers were measured at the beginning (0 weeks), middle (8 weeks), and end (12 weeks) of the intervention. After the intervention, the SDR group displayed significant gains in hand grip strength, back and leg strength, standing broad jump, vertical leap, push-up and sit-up scores, flexibility, speed, anaerobic power, fatigue index, $VO_{2max}$, $FEV_1$, and $FEV_1$/FVC ratio. Compared to baseline, there were substantial ($p<0.05$) reductions in body fat percentage, BMI, body mass, 30 m and 100 m sprint times, response time, resting and exercise heart rate, blood pressure, and peak blood lactate levels. These findings highlight the practical importance of establishing comprehensive sprint training programs to improve performance-related qualities in young athletes. Coaches and practitioners are advised to incorporate strength, conditioning, and recovery measures into training programs in order to maximize sprinting performance. Future research should look into the long-term effects of training at various levels and developmental phases, as well as individual responses and recovery dynamics.

***Keywords:*** *body fat, strength, power, blood lactate, training, sprinters*

## Introduction

Physical, physiological, and morphological elements interact in a complex way to affect sprint performance in sports. Optimizing these factors through methodical training is crucial for long-term athletic advancement and performance improvement in young sub-elite sprinters, who are at a transitional stage between developmental and elite-level competition (Bompa & Buzzichelli, 2015). Relatively few studies have thoroughly investigated how training-induced modifications in body composition, physical fitness, and physiological variables translate into improvements in sprint performance in sub-elite groups, despite the abundance of research on elite-level athletes.

Sprinting mechanics and efficiency are greatly impacted by body composition, especially the distribution of lean mass and the reduction of fat mass. While increasing lean mass, particularly in the lower extremities, correlates to better force output and stride frequency, decreased fat content

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is linked to reduced inertia and enhanced stride economy (Walker et al., 2023). Similar to this, physical fitness qualities that are suitable to focused training interventions, including as muscular strength, explosive power, linear speed, agility, and flexibility, are fundamental to sprinting performance (Li et al., 2024).

An athlete's ability to maintain and recover from high-intensity activities is reflected in physiological markers such as maximal oxygen uptake ($VO_{2max}$), anaerobic capacity, lactate tolerance, and heart rate recovery (Kantanista et al., 2021; Molinari et al., 2020; Xing et al., 2021). Even though sprinting is mostly anaerobic, there is growing evidence that aerobic and recovery-related abilities also play a role, especially in training adaptation and repeated sprint circumstances (Molinari et al., 2020; Xing et al., 2021). In young sub-elite populations, the precise relationship between these physiological traits and sprint performance is still poorly understood.

By examining the degree to which a structured sprint training program alters physiological and physical parameters and how these modifications relate to quantifiable performance results, the current study fills this knowledge gap. This study provides an integrated approach to comprehending the multifactorial predictors of sprint performance in a sub-elite developmental setting, in contrast to earlier research that solely focused on elite athletes. This main goal of this study is to assess how a twelve weeks sprint-specific training intervention affects young sub-elite sprinters' body composition, physical fitness and physiological factors. The study hypothesizes that sprint-specific training improves body composition, physical fitness, and physiological indicators.

## Methods

*Participants*

This study was conducted by Department of Physiology, Midnapore College Research Centre, Vidyasagar University, W.B., India, on randomly selected male volunteers (age: 18–20 years). In this study required sample size was computed by using G*power software (Kang, 2021). As per the software minimum 128 subjects were needed to carry out this study. To avoid mid study withdrawal a total of 155 (82 short-distance runners and 73 control individuals) were included; among them 17 short- distance runners and 08 control volunteers were excluded. The remaining 130 volunteers were grouped as the (i) control group (CG, n=65, sedentary) and (ii) short-distance runners (SDR, n=65, state level athletes).

*Ethical Considerations and informed consent statement*

The volunteers were given written information about the objectives of the study. The volunteers gave written consent to participate in this study. The ethical guideline for human studies framed by Indian Council of Medical Research (ICMR) was followed. The Institutional Ethics Committee approval was obtained for the present study [No. MC/IEC (HS)/PHY/Ph.D.RF/02/2023; Date: 19.08.2023].

*Experimental design*

The volunteers joined this study fifteen days before for acclimatize. The short-distance runners completed a training program [4 hours/day (morning-2 hrs and evening-2 hrs), 5 days/week, for 12 weeks] under the supervision of trained coaches. The training sessions were completed in two phases: the (i) Preparatory Phase (PP, 8 weeks) and the Competitive Phase (CP, 4 weeks) (Bompa & Buzzichelli, 2015) (Table 1 and 2). The volunteers of control group engaged in unsupervised recreational activities (e.g., walking) for an average of 30 minutes per day. Assessment of selected body composition, physical fitness, and physiological variables was performed at baseline data (BD, 0 week), and at the end of 8 weeks and 12 weeks of study (Figure 1).

**Table 1.** Training Periodisation for Short-Distance Runners

| **Phases** | | | **12 Weeks plan** | | | | |
|---|---|---|---|---|---|---|---|
| **Phases of Training** | | | **Baseline** | **Preparatory (8 weeks)** | | **Competitive (4 weeks)** | |
| **Sub-phases** | | | **Zero level baseline** | **General Preparation** | **Specific Preparation** | **Pre Competitive (maintenance)** | **Competitive (psychological)** |
| Periodization | Strength | | - | Anatomical adaptation | Maximal Strength | Power | |
| | Endurance | | - | Aerobic | Anaerobic | Ergogenesis | |
| | Speed | | - | Specific high | | Specific | |
| | Skills | | - | Foundation | Advanced | Stimulation | |
| Macro Cycles | | | 0 weeks | 1-4 weeks | 4-8 weeks | 8-10 weeks | 10-12 weeks |
| Training Factors | Volume | 100% | - | 80-90% | | 70% | 60-70% |
| | Intensity | 90% | - | 70-80% | | 80% | 80-90% |
| | Peaking | 80% | - | 70-75% | | 80% | >90% |
| | Physical Preparation | 70% | - | 50-55% | 40-45 % | 30% | 30% |
| | Technical Preparation | 60% | - | 40-45% | 40-45% | 35% | 35% |
| | Tactical Preparation | 50% | - | 10% | 10% | 35% | 35% |
| | Psychological Preparation | 40% | - | | 10% | 20% | 30-35% |

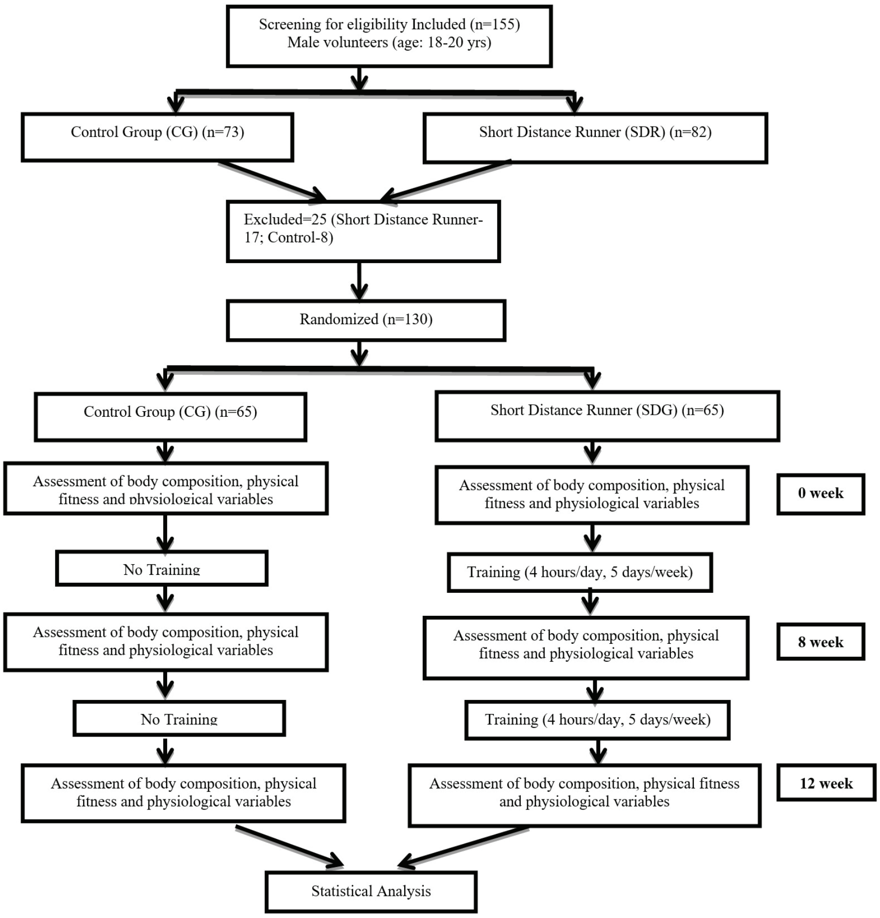


FIGURE 1. The experimental design

**Table 2.** Detailed of training schedule followed during preparatory and competitive phases by the short distance runners.

| Day | Preparatory phase (0-8 weeks) | | Competitive phase (8-12 weeks) | |
|---|---|---|---|---|
| | Morning (2 hr) | Evening (2 hr) | Morning (2 hr) | Evening (2 hr) |
| Monday | - Warm-up<br>- Strength Training: Lower body, core exercises<br>- Cool down | - Warm-up<br>- Speed Workout:<br>60m × 5 × 2 sets<br>120m × 4 × 2 sets @ 60–70%<br>150m × 3 × 2 sets<br>- Cool down | - Warm-up<br>- Speed Workout: 8 × 200m sprints at race pace<br>- Cool down | - Warm-up<br>- Strength Training: Explosive, core exercises<br>- Stretching,<br>- Cool down |
| Tuesday | - Warm-up<br>- Weight training (40–60%)<br>- Bounding & hopping<br>- Static stretching<br>- Cool down | - Warm-up<br>- Sprinting Workout: 30m × 6 × 2 sets, 40m × 4 × 2 sets<br>- Static stretching<br>- Cool down | - Warm-up<br>- Lunges, speed drills<br>- Active recovery: Light jogging, mobility drills<br>- Cool down | - Warm-up<br>- Foam rolling & self-myofascial release<br>- Flexibility training<br>- Core exercises<br>- Cool down |
| Wednesday | - Active recovery<br>- Mobility exercises | - Warm-up<br>- Foam rolling & myofascial release<br>- Flexibility, core, recreation<br>- Cool down | - Warm-up<br>- Speed endurance: 4 × 200m at race pace<br>- Cool down<br>- Motivation & counseling | - Warm-up<br>- Power exercises<br>- Recreation, static stretching<br>- Recovery session |
| Thursday | - Warm-up<br>- Weight training (40–50%) - Circuit style<br>- Plyometrics, bounding & hopping<br>- Cool down | - Warm-up<br>- Endurance run: 30–40 mins @ moderate pace<br>- Cool down | - Warm-up<br>- Tempo run: 30 mins at race pace<br>- 200m/400m × 2 × 2 sets<br>- 250m/400m × 2 × 2 sets<br>- 300m × 2 × 1 set<br>- Cool down | - Warm-up<br>- Strength Training: Compound, core exercises<br>- Recovery session |

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**Table 2.** Detailed of training schedule followed during preparatory and competitive phases by the short distance runners.

| Day | Preparatory phase (0-8 weeks) | | Competitive phase (8-12 weeks) | |
|---|---|---|---|---|
| | Morning (2 hr) | Evening (2 hr) | Morning (2 hr) | Evening (2 hr) |
| Friday | - Warm-up<br>-Flexibility/ mobility/ agility drills<br>- Easy stretching<br>- Cool down | - Warm-up<br>- 200m/400m × 2 × 2 sets<br>- 250m/400m × 2 × 2 sets<br>- 300m × 2 × 1 set<br>- Cool down | - Warm-up<br>- Active recovery: Light jogging, mobility drills<br>- Straddling<br>- Cool down | - Warm-up<br>- Foam rolling & myofascial release<br>- Flexibility training<br>- Core exercises<br>- Cool down |
| Saturday | - Warm-up<br>- Speed endurance: 8–10 × 200/400m sprints<br>- Stretching exercises<br>- Cool down | - Warm-up<br>- Hurdle drills, stretching<br>- Core stability<br>- Tapering: reduce volume/ intensity<br>- Cool down | - Warm-up<br>- Speed maintenance: 6 × 100/200/400m sprints at max effort<br>- Cool down | - Warm-up<br>- Hurdle drills<br>- Stretching<br>- Core stability<br>- Cool down |
| Sunday | Rest and Recovery | Rest and Recovery | Rest and Recovery | Rest and Recovery |

*Measurement of body composition variables*

The height (stature) and body mass were measured, and body mass index (BMI) and body surface area (BSA) were determined (Chandrasekar et al., 2023). A skin fold caliper (Cescorf, USA) was used for the determination of percent body fat, total fat mass and lean body mass (LBM) following standard methods (Siri, 1961). The mid-upper arm circumference (MUAC), mid-calf circumference (MCC) and waist-hip ratio (WHR) were determined by using standard procedures (Chandrasekar et al., 2023). The lengths of the arm, hand, leg, and foot were measured using sliding calipers (Chandrasekar et al., 2023).

*Measurements of physical fitness variables*

A hand grip dynamometer, back and leg dynamometer (Baseline, USA) were used for measurement of hand grip strength, back and leg strength following standard methods (Chandrasekar et al., 2023). The standing broad jump (SBJ), vertical jump (VJ), sit-up (SU) test, push-up (PU), reaction time, and flexibility tests were performed using standard procedures (Chandrasekar et al., 2023). The 30-m and 100-m sprint time were taken, and speed was determined (Chandrasekar et al., 2023). The running-based anaerobic sprint test (RAST) was performed to determine the anaerobic power (Burgess et al., 2016).

*Measurements of physiological variables*

Volunteers were asked to take fifteen minutes rest; resting heart rate and blood pressure was measured (McArdle et al., 2015). Heart rate during sub-maximal exercise, maximal exercise, and recovery was taken by Polar H10 heart rate monitor (Polar, USA) following a treadmill test (McArdle et al., 2015). The lung function tests including- force vital capacity (FVC), force expiratory volume in 1st sec ($FEV_1$) and peak expiratory flow rate (PEFR) were measured by using a digital spirometer (CareFusion, Japan) (Gallucci et al., 2019). The Yo-Yo Intermittent Recovery Test 1 (YYR1) was used for determination of maximum oxygen uptake ($VO_{2max}$) of the volunteer (Bangsbo et al., 2008). The participant was asked to take rest for 15 min, and 2 ml of 12 hour fasting blood sample was taken from the fingertip for measurement of resting blood lactate. For the measurement of peak lactate, blood sample was taken 3 min after the completion of running based anaerobic sprint test (RAST). The blood lactate analysis was performed by using portable blood lactate analyser (Lactate Scout 4, EKF Diagnostics, USA) (Bosquet et al., 2001).

*Statistical analysis*

Descriptive statistics were computed for all variables. A two-way ANOVA with Bonferroni post-hoc multiple comparison tests was used to detect both within-group and between-group differences. For each dependent variable, the main effects of time and group, as well as the interaction effect (group × time), were reported along with their corresponding F-values, degrees of freedom, and partial eta squared ($\eta^2p$) as a measure of effect size. Pearson's correlation analysis was used to investigate the relationship between variables. The statistical significance was chosen at $p<0.05$ (Banerjee, 2018). All statistical analyses were carried out using SPSS software (version 27.0; IBM Corp., Armonk, NY, USA).

## Results

*Effects of training on body composition variables of short-distance runners*

The training program resulted in considerable improvements in numerous key anthropometric and body composition indicators among the sprinters. The study found substantial reductions in body mass, BMI, BSA, body fat percentage, and fat mass ($p\leq0.05$) compared to the baseline. Reduced fat mass and body fat percentage were the most obvious signs of better body composition. Furthermore, the reciprocal ponderal index increased considerably after training, indicating improved body proportionality. Sprinters had significantly lower values than the control group for body mass, BMI, BSA, body fat percentage, fat mass, basal metabolic rate, lean body mass, and waist-hip ratio ($p\leq0.05$). They also had significantly larger mid-upper arm and mid-calf circumferences, indicating better muscle growth. There were no significant changes in limb lengths (arm, hand, leg, or foot) following training (Table 3).

*Effects of training of physical fitness variables and performance of short distance runners*

Training resulted in significant ($p\leq0.05$) increases in numerous physical fitness parameters among short-distance runners. After 8 and 12 weeks of training, participants had

**Table 3.** Anthropometric changes over time in response to training among short-distance runners

| Parameter | Control Group (n=65) | | | Short Distance Runners (n=65) | | | Two Way ANOVA | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 Wk | 8 Wk | 12 Wk | 0 Wk | 8 Wk | 12 Wk | Group F1 ($\eta p^2$) [p value] | Time F2 ($\eta p^2$) [p value] | Interaction F3 ($\eta p^2$) [p value] |
| Height (cm) | 168.36 ± 5.23 | 168.40 ± 5.17 | 168.42 ± 5.20 | 170.91 ± 5.57 | 170.95NS ± 5.56 | 170.97NS ± 5.56 | 21.90 (0.05) [p≤0.001] | 0.004 (0.00) [p=0.996] | 0.000 (0.00) [p=1.00] |
| Body mass (kg) | 66.25 ± 5.05 | 66.87 ± 4.85 | 67.05 ± 4.68 | 62.44 ± 4.60 | 59.90*$ ± 4.47 | 58.82*$ ± 4.05 | 182.62 (0.32) [p≤0.001] | 3.16 (0.02) [p=0.043] | 7.89 (0.04) [p≤0.001] |
| BMI (kg/m²) | 23.38 ± 1.56 | 23.58 ± 1.50 | 23.64 ± 1.44 | 21.37$ ± 1.20 | 20.49*$ ± 1.16 | 20.13*$ ± 1.12 | 445.77 (0.54) [p≤0.001] | 4.54 (0.02) [p=0.011] | 11.004 (0.05) [p≤0.001] |
| BSA (m²) | 1.75 ± 0.084 | 1.76 ± 0.082 | 1.76 ± 0.081 | 1.73 ± 0.087 | 1.70$ ± 0.086 | 1.68*$ ± 0.081 | 41.04 (0.10) [p≤0.001] | 1.34 (0.01) [p=0.264] | 3.34 (0.02) [p=0.035] |
| RPI | 0.42 ± 0.011 | 0.42 ± 0.011 | 0.41 ± 0.010 | 0.43 ± 0.010 | 0.45*$ ± 0.011 | 0.44*$ ± 0.011 | 344.02 (0.47) [p≤0.001] | 3.67 (0.02) [p=0.026] | 7.73 (0.04) [p≤0.001] |
| PI | 13.91 ± 1.13 | 14.03 ± 1.10 | 14.06 ± 1.08 | 12.52 ± 0.90 | 12.00*$ ± 0.87 | 11.79*$ ± 0.87 | 347.18 (0.48) [p≤0.001] | 2.85 (0.02) [p=0.059] | 6.79 (0.03) [p=0.001] |
| BMR (kcal/day) | 1676.84 ± 84.21 | 1685.31 ± 81.38 | 1687.87 ± 79.75 | 1639.33 ± 81.43 | 1605.40 ± 79.65 | 1591.01$ ± 73.80 | 77.52 (0.17) [p≤0.001] | 1.84 (0.01) [p=0.160] | 4.73 (0.02) [p=0.009] |
| Body Fat (%) | 16.19 ± 1.88 | 16.44 ± 1.83 | 16.52 ± 1.75 | 13.74$ ± 1.44 | 12.68*$ ± 1.39 | 12.24*$ ± 1.34 | 451.90 (0.54) [p≤0.001] | 4.47 (0.02) [p=0.012] | 10.84 (0.05) [p≤0.001] |
| Fat Mass (kg) | 10.78 ± 1.87 | 11.04 ± 1.82 | 11.12 ± 1.73 | 8.61 ± 1.32 | 7.63*$ ± 1.21 | 7.22*$ ± 1.09 | 410.13 (0.52) [p≤0.001] | 4.00 (0.02) [p=0.019] | 10.80 (0.05) [p≤0.001] |
| LBM (kg) | 55.46 ± 3.57 | 55.82 ± 3.45 | 55.93 ± 3.38 | 52.83 ± 3.58 | 52.27*$ ± 3.52 | 51.59$ ± 3.25 | 81.85 (0.18) [p≤0.001] | 2.21 (0.01) [p=0.111] | 5.25 (0.03) [p=0.006] |
| Waist- Hip Ratio | 0.932 ± 0.055 | 0.937 ± 0.057 | 0.940 ± 0.056 | 0.860 ± 0.040 | 0.858$ ± 0.039 | 0.853$ ± 0.036 | 263.73 (0.41) [p≤0.001] | 0.04 (0.00) [p=0.962] | 0.75 (0.00) [p=0.470] |
| MUAC (cm) | 21.01 ± 2.31 | 21.13 ± 2.29 | 21.37 ± 2.26 | 28.53 ± 3.01 | 28.32$ ± 2.87 | 28.27$ ± 2.84 | 738.06 (0.66) [p≤0.001] | 0.04 (0.00) [p=0.960] | 0.45 (0.00) [p=0.636] |
| MCC (cm) | 30.84 ± 2.09 | 30.93 ± 2.08 | 31.12 ± 2.05 | 34.55 ± 1.00 | 34.67$ ± 1.05 | 34.71$ ± 1.06 | 488.34 (0.56) [p≤0.001] | 0.62 (0.00) [p=0.539] | 0.07 (0.00) [p=0.930] |
| Arm Length (cm) | 57.85 ± 1.75 | 57.86 ± 1.75 | 57.86 ± 1.75 | 58.48 ± 2.44 | 58.49 NS ± 2.43 | 58.50NS ± 2.43 | 8.59 (0.02) [p=0.004] | 0.002 (0.00) [p=0.998] | 0.000 (0.00) [p=1.00] |
| Hand Length (cm) | 16.97 ± 1.15 | 16.98 ± 1.15 | 16.98 ± 1.15 | 17.22 ± 0.92 | 17.23 NS ± 0.91 | 17.23NS ± 0.91 | 5.58 (0.01) [p=0.019] | 0.01 (0.00) [p=0.995] | 0.000 (0.00) [p=1.00] |
| Leg Length (cm) | 87.33 ± 3.25 | 87.39 ± 3.23 | 87.42 ± 3.25 | 87.78 ± 3.18 | 87.79 NS ± 3.17 | 87.81NS ± 3.18 | 1.62 (0.00) [p=0.204] | 0.01 (0.00) [p=0.987] | 0.003 (0.00) [p=0.997] |
| Foot Length (cm) | 24.71 ± 1.17 | 24.74 ± 1.16 | 24.76 ± 1.17 | 24.79 ± 0.77 | 24.80 NS ± 0.79 | 24.81NS ± 0.79 | 0.46 (0.00) [p=0.497] | 0.04 (0.00) [p=0.965] | 0.01 (0.00) [p=0.992] |

Note. [Data presented as Mean ± SD, Two-Way ANOVA followed by post-hoc tests (Bonferroni) was performed. * when compared to 0 week p≤0.05, # when compared to 8 week p≤0.05, $when compared to control group p≤0.05; df for training= 2, df for group = 1, df for interaction = 2, df within = 384, df total = 389, Critical F for Group = 3.865, Critical F for Time =3.019, Critical F for Interaction = 3.019; In the table calculated F values, partial eta squared (ηp2) and p value; SD = standard deviation, ANOVA= Analysis of Variance, CG= control group, SDR= short distance runners, NS= not significant; BMI= body mass index, BSA= body surface area, BMR= basal metabolic rate RPI= reciprocal ponderal index, PI= ponderal index, LBM = lean body mass, MUAC = mid upper arm circumference, MCC= mid calf circumference.]

significant decreases in 30 m and 100 m sprint times; as well as an increase (p≤0.05) in sprint speed. Sprinters outperformed control group volunteers with significantly higher sprint performance and faster reaction times. Significant (p≤0.05) improvements in handgrip, back, and leg strength were noted over time and compared to controls. Explosive power, measured by standing broad jump and vertical jump tests, as well as muscular endurance (push-ups and sit-ups), improved consistently and significantly (p≤0.05) across the training period. Sprinters also showed significant (p≤0.05) gains in anaerobic performance measures such as maximum and relative power outputs, fatigue index, and anaerobic capacity. Flexibility improved significantly (p≤0.05) after training. All observed variables were improved significantly (p≤0.05) compared to baseline and control group values (Table 4).

*Impact of athletic training on physiological determinants of short-distance runners*

Training led to considerable improvements in numerous key physiological indicators among sprinters. Significant reductions (p≤0.05) in heart rate measurements (basal, pre-exercise, sub-maximal, maximum, and recovery) were seen, indicating improved cardiovascular efficiency. Sprinters' blood pressure was also considerably lowers than controls, indicating

**Table 4.** Changes in physical fitness variables following training in short-distance runners

| Parameters | Control Group (n=65) | | | Short Distance Runners (n=65) | | | Two Way ANOVA | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 Wk | 8 Wk | 12 Wk | 0 Wk | 8 Wk | 12 Wk | Group F1 (ηp2) [p value] | Time F2 (ηp2) [p value] | Interaction F3 (ηp2) [p value] |
| GSRH (Kg) | 38.94 ± 3.06 | 39.84 ± 3.76 | 40.09 ± 3.87 | 42.48 ± 4.34 | 45.78*$ ± 5.86 | 48.52*#$ ± 6.71 | 152.20 (0.28) [p≤0.001] | 18.61 (0.09) [p≤0.001] | 8.53 (0.04) [p≤0.001] |
| GSLH (kg) | 35.91 ± 3.02 | 36.03 ± 3.03 | 36.44 ± 3.40 | 38.42 ± 4.12 | 40.94*$ ± 4.69 | 42.48*$ ± 4.00 | 138.56 (0.27) [p≤0.001] | 12.12 (0.06) [p≤0.001] | 7.49 (0.04) [p≤0.001] |
| Back Strength (kg) | 81.36 ± 4.19 | 82.04 ± 4.23 | 82.88 ± 4.55 | 110.76$ ± 6.36 | 116.13$ *± 6.75 | 118.47*$ ± 6.18 | 3530.70 (0.90) [p≤0.001] | 23.69 (0.11) [p≤0.001] | 11.25 (0.06) [p≤0.001] |
| Leg Strength (kg) | 92.03 ± 5.27 | 92.55 ± 5.76 | 93.21 ± 6.10 | 122.16$ ± 5.71 | 129.65*$ ± 9.27 | 135.54*#$ ± 7.97 | 2780.47 (0.88) [p≤0.001] | 36.90 (0.16) [p≤0.001] | 26.04 (0.12) [p≤0.001] |
| SBJ score (m) | 1.51 ± 0.22 | 1.49 ± 0.21 | 1.47 ± 0.21 | 2.73$ ± 0.27 | 2.87*$ ± 0.30 | 2.91*$ ± 0.29 | 2678.67 (0.88) [p≤0.001] | 2.84 (0.02) [p=0.060] | 6.27 (0.03) [p=0.002] |
| VJ score (m) | 0.28 ± 0.043 | 0.27 ± 0.037 | 0.28 ± 0.040 | 0.53$ ± 0.058 | 0.60*$ ± 0.051 | 0.64*#$ ± 0.056 | 3961.21 (0.91) [p≤0.001] | 38.22 (0.17) [p≤0.001] | 52.19 (0.21) [p≤0.001] |
| Push-up score (no/min) | 14.44 ± 3.51 | 14.70 ± 3.67 | 14.96 ± 4.05 | 30.07$ ± 5.53 | 34.40*$ ± 5.59 | 36.89*#$ ± 4.91 | 1658.91 (0.81) [p≤0.001] | 20.87 (0.10) [p≤0.001] | 15.46 (0.08) [p≤0.001] |
| Sit-up score (no/min) | 14.86 ± 4.06 | 15.03 ± 4.25 | 15.16 ± 4.01 | 30.56$ ± 4.72 | 38.03*$ ± 6.54 | 39.14*$ ± 5.04 | 1808.46 (0.83) [p≤0.001] | 31.90 (0.14) [p≤0.001] | 28.17 (0.13) [p≤0.001] |
| Pmax (watt) | 553.25 ± 62.23 | 541.53 53.89 | 540.05 ± 52.37 | 805.58$ ± 60.82 | 829.20*$ ± 57.77 | 836.88*$ ± 57.05 | 2297.37 (0.86) [p≤0.001] | 0.83 (0.00) [p=0.436] | 5.44 (0.03) [p=0.005] |
| RPmax (watt/kg) | 8.39 ± 1.12 | 8.14 ± 1.03 | 8.03 ± 0.96 | 12.97$ ± 1.40 | 13.91*$ ± 1.39 | 14.28*$ ± 1.31 | 2002.44 (0.84) [p≤0.001] | 5.87 (0.03) [p=0.003] | 15.44 (0.07) [p≤0.001] |
| Pavg (watt) | 397.73 ± 54.59 | 388.41 ± 56.08 | 381.58 ± 54.43 | 608.41$ ± 64.11 | 626.43$ ± 64.89 | 632.02$ ± 65.48 | 1506.35 (0.80) [p≤0.001] | 0.50 (0.00) [p=0.605] | 2.88 (0.02) [p=0.057] |
| RPavg (watt/kg) | 5.97 ± 0.94 | 5.84 ± 0.98 | 5.72 ± 0.89 | 9.79$ ± 1.26 | 10.51*$ ± 1.34 | 10.78*$ ± 1.29 | 1548.01 (0.80) [p≤0.001] | 3.87 (0.02) [p=0.022] | 10.22 (0.05) [p≤0.001] |
| Pmin (watt) | 219.57 ± 36.64 | 215.60 ± 35.28 | 213.41 ± 34.40 | 429.16$ ± 40.91 | 433.12$ ± 37.84 | 437.73$ ± 33.68 | 3442.57 (0.90) [p≤0.001] | 0.05 (0.00) [p=0.954] | 1.33 (0.01) [p=0.267] |
| Fatigue Index | 11.12 ± 1.95 | 10.86 ± 1.53 | 10.88 ± 1.49 | 12.54$ ± 1.53 | 13.20$ ± 1.76 | 13.30*$ ± 1.83 | 143.96 (0.27) [p≤0.001] | 0.84 (0.00) [p=0.431] | 3.44 (0.02) [p=0.033] |
| AC (watt) | 2386.39 ± 327.58 | 2330.49 ± 336.50 | 2289.53 ± 326.61 | 3650.46$ ± 384.69 | 3758.62$ ± 389.35 | 3792.15$ ± 392.87 | 1506.35 (0.80) [p≤0.001] | 0.50 (0.00) [p=0.605] | 2.89 (0.02) [p=0.057] |
| Flexibility score (cm) | 23.43 ± 3.90 | 22.92 ± 3.39 | 22.54 ± 3.30 | 31.56$ ± 4.53 | 34.10*$ ± 4.75 | 35.02*$ ± 4.87 | 628.17 (0.62) [p≤0.001] | 3.42 (0.02) [p=0.034] | 9.25 (0.05) [p≤0.001] |
| Reaction Time (ms) | 379.15 ± 36.20 | 377.74 ± 35.46 | 375.70 ± 34.51 | 342.98$ ± 26.38 | 338.26$ ± 30.83 | 337.63$ ± 28.68 | 134.97 (0.26) [p≤0.001] | 0.64 (0.00) [p=0.529] | 0.09 (0.00) [p=0.917] |
| 30m Sprint Time (sec) | 6.21 ± 0.23 | 6.25 ± 0.27 | 6.29 ± 0.28 | 4.41$ ± 0.15 | 4.28*$ ± 0.10 | 4.23*$ ± 0.11 | 8449.46 (0.96) [p=<0.001] | 2.364 (0.01) [p=0.095] | 14.233 (0.07) [p=<0.001] |
| 100m Sprint Time (sec) | 16.35 ± 0.58 | 16.31 ± 0.61 | 16.37 ± 0.47 | 11.90$ ± 0.42 | 11.77$ ± 0.41 | 11.32*#$ ± 0.35 | 9008.48 (0.96) [p≤0.001] | 11.48 (0.06) [p≤0.001] | 14.02 (0.07) [p≤0.001] |
| Speed (m/s) | 4.83 ± 0.18 | 4.80 ± 0.21 | 4.77 ± 0.22 | 6.79$ ± 0.22 | 7.01*$ ± 0.16 | 7.09*#$ ± 0.17 | 11595.32 (0.97) [p≤0.001] | 12.53 (0.06) [p≤0.001] | 27.765 (0.13) [p≤0.001] |

Note. [Data presented as Mean ± SD, Two-Way ANOVA followed by post-hoc tests (Bonferroni) was performed. * when compared to 0 week p≤0.05, # when compared to 8 week p≤0.05, $when compared to control group p≤0.05; df for training= 2, df for group = 1, df for interaction = 2, df within = 384, df total = 389, Critical F for Group = 3.865, Critical F for Time =3.019, Critical F for Interaction = 3.019; In the table calculated F values, partial eta squared ($\eta p^2$) and p value; SD = standard deviation, ANOVA= Analysis of Variance, CG= control group, SDR= short distance runners, NS= not significant; GSR= grip strength in right hand, GSL= grip strength in left hand, SBJ= standing broad jump, VJ= vertical jump, Pmax= maximum power, RPmax= relative maximum power, Pavg= average power, RPavg= relative average power, Pmin= minimum power, AC= anaerobic capacity]

superior cardiovascular function. Training resulted in a significant increase in aerobic capacity ($VO_{2max}$) (p≤0.05) and improved pulmonary function ($FEV_1$). Sprinters outperformed control subjects with considerably higher $VO_{2max}$, FVC, $FEV_1$, and PEFR values, indicating improved respiratory and aerobic performance. After training, peak blood lactate levels decreased significantly (p ≤ 0.05), indicating enhanced anaerobic efficiency and lactate clearance. Resting lactate levels remained constant. There were no significant difference in lactate levels between sprinters and control group individuals (Table 5).

**Table 5.** Changes in physiological variables following training in short-distance runners

| Parameters | Control Group (n=65) | | | Short Distance Runners (n=65) | | | Two Way ANOVA | | |
|---|---|---|---|---|---|---|---|---|---|
| | 0 Wk | 8 Wk | 12Wk | 0 Wk | 8 Wk | 12 Wk | Group F1 ($\eta p^2$) [p value] | Time F2 ($\eta p^2$) [p value] | Interaction F3($\eta p^2$) [p value] |
| SBP (mmHg) | 119.27 ± 5.74 | 120.76 ± 5.44 | 121.05 ± 5.19 | 119.69 ± 5.44 | 117.83 ± 4.15 | 116.70$ ± 4.37 | 19.16 (0.05) [p≤0.001] | 0.47 (0.00) [p=0.623] | 7.29 (0.04) [p≤0.001] |
| DBP (mmHg) | 79.23 ± 5.18 | 80.63 ± 5.49 | 80.95 ± 5.55 | 76.89 ± 4.75 | 74.48*$ ± 4.74 | 73.95$ ± 4.72 | 100.35 (0.21) [p≤0.001] | 0.53 (0.00) [p=0.587] | 7.74 (0.04) [p≤0.001] |
| PP (mmHg) | 40.05 ± 5.80 | 40.13 ± 6.31 | 40.09 ± 6.89 | 42.80 ± 5.07 | 43.35$ ± 5.23 | 42.75NS ± 4.85 | 24.49 (0.06) [p≤0.001] | 0.14 (0.00) [p=0.872] | 0.09 (0.00) [p=0.917] |
| MAP (mmHg) | 92.57 ± 4.62 | 94.01 ± 4.59 | 94.31 ± 4.52 | 91.16 ± 4.38 | 88.92$ ± 3.83 | 88.21$ ± 4.00 | 91.59 (0.19) [p≤0.001] | 0.66 (0.00) [p=0.518] | 10.49 (0.05) [p≤0.001] |
| BHR (bpm) | 64.51 ± 4.04 | 65.04 ± 3.46 | 65.15 ± 3.60 | 59.93 ± 3.16 | 58.21*$ ± 3.53 | 57.51*$ ± 3.16 | 319.40 (0.45) [p≤0.001] | 2.18 (0.01) [p=0.115] | 6.71 (0.03) [p=0.001] |
| PEHR (bpm) | 71.46 ± 3.12 | 71.87 ± 3.13 | 72.40 ± 2.73 | 67.56 ± 3.41 | 65.43*$ ± 3.03 | 64.56*$ ± 2.76 | 387.00 (0.50) [p≤0.001] | 4.30 (0.02) [p=0.014] | 14.04 (0.07) [p≤0.001] |
| SMHR1 (bpm) | 136.70 ± 4.16 | 137.20 ± 3.57 | 137.56 ± 3.73 | 133.29 ± 5.77 | 130.53*$ ± 3.47 | 128.41*$ ± 5.92 | 193.19 (0.34) [p≤0.001] | 6.35 (0.03) [p=0.002] | 12.97 (0.06) [p≤0.001] |
| SMHR2 (bpm) | 160.38 ± 4.69 | 160.86 ± 4.47 | 161.27 ± 4.46 | 145.83$ ± 4.02 | 143.63*$ ± 5.63 | 141.72*$ ± 4.06 | 1354.70 (0.78) [p≤0.001] | 3.99 (0.02) [p=0.019] | 9.65 (0.05) [p≤0.001] |
| HRmax (bpm) | 193.70 ± 4.64 | 194.47 ± 4.46 | 195.22 ± 4.85 | 198.64 ± 3.08 | 196.35* ± 3.80 | 194.89* ± 4.42 | 25.21 (0.06) [p≤0.001] | 2.36 (0.01) [p=0.096] | 12.53 (0.06) [p≤0.001] |
| RecHR1 (bpm) | 173.75 ± 5.46 | 174.05 ± 5.13 | 174.28 ± 5.54 | 169.00 ± 5.16 | 168.56$ ± 4.43 | 167.89$ ± 3.70 | 122.20 (0.24) [p≤0.001] | 0.12 (0.00) [p=0.883] | 0.89 (0.01) [p=0.413] |
| RecHR2 (bpm) | 152.29 ± 5.06 | 152.95 ± 4.68 | 153.17 ± 4.72 | 145.43 ± 3.77 | 144.92$ ± 4.42 | 143.33*$ ± 4.67 | 316.23 (0.45) [p≤0.001] | 0.87 (0.01) [p=0.418] | 3.47 (0.02) [p=0.032] |
| RecHR3 (bpm) | 127.52 ± 3.62 | 126.86 ± 3.64 | 126.35 ± 3.68 | 125.87 ± 3.27 | 121.58*$ ± 3.36 | 119.05*#$ ± 3.45 | 178.46 (0.32) [p≤0.001] | 43.10(0.18) [p≤0.001] | 21.75 (0.10) [p≤0.001] |
| FVC (l) | 2.40 ± 0.34 | 2.43 ± 0.33 | 2.44 ± 0.34 | 3.71$ ± 0.29 | 3.76$ ± 0.30 | 3.80$ ± 0.27 | 1748.58 (0.82) [p≤0.001] | 1.47 (0.01) [p=0.232] | 0.23 (0.00) [p=0.794] |
| $FEV_1$ (l) | 2.33 ± 0.30 | 2.36 ± 0.29 | 2.38 ± 0.31 | 3.63$ ± 0.29 | 3.70$ ± 0.29 | 3.75*$ ± 0.26 | 1989.09 (0.84) [p≤0.001] | 2.69 (0.01) [p=0.069] | 0.48 (0.00) [p=0.621] |
| $FEV_1$/FVC (%) | 97.15 ± 3.58 | 97.25 ± 3.29 | 97.47 ± 3.03 | 97.82 ± 1.22 | 98.47* ± 0.77 | 98.62* ± 1.00 | 16.63 (0.04) [p≤0.001] | 1.77 (0.01) [p=0.172] | 0.47 (0.00) [p=0.625] |
| PEFR (l) | 374.63 ± 17.61 | 376.30 ± 18.94 | 377.46 ± 19.91 | 447.55$ ± 19.53 | 449.53$ ± 17.86 | 451.38$ ± 16.79 | 1536.87 (0.80) [p≤0.001] | 1.06 (0.01) [p=0.348] | 0.03 (0.00) [p=0.975] |
| $VO_{2max}$ (ml/min/kg) | 38.21 ± 1.43 | 38.29 ± 1.47 | 38.64 ± 1.57 | 43.17$ ± 4.28 | 45.69*$ ± 5.13 | 46.20*$ ± 5.43 | 318.22 (0.45) [p≤0.001] | 7.83 (0.04) [p≤0.001] | 5.13 (0.03) [p=0.006] |
| RL (mmol/lit) | 2.03 ± 0.53 | 2.07 ± 0.50 | 2.09 ± 0.52 | 2.17 ± 0.76 | 2.13 NS ± 1.22 | 2.80NS ± 0.82 | 0.75 (0.00) [p=0.385] | 0.00 (0.00) [p=0.997] | 0.22 (0.001) [p=0.80] |
| PL (mmol/lit) | 16.49 ± 2.23 | 16.81 ± 2.48 | 17.09 ± 2.10 | 17.97 ± 2.31 | 16.07* ± 1.12 | 15.88* ± 1.28 | 0.59 (0.00) [p=0.443] | 6.40 (0.03) [p=0.002] | 16.88 (0.08) [p≤0.001] |

Note. [Data presented as Mean ± SD, Two-Way ANOVA followed by post-hoc tests (Bonferroni) was performed. * when compared to 0 week p≤0.05, # when compared to 8 week p≤0.05, $when compared to control group p≤0.05; df for training= 2, df for group = 1, df for interaction = 2, df within = 384, df total = 389, Critical F for Group = 3.865, Critical F for Time =3.019, Critical F for Interaction = 3.019; In the table calculated F values, partial eta squared ($\eta p^2$) and p value; SD = standard deviation, ANOVA= Analysis of Variance, CG= control group, SDR= short distance runners, NS= not significant; SBP= systolic blood pressure, DBP= diastolic blood pressure, PP= pulse pressure, MAP= mean arterial pressure, BHR= basal heart rate, PEHR= pre exercise heart rate, SMHR1= sub maximal heart rate1, SMHR2= sub maximal heart rate2, HRmax= maximum heart rate, RecHR1= recovery heart rate 1st min, RecHR2= recovery heart rate 2nd min, RecHR3= recovery heart rate 3rd min, FVC= force vital capacity, $FEV_1$= force expiratory volume in 1st sec, PEFR= peak expiratory flow rate, $VO_{2max}$ = maximal aerobic capacity, RL= resting lactate, PL= peak lactate]

*Correlation studies*

The percent body fat had significant (p<0.001) positive correlation with resting heart rate (r=0.575); and significant (p<0.001) negative correlation with FVC (r= -0.647), $FEV_1$ (r=-0.654), PEFR (r=-0.629), speed (r=-0.720), maximum power (r=-0.674) and fatigue index (r=-0.649). Waist hip ratio had significant (p<0.001) negative correlation with speed (r=-0.629) and anaerobic capacity (r=-0.559). Speed showed significant (p<0.001) positive correlation with mid calf circumference (r=0.744), FVC(r=0.897), $FEV_1$(r=0.907), back strength (r=0.935) and leg strength (r=0.918); and significant (p<0.001) negative correlation with resting heart rate (r=-0.694). $VO_{2max}$ had significant (p<0.001) negative correlation with resting heart rate (r=-0.504); and significant (p<0.001) positive correlation with PEFR (r=0.552) and flexibility(r=0.550). The resting heart rate showed significant (p<0.001) negative correlation (r=-0.653) with maximum power of the volunteers.

## Discussion

The current study found significant reductions in body mass, body mass index (BMI), body fat percentage, fat mass, and waist-hip ratio (WHR) among short-distance sprinters after training. There were increases in both mid-upper arm circumference (MUAC) and mid-calf circumference (MCC). Body fat percentage had a strong negative association with performance measures such maximum power, fatigue index, and speed. WHR associated adversely with anaerobic capacity and sprint speed, whereas MCC correlated positively with speed. Furthermore, body fat showed a negative relationship with lung function measurements and a positive relationship with resting heart rate, implying larger physiological effects beyond performance metrics. The detrimental impact of excess adiposity on sprint performance is consistent with prior research suggesting that increased fat mass reduces power production, speed, and acceleration due to mechanical inefficiencies and metabolic burden (Scheer et al., 2022). Similarly, positive relationships between lean muscle mass, particularly in the lower limbs, and force generation are consistent with the findings of Bustamante-Garrido et al. (2024) and Feser et al. (2020), who observed increased stride power and propulsion associated to muscular growth. The observed connections between fat-related markers and lower pulmonary function are consistent with previous results demonstrating that increased fat mass can impair respiratory efficiency and increase cardiovascular load, affecting endurance and recovery capacity. According to the findings, reducing body fat and increasing muscle mass significantly improves sprint performance via both mechanical and physiological pathways. Lower fat mass most likely improves sprinting efficiency by reducing inertial load, increasing power transfer, and lowering metabolic cost. MCC and speed have a positive association, which indicates the importance of muscle hypertrophy in improving explosive force generation and stride mechanics. Furthermore, the relationship between body composition and cardiopulmonary measures suggests that changing lean-to-fat ratio may improve not just performance but also respiratory function and cardiovascular efficiency, all of which are crucial for recovery and repeated sprint efforts.

The study's most notable finding was a considerable improvement in sprint performance, as shown by shorter 30m and 100m sprint times and faster running speeds among sprinters following the training intervention. Muscular strength and power were also significantly increased, as evidenced by improvements in hand grip (right and left), back strength, leg strength, standing broad jump, vertical jump, push-up, and sit-up test scores. Furthermore, the sprinters demonstrated increased flexibility following the training program. Speed had a substantial positive connection with back and leg strength, indicating that these physical fitness characteristics are important for performance. The current findings are consistent with those of França et al. (2024), who found that youth athletes with higher fat-free mass and lower fat percentages had considerably faster 35-meter sprint times. Furthermore, the link between strength and sprinting performance observed in this study is consistent with previous findings emphasizing the importance of explosive strength and muscle power—as measured by vertical and horizontal jump tests—to sprint performance. McKinlay et al. (2018) also found that resistance and plyometric training provide neuromuscular changes such as increased rate of force creation and motor unit recruitment, which help to improve sprint ability. Flexibility improvements in this study are consistent with the findings of Moir et al. (2018), who proposed that increased range of motion, particularly in the hip and hamstring areas, may improve stride mechanics and lessen biomechanical restrictions while sprinting. The findings show that increasing strength and power directly contributes to better sprinting performance in short-distance runners. The substantial connections between sprint speed and lower-body strength (back and leg) highlight the importance of muscle force production in accelerating and reaching maximum sprint velocity. This link is further supported by improvements in explosive strength, as measured by jumping and calisthenic tests. Flexibility, while not directly connected to sprint speed, most likely led to greater stride efficiency and a lower risk of musculoskeletal injury, indirectly boosting performance increases.

The current study found considerable increases in sprinters' anaerobic ability, as seen by increased sprint time and power output. Maximum anaerobic power had a strong negative correlation with percent body fat, waist-hip ratio (WHR), and resting heart rate. Several cardiovascular metrics improved, including lower basal, pre-exercise, sub-maximal, maximum, and recovery heart rates after training. After training, pulmonary function indices like $FEV_1$, $FEV_1$/FVC, PEFR, and $VO_{2max}$ increased significantly. Peak post-exercise blood lactate concentrations decreased, while resting lactate levels remained constant. Sprinters outperformed the control group in terms of anaerobic power, $VO_{2max}$, pulmonary function, and heart rate. The gains in anaerobic ability are consistent with the findings of Archacki et al. (2024), who discovered that sprint and resistance training improve phosphagen system efficiency, buffering capacity, and lactate tolerance. The observed aerobic increases in $VO_{2max}$ and ventilatory function measurements align with the findings of Ouali et al. (2023), who underlined the role of aerobic capacity in aiding phosphocreatine re-synthesis and metabolic clearance during repeated sprint episodes. Molinari et al. (2020) acknowledge this dual metabolic contribution to sprint performance, implying that aerobic growth promotes high-intensity training and recovery. Stephenson et al. (2021) support the observed decline in heart rate parameters, citing increased parasympathetic activity and improved cardiovascular efficiency. In terms of blood lactate, the current findings are consistent with Kano and Sato's (2021) report that healthy individuals typically maintain resting lactate levels between 0.7 and 1.4 mmol/L, but peak values post-sprint can vary greatly. The reduction from 17.97±2.31 to 15.88±1.28 mmol/L is within the expected post-exercise range, as discussed by Batra et al. (2021). Lactate levels can range from 4-17 mmol/L or more depending on sprint demands and individual conditioning. The negative relationships between anaerobic power and body fat indicators suggest that losing extra fat helps to increase power output, most likely by improving movement efficiency and force production. Increased $VO_{2max}$ and ventilatory functions indicate enhanced oxygen supply and usage, promoting recovery during interval training and sprint endurance. The constant decrease in heart rate readings suggests autonomic modifications that favour parasympathetic dominance, indicating improved cardiovascular conditioning and less physiological strain during high-intensity exercise. Finally, the decrease in peak lactate levels after training indicates better lactate clearance and tolerance, which is essential for repeated sprint efforts and fatigue resistance.

These findings have significant implications for coaches and performance experts who work with short-distance runners. Body composition modification, specifically reducing fat mass while fostering muscle development, can improve sprint performance. Combining resistance and plyometric exercises appears to be critical for increasing strength and power outputs. Although flexibility had a weaker direct association with sprint performance, improving it may help with injury prevention and stride efficiency. The observed cardiovascular and metabolic adaptations indicate that, even in anaerobic-dominant sports such as sprinting, aerobic development should not be overlooked.

This study used a small sample of young sub-elite male sprinters, which limits the findings' applicability to larger populations such as elite or leisure athletes, females, and older or younger age groups. The 12-week intervention timeframe may not account for long-term adaptations or potential performance plateaus. Future studies should look into the long-term impacts of training across various stages of athletic development. Studies involving elite, sub-elite, and developmental-level athletes of both genders are recommended to investigate differential training responses.

## Conclusions

The current findings demonstrate that young sub-elite athletes' sprint performance is influenced by a dynamic combination of body composition, physical fitness, and physiological capability. Notably, reducing non-functional fat mass, while increasing strength, power and flexibility improves sprint mechanics and acceleration. Physiological adaptations such as greater aerobic capacity and improved recovery responses allow athletes to endure training loads and maintain high-intensity workouts. These findings emphasize the relevance of developing training programs that include several performance categories. Coaches and scientists should prioritize training methods that integrate strength, conditioning, sprint-specific drills, and recovery measures to improve sprint performance. The use of scientific training is critical in athlete development, injury prevention, and transitioning from sub-elite to elite levels.

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**Conflicts of Interest**

The authors declare no conflict of interest.

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