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Physical And Physiological Responses to Training and Their Association with Performance Outcomes in Young Sub-Elite Middle Distance Runners

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ABSTRACT:

Introduction: The Middle-distance running events demands combination of endurance, anaerobic power, neuromuscular efficiency, and muscular strength. This study examined how a 12-week structured training program on anthropometric, physical fitness, and physiological variables and performance of the middle-distance runners.

Methods: One hundred and sixty male (age: 18-20 yrs) participants were randomly included, among them thirty were excluded due to illness and injury, the remaining one hundred thirty (n=130) were divided into (i) middle distance runner (n=65) and (ii) sedentary controls (n=65).Assessments of morphological, physical fitness and physiological variables were assessed in 0 wk, 8 weeks, 12 weeks. Data analysis employed repeated measures ANOVA and Pearson's correlation analysis.

Results: The middle distance runners shows statistically significant improvement ($p \leq 0.05$) in middle-distance running performance (1500m), 30m sprint performance, speed, strength (handgrip, back, and leg muscles), explosive power (SBJ and VJ scores), muscular endurance (push-ups and sit-ups scores), anaerobic power, flexibility, maximum aerobic capacity (VO2max), pulmonary function; and significant reduction ($p \leq 0.05$) in body weight, body mass index (BMI), body fat percentage, reaction time, and heart rate measurements (basal, sub-maximal, maximum, and recovery) and blood pressure after the training when compared to the baseline data. The VO2max showed negative ($p < 0.05$) correlation with BMI and fat mass; positive ($p < 0.05$) correlation with flexibility and speed. Speed showed positive ($p < 0.05$) correlation with back strength, flexibility and anaerobic power. Lung functions showed negative ($p < 0.05$) correlation with body fat and blood lactate levels.

Conclusion: These findings demonstrate training elicits multifaceted adaptations that enhance performance determinants in middle-distance running athletes.

1. INTRODUCTION

Morphological, physical and physiological characteristics interact in a complicated manner to interact middle-distance running. Optimizing these factors through methodical training is crucial for long-term athletic advancement and performance improvement in young sub-elite middle-distance runners, who are at a transitional stage between developmental and elite-level competition [1].

Anthropometric, physical factors and physiological elements plays the foundational role in middle-distance performance. Factors such as height, body mass, body mass index (BMI), body-fat percentage (BF%), lean body mass (LBM), mid-upper-arm circumference (MUAC), waist-to-hip ratio (WHR), and leg length influence biomechanical efficiency, heat dissipation, and force application during the running stride [2-4]. Physical fitness qualities suitable to focused training interventions, including muscular strength, power, speed, flexibility, and endurance are fundamental to middle-distance performance [5, 6]. Physiological indicators like maximal oxygen uptake (VO_{2max}), cardiovascular efficiency, pulmonary function, and lactate kinetics show an athlete's capacity to maintain high-intensity activity and recover quickly [7, 8].

Few studies have fully examined that in which way the training-induced changes in morphological, physical factors, and the physiological elements translates into the developments in middle-distance running (1500m) in the sub-elite level groups. By assessing extent to which a structured 12-week training programme changes in anthropometric, physical factors, and physiological elements but also how these changes are related to the middle-distance running performance (1500m) outcomes, the present study fill ups this knowledge gap. Unlike most previous studies that have primarily examined elite-level athletes, the present study offers a more comprehensive look at the multiple factors influencing middle-distance running in young sub-elite level runners during their developmental years. This study's main goal was to find out how a 12-week organized training program affected these young middle-distance runners' body composition, physical fitness and physiological characteristics.

2. MATERIALS AND METHODS

Participants:

Department of Physiology conducted the investigation, of Midnapore College (Autonomous) Research Centre, Vidyasagar University. Required number of sample determined using the G Power software [9], which showed that at least 128 volunteers will be needed. To account for possible dropouts, a total of 160 male participants (85 middle-distance runners and 75 sedentary controls) were initially recruited. During the study, 20 middle-distance runners and 10 control participants were excluded due to injury or illness, leaving (n =130) participants for final analysis. The remaining individuals were divided into two groups.(i) Control Group participants (CG, n=65) and (ii) Middle-Distance Running participants (MDR, n=65, participated in district competitions).

Training:

Fifteen days before all the participants joined for acclimatization. The middle-distance runners followed a structured training program consisting during twelve weeks, four hours a day, five days a week. All sessions were conducted under the direct supervision of qualified and experienced coaches. The training sessions were completed in two phases: (i) Preparatory Phase (8 weeks) and the Competitive Phase (4 weeks) [1]. The training sessions incorporated endurance training, flexibility work, high-intensity interval training, speed drills, and strength and power exercise (Table 1 and 2). Control group participants continued with their normal routine and performed only light recreational activities (mainly walking) for approximately 30 minutes per day, without any structured training.

Experimental Design:

In this study one hundred and sixty male (age: 18-20 years) participants were randomly included, among them thirty were excluded, the remaining one hundred thirty (n=130) were divided into (i) middle distance runner (n=65) and (ii) sedentary controls (n=65). The middle-distance runners followed a structured training program of 4 hours per day, 5 days in every week for the duration of 12 weeks, while that control participants carried on as normal lite recreational activities (mainly walking). Assessments of body proportions, physical factors, and physiological variables were carried out on baseline (i.e. 0 week), after 8 weeks, and after ending of 12 weeks (Figure 1).

Table 1: Training Periodisation for middle distance runner

Phases			12 Weeks plan				
Phases of Training			Baseline	Preparatory (8 weeks)		Competitive (4 weeks)	
Sub-phases			Zero level baseline	General Preparation (Physical Preparation)	Specific Preparation (Technical and tactical Preparation)	Pre Competitive (maintainance)	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%

Table 2: Detailed of training schedule followed during preparatory and competitive phases by the middle 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 20min Stride ABC exercise, 4 strides (6x 120m) Jogging (high knees) Cool down	Warm-up, Stretching, 45 min slow running 2x 1500 m at race pace Cool down	Warm-up 20min Easy running Fartlek training 3x 2000m slow running Cool down	Warm-up, Stretching, 4 strides jogging 45 min slow running High hills, dynamic drills Cool down

Tuesday	Warm-up Dynamic Drills: Lunges, Speed drills, butt kics Strength training Fartlek Training Cool down	Warm-up 40 min slow running exercise Pure speed (hills) 6 stride jogging with event specific Cool down	Warm-up Dynamic Drills: Lunges, Speed drills, butt kics Strength training 4x300m (45-48 sec) maximum speed Cool down	Warm-up 40 min slow running exercise Interval Training Cool down
Wednesday	Warm-up Speed Endurance: 4 x 2000 m sprints at race pace Slow running pace, easy jogging Cool down Motivation Building and Counseling	Warm-up Recreational activity, Static Stretching, Dynamic drills Recovery Session	Warm-up Speed Endurance: 2x 2000 m sprints at race pace or event specific Slow running pace Motivation Building and Counseling	Warm-up Recreational activity, Static Stretching, Dynamic drills Recovery Session
Thursday	Warm-up Slow running 30 min 4x300m (48-52sec) ABC exercise and strides Cool down	Warm-up 8-12x 400m (70-72 sec) Fartlek training 6 strides Recovery Session	Warm-up Interval training: 30 minutes ABC exercise and strides 4x300m (48-52 sec) Cool down	Warm-up 70 min slow running jogging Recovery Session
Friday	Warm-up Strength training exercise 4x2000m (at race pace or event pace) Jogging and Cool down	Warm-up 45 min slow running, 4 strides, Foam Rolling and Flexibility Training, Core exercises Cool down	Warm up Easy running, train at or above event specific pace Jogging and Cool down	Warm-up, 45 min slow running, 4 strides Foam Rolling and Flexibility Training, Core exercises Cool down
Saturday	Warm-up Speed building: 6 -12 x 1000m (3.18-3.25 min) Rest 3 min between maximum effort Jogging Cool down	Warm-up Endurance training,70 min slow running exercise 8-12 x 400m (70-72 sec) Cool down Core stability	Warm-up Speed maintenance: sprints at maximum effort or race pace AM running, slow jog (4 x 2000m) Cool down	Warm-up 70 min slow running exercise, strength training Core stability
Sunday	Rest and Recovery	Rest and Recovery	Rest and Recovery	Rest and Recovery

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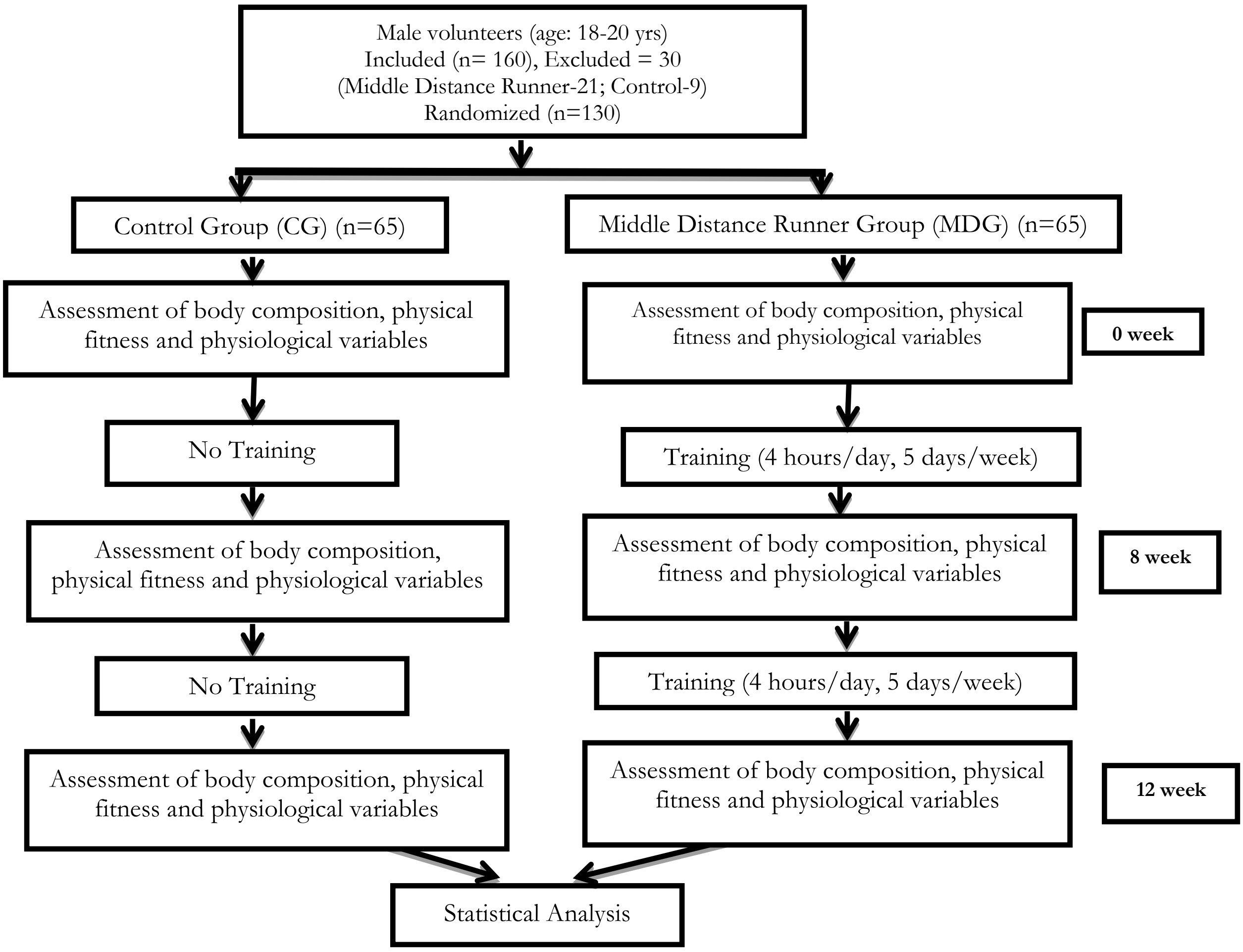

Figure 1: The experimental design

Ethical Considerations and informed consent statement:

Every participant received thorough information about the study's objectives and methods, along with involvement of the potential risk. After that they were requested to supply the written informed consent before taking part. The study was carried out in compliance with the Indian Council of Medical Research's (ICMR) ethical standards for biomedical research involving human subjects. The Midnapore College Institutional Ethics Committee granted the approval [No. MC/IEC (HS)/PHY/Ph.D.RF/02/2023; Date: 19.08.2023].

Measurement of body composition variables:

The height (stature) and body mass were measured; body mass index (BMI) and body surface area (BSA) were determined [10]. A skin fold caliper (Cescorf, Brasil) was used for the determination of percent body fat, total fat mass and lean body mass (LBM) following standard methods [11, 12]. The mid-upper arm circumference, mid-calf circumference and waist-hip ratio (WHR) were determined [10]. The lengths of the arm, hand, leg, and foot were measured using a standard methods [13, 14].

Measurements of physical fitness variables:

The measurement of hand grip strength (by hand grip dynamometer, Baseline, USA), back and leg strength (by back and leg dynamometer, Baseline, USA) were performed following standard procedure [10, 15, 16]. The tests for standing broad jump (SBJ), vertical jump (VJ), sit-up (SU), push-up (PU), reaction time, and flexibility (modified sit-and-reach) andspeed were performed [10]. The 30m sprint test and was determined [10]. The running-based anaerobic sprint test (RAST) was

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performed to determine the anaerobic power [17]. Sprinting time of 30 meters and 1500m running time on a standard track was recorded.

Measurements of physiological variables:

The participants were asked to take fifteen minutes rest, resting heart rate and blood pressure were measured [18, 19]. Heart rate during sub-maximal exercise, maximal exercise, and recovery was taken by Polar H10 heart rate monitor (Polar, USA) following the Yo-Yo Intermittent Recovery Test 1 [19, 20]. The lung function tests including forced vital capacity (FVC), forced expiratory volume in 1st sec (FEV1) and peak expiratory flow rate (PEFR) were measured by using a portable spirometer [21]. The Yo-Yo Intermittent Recovery Test 1 (YYIR1) was used for determination of maximum oxygen uptake (VO_{2max}) [20]. Blood lactate was measured at rest and 3 min after the RAST using a portable lactate analyzer (Lactate Scout 4, EKF Diagnostics, USA) [22].

Statistical analysis:

For every study variable, descriptive statistics were computed. Differences between and within groups over time were examined using a two-way repeated measures ANOVA. Bonferroni post-hoc tests were used for multiple comparisons where significant main impacts or interactions discovered. For each dependent variable, the main effects of time and group, as well as the group × time interaction, were reported along with their corresponding F-values, degrees of freedom, and as a measure of the effect size partial eta squared (η^2p). To investigate correlations between variables, Pearson's correlation analysis was used. Significance level of statistics was chosen at $p < 0.05$ [23]. SPSS software was used for all the analysis.

3. RESULTS AND DISCUSSION

3.1. RESULTS

Training's effects on middle distance runner's body composition factors:

Significant noticeable improvements on various key anthropometric and body composition variables among the middle distance running athletes. Significant reduction in weight, body mass index (BMI), body surface area (BSA), ponderal index, fat percentage, and body fat mass among middle-distance runners after the training when the data at baseline. The decreased body fat mass and fat percentage indicated improvement in body composition. No significant variation was noted in limb lengths (i.e. arm length, hand length, leg length, or foot length) as follows the training programme. The runners had decreased ponderal index, weight, body mass index (BMI), fat percentage, the body fat mass, fat free mass, and waist–to-hip ratio; and increase in mid upper arm circumference and in mid-calf circumference than the control group participants. The anthropometric variables like hand length, leg length and foot length did not significantly differ among the groups (Table 3).

Table 3: Anthropometric changes over time in response to training among middle distance runners

Parameter	Control Group (n=65)			Middle Distance Runners (n=65)			Two Way ANOVA		
	0 Wk	8 Wk	12 Wk	0 Wk	8 Wk	12 Wk	Group F1 (ηp^2) [p value]	Time F2 (ηp^2) [p value]	Interaction F3 (ηp^2) [p value]
Height (cm)	168.4 ± 5.2	168.4 ± 5.2	168.4 ± 5.2	170.9^{NS} ± 5.2	170.9^{NS} ± 5.2	170.9^{NS} ± 5.2	22.48 (0.055) [<0.001]	0.001 (0.000) [0.999]	0.000 (0.000) [1.00]
Body mass (kg)	66.3 ± 5.1	66.9 ± 4.9	67.1 ± 4.7	61.0 ± 4.1	58.9 ± 4.1	57.9* ± 4.0	268.84 (0.412) [<0.001]	2.22 (0.011) [0.110]	6.49 (0.033) [0.002]
BMI	23.4	23.6	23.6	20.9$	20.2$*	19.8*$	685.57 (0.641)	3.56 (0.018)	10.08 (0.050)

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(kg/m²)	± 1.6	± 1.5	± 1.4	± 0.8	± 0.9	± 0.9	[<0.001]	[0.029]	[<0.001]
BSA (m²)	1.75 ± 0.08	1.76 ± 0.08	1.76 ± 0.08	1.71NS ± 0.08	1.68NS ± 0.08	1.67* ± 0.08	66.15 (0.147) [<0.001]	0.96 (0.005) [0.383]	2.78 (0.014) [0.063]
RPI	0.42 ± 0.01	0.42 ± 0.01	0.41 ± 0.01	0.43NS ± 0.01	0.44 NS ± 0.01	0.44 NS ± 0.01	539.79 (0.584) [<0.001]	3.31 (0.017) [0.037]	7.71 (0.039) [<0.001]
PI	13.9 ± 1.1	14.0 ± 1.1	14.1 ± 1.1	12.2$ ± 0.6	11.8$* ± 0.7	11.6$* ± 0.7	523.08 (0.577) [<0.001]	2.23 (0.011) [0.109]	6.20 (0.031) [0.002]
BMR (kcal/day)	1676.8 ± 84.2	1685.3 ± 81.4	1687.9 ± 79.8	1619.3 ± 77.7	1592.0 ± 75.7	1577.5* ± 74.9	118.58 (0.236) [<0.001]	1.25 (0.006) [0.287]	3.78 (0.019) [0.024]
Body Fat (%)	16.2 ± 1.9	16.4 ± 1.8	16.5 ± 1.8	13.1$ ± 1.0	12.3*$ ± 1.1	11.9*$ ± 1.1	675.33 (0.638) [<0.001]	3.37 (0.017) [0.035]	9.64 (0.048) [<0.001]
Fat Mass (kg)	10.9 ± 1.9	11.1 ± 1.8	11.1 ± 1.7	8.0$ ± 1.0	7.3$* ± 1.0	6.9*$ ± 1.0	586.53 (0.604) [<0.001]	2.57 (0.013) [0.078]	8.71 (0.043) [<0.001]
LBM (kg)	55.5 ± 3.6	55.8 ± 3.5	55.9 ± 3.4	53.0$ ± 3.4	51.7$ ± 3.3	51.4$ ± 3.3	127.07 (0.249) [<0.001]	1.65 (0.009) [0.194]	4.41 (0.022) [0.013]
WHR	0.93 ± 0.06	0.94 ± 0.06	0.94 ± 0.06	0.80$ ± 0.02	0.80$ ± 0.03	0.80$ ± 0.03	1048.04 0.732) [<0.001]	0.06 (0.000) [0.940]	1.45 (0.007) [0.236]
MUAC (cm)	21.0 ± 2.3	21.1 ± 2.3	21.4 ± 2.3	24.1$ ± 1.6	24.0$ ± 1.6	23.9$ ± 1.6	202.66 (0.345) [<0.001]	0.05 (0.000) [0.947]	0.69 (0.004) [0.498]
MCC (cm)	30.8 ± 2.1	30.9 ± 2.1	31.1 ± 2.1	33.6$ ± 1.3	33.5$ ± 1.3	33.5$ ± 1.3	218.57 (0.363) [<0.001]	0.126 0.001) [0.882]	0.372 (0.002) [0.690]
Arm Length (cm)	57.9 ± 1.8	57.9 ± 1.7	57.9 ± 1.7	58.8NS ± 2.0	58.8NS ± 2.0	58.9NS ± 2.0	25.47 (0.065) [<0.001]	0.003 0.000) [0.997]	0.00 (0.00) [1.00]
Hand Length (cm)	17.0 ± 1.2	17.0 ± 1.2	17.0 ± 1.2	17.0NS ± 1.1	17.1NS ± 1.1	17.1NS ± 1.1	0.350 (0.001) [0.554]	0.005 0.000) [0.995]	0.001 (0.000) [0.999]
Leg Length (cm)	87.3 ± 3.3	87.4 ± 3.2	87.4 ± 3.3	86.5 NS ± 2.7	86.6NS ± 2.7	86.6NS ± 2.7	7.73 (0.020) [0.006]	0.015 0.000) [0.985]	0.004 (0.000) [0.996]
Foot Length (cm)	24.7 ± 1.2	24.7 ± 1.2	24.8 ± 1.2	24.7 NS ± 0.8	24.7NS ± 0.7	24.7NS ± 0.7	0.014 (0.000) [0.906]	0.031 0.000) [0.970]	0.010 (0.000) [0.990]

[Data presented as Mean ± SD, Two-Way ANOVA followed by post-hoc tests (Bonferroni) was performed; * when compared to 0 week $p \leq 0.05$, # when compared to 8 week $p \leq 0.05$, $ when compared to control group $p \leq 0.05$; 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 (ηp^2) and p value; SD = standard deviation, ANOVA= Analysis of Variance, 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, WHR = Waist- Hip Ratio, MUAC = mid upper arm circumference, MCC= mid calf circumference.]

Table 4: Changes in physical fitness variables following training in **Middle Distance Runners**

Parameters	Control Group (n=65)			Middle Distance Runners (n=65)			Two Way ANOVA		
	0 Wk	8 Wk	12 Wk	0 Wk	8 Wk	12 Wk	Group F1 (ηp^2) [p value]	Time F2 (ηp^2) [p value]	Interaction F3 (ηp^2) [p value]
GSTR (Kg)	37.9 ± 3.1	38.4 ± 3.8	38.9 ± 3.9	37.0^{NS} ± 3.9	39.5* ± 4.1	40.1* ± 3.7	3.942 (0.010) [0.048]	12.13 (0.059) [<0.001]	2.69 (0.014) [0.069]
GSTL (kg)	34.9 ± 3.0	35.0 ± 3.0	35.4 ± 3.4	34.0^{NS} ± 3.1	36.3* ± 3.7	37.1* ± 3.8	0.815 (0.002) [0.367]	9.79 (0.049) [<0.001]	5.55 (0.028) [0.004]
BS (kg)	81.4 ± 4.2	82.0 ± 4.2	82.9 ± 4.6	102.8$ ± 4.8	107.0*$ ± 4.1	108.4*$ ± 5.0	2786.39 (0.879) [<0.001]	21.49 (0.101) [<0.001]	7.99 (0.040) [<0.001]
LS (kg)	92.0 ± 5.3	92.6 ± 5.8	93.2 ± 6.1	112.6$ ± 7.4	116.9* ± 6.2	118.8* ± 6.2	1399.51 (0.785) [<0.001]	12.03 (0.059) [<0.001]	5.91 (0.030) [0.003]
SBJ score (m)	1.5 ± 0.2	1.5 ± 0.2	1.5 ± 0.2	2.6$ ± 0.3	2.8$* ± 0.3	2.9$* ± 0.3	2128.94 (0.847) [<0.001]	3.65 (0.019) [0.027]	7.29 (0.037) [<0.001]
VJ score (m)	0.38 ± 0.04	0.27 ± 0.03	0.27 ± 0.04	0.47$ ± 0.05	0.48$ ± 0.06	0.49$ ± 0.06	1570.32 (0.804) [<0.001]	0.49 (0.003) [0.012]	1.63 (0.008) [0.197]
Push-up score (no/min)	14.5 ± 3.5	14.7 ± 3.7	15.0 ± 4.1	27.8$ ± 5.9	30.3$ ± 7.3	31.2$* ± 6.8	751.48 (0.662) [<0.001]	4.49 (0.023) [0.012]	2.52 (0.013) [0.082]
Sit-up score (no/min)	14.9 ± 4.1	15.0 ± 4.3	15.2 ± 4.0	27.1^{NS} ± 5.4	28.3^{NS} ± 5.9	29.8$* ± 6.0	699.31 (0.646) [<0.001]	3.11 (0.016) [0.046]	2.00 (0.010) [0.137]
Power max (watt)	553.3 ± 62.2	541.5 ± 53.9	540.1 ± 52.4	640.9$ ± 31.1	645.1$ ± 33.7	651.1$ ± 32.7	467.84 (0.549) [<0.001]	2.29 (0.012) [0.103]	0.12 (0.001) [0.882]
R Power max (watt/kg)	8.4 ± 1.1	8.1 ± 1.0	8.1 ± 1.0	10.7^{NS} ± 0.9	11.0^{NS} ± 0.9	11.1*$ ± 0.9	747.57 (0.661)	0.09 (0.000) [0.909]	4.45 (0.023) [0.012]

							[<0.001]		
Power avg (watt)	393.0 ± 51.6	388.4 ± 56.1	381.6 ± 54.4	478.3$ ± 32.8	481.6$ ± 31.7	485.5$ ± 30.6	439.84 (0.534) [<0.001]	1.44 (0.007) [0.239]	0.084 (0.000) [0.919]
R Power avg (watt/kg)	6.0 ± 1.0	5.8 ± 1.0	5.7 ± 0.9	8.0NS ± 0.8	8.2NS ± 0.9	8.3NS ± 0.9	669.91 (0.636) [<0.001]	0.082 (0.000) [0.921]	3.29 (0.017) [0.038]
Power min (watt)	219.6 ± 36.7	215.6 ± 35.3	213.4 ± 34.4	316.1NS ± 32.8	320.1NS ± 33.6	325.2NS ± 34.2	890.44 (0.699) [<0.001]	1.59 (0.008) [0.203]	0.057 (0.000) [0.944]
FI	11.1 ± 2.0	10.9 ± 1.5	10.9 ± 1.5	10.8NS ± 1.7	10.8NS ± 1.7	10.9NS ± 1.6	0.482 (0.001) [0.488]	0.31 (0.000) [0.734]	0.17 (0.001) [0.837]
AC (watt)	2358.0 ± 309.4	2330.5 ± 36.5	2289.5 ± 26.6	2869.7$ ± 196.7	2889.8$ ± 190.0	2912.8$ ± 183.8	439.84 (0.534) [<0.001]	1.44 (0.007) [0.239]	0.084 (0.000) [0.919]
Flexibility score (cm)	23.4 ± 3.9	22.9 ± 3.4	22.5 ± 3.3	32.1$ ± 3.5	34.4*$ ± 3.9	35.3$*$ ± 4.2	847.22 (0.688) [<0.001]	3.53 (0.018) [0.030]	10.38 (0.051) [<0.001]
RT (ms)	379.2 ± 36.2	377.7 ± 35.5	375.7 ± 34.5	358.8NS ± 34.9	344.7NS ± 35.4	339.6* ± 35.6	69.38 (0.153) [<0.001]	3.49 (0.018) [0.031]	1.82 (0.009) [0.164]
Speed (m/s)	4.8 ± 0.2	4.8 ± 0.2	4.8 ± 0.2	5.9$ ± 0.3	6.3$* ± 0.4	6.5*$# ± 0.5	1961.43 (0.836) [<0.001]	20.56 (0.097) [<0.001]	31.52 (0.141) [<0.001]
30m sprint time (sec)	6.2 ± 0.2	6.3 ± 0.3	6.3 ± 0.3	5.1NS ± 0.2	4.8$* ± 0.3	4.6*#$ ± 0.3	2395.17 (0.862) [<0.001]	12.01 (0.059) [<0.001]	26.16 (0.120) [<0.001]
1500m running time (min)	10.4 ± 1.4	10.6 ± 1.3	10.8 ± 1.2	5.6$ ± 0.4	5.3$ ± 0.4	5.2*$ ± 0.4	2592.29 (0.871) [<0.001]	0.457 (0.002) [0.634]	1.834 (0.009) [0.161]

[Data presented as Mean ± SD, Two-Way ANOVA followed by post-hoc tests (Bonferroni) was performed. * when compared to 0 week $p \leq 0.05$, # when compared to 8 week $p \leq 0.05$, $when compared to control group $p \leq 0.05$; 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 (ηp^2) and p value; SD = standard deviation, ANOVA= Analysis of Variance, NS= not significant; GSR= grip strength in right hand, GSL= grip strength in left hand, BS= back strength, LS= leg strength, SBJ= standing broad jump, VJ= vertical jump, Pmax= maximum power, RPmax= relative maximum power, Pavg= average power, RPavg= relative average power, Pmin= minimum power, FI= fatigue index, AC= anaerobic capacity, RT= reaction time]

Table 5: Changes in physiological variables following training in **Middle distance runners**

Parameters	Control Group (n=65)			Middle Distance Runners (n=65)			Two Way ANOVA		
	0 Wk	8 Wk	12Wk	0 Wk	8 Wk	12 Wk	Group F1 (ηp^2) [p value]	Time F2 (ηp^2) [p value]	Interaction F3(ηp^2) [p value]
SBP (mmHg)	119.3 ± 5.7	120.8 ± 5.4	121.1 ± 5.6	117.0 ± 5.5	112.1* ± 5.6	111.4* ± 5.8	147.85 (0.278) [<0.001]	4.55 (0.023) [0.011]	16.53 (0.079) [<0.001]
DBP (mmHg)	79.2 ± 5.2	80.6 ± 5.5	81.0 ± 5.6	76.3 ± 5.8	72.2* ± 6.0	70.9* ± 5.9	154.72 (0.287) [<0.001]	3.72 (0.019) [0.025]	14.22 (0.069) [<0.001]
PP (mmHg)	40.1 ± 5.8	40.1 ± 6.3	40.1 ± 6.9	40.6 ± 5.5	39.8$* ± 4.5	40.5* ± 5.7	0.133 (0.000) [0.715]	0.13 (0.001) [0.879]	0.19 (0.001) [0.820]
MAP (mmHg)	92.6 ± 4.6	94.0 ± 4.6	94.3 ± 4.5	89.9 ± 5.1	85.5* ± 5.4	84.4* ± 5.2	199.74 (0.342) [<0.001]	5.18 (0.026) [0.006]	19.57 (0.093) [<0.001]
BHR (bpm)	64.5 ± 4.1	65.1 ± 3.5	65.2 ± 3.6	59.3$ ± 3.0	57.3* ± 3.1	56.8* ± 3.0	425.19 (0.525) [<0.001]	2.60 (0.013) [0.075]	7.69 (0.039) [<0.001]
PEHR (bpm)	71.5 ± 3.1	71.9 ± 3.1	72.4 ± 2.7	65.6 ± 2.9	64.7 ± 2.7	63.6* ± 2.5	631.47 (0.622) [<0.001]	1.09 (0.006) [0.335]	8.55 (0.043) [<0.001]
SMHR1 (bpm)	136.7 ± 4.2	137.2 ± 3.6	137.6 ± 3.7	127.9 ± 4.4	126.9 ± 3.8	125.1*# ± 4.2	680.21 (0.639) [<0.001]	2.13 (0.011) [0.121]	7.02 (0.035) [0.001]
SMHR2 (bpm)	160.4 ± 4.7	180.7 ± 4.5	161.3 ± 4.5	143.4 ± 5.1	140.2* ± 5.3	138.8* ± 4.6	1718.82 (0.817) [<0.001]	5.05 (0.026) [0.007]	10.86 (0.054) [<0.001]
HRmax (bpm)	193.7 ± 4.6	194.5 ± 4.5	195.2 ± 4.9	194.2 ± 5.1	190.1$* ± 6.1	187.1*# ± 5.9	57.63 (0.130) [<0.001]	9.61 (0.048) [<0.001]	22.51 (0.105) [<0.001]
RecHR1 (bpm)	173.8 ± 5.5	174.1 ± 5.1	174.3 ± 5.5	171.2 ± 5.6	166.9* ± 6.3	164.3* ± 6.6	125.06 (0.246) [<0.001]	9.82 (0.049) [<0.001]	13.31 (0.065) [<0.001]
RecHR2 (bpm)	152.3 ± 5.1	153.0 ± 4.7	153.2 ± 4.7	140.3 ± 5.6	139.7 ± 5.5	138.9 ± 5.1	653.81 (0.630) [<0.001]	0.15 (0.001) [0.863]	1.62 (0.008) [0.199]
RecHR3 (bpm)	127.5 ± 3.6	126.9 ± 3.7	126.4 ± 3.7	118.9$ ± 5.0	116.1$* ± 5.4	114.1* ± 4.7	567.97 (0.597) [<0.001]	15.49 (0.075) [<0.001]	5.79 (0.029) [0.003]
FVC (l)	2.4 ± 0.3	2.4 ± 0.3	2.5 ± 0.3	3.6$ ± 0.2	3.9$ ± 0.1	4.0*$ ± 0.2	3349.05 (0.897) [<0.001]	1.82 (0.009) [0.163]	0.23 (0.001) [0.793]

FEV1 (l)	2.3 ± 0.3	2.4 ± 0.3	2.4 ± 0.3	3.6$ ± 0.2	3.9$ ± 0.2	4.0*$ ± 0.2	3836.73 (0.909) [<0.001]	1.84 (0.009) [0.160]	0.048 (0.000) [0.953]
FEV1/FVC (%)	97.2 ± 3.6	97.3 ± 3.3	97.5 ± 3.0	98.7$ ± 1.4	98.6$ ± 1.0	98.3$ ± 1.1	25.16 (0.061) [<0.001]	0.008 (0.000) [0.992]	0.66 (0.003) [0.515]
PEFR (l)	374.6 ± 17.6	376.3 ± 18.9	377.5 ± 19.9	453.5$ ± 17.2	486.3$ ± 17.5	497.7*$ ± 18.6	4166.76 (0.916) [<0.001]	1.22 (0.006) [0.297]	0.051 (0.000) [0.951]
VO_{2max} (ml/min/kg)	38.2 ± 1.4	38.3 ± 1.5	38.7 ± 1.6	52.6$ ± 4.4	55.3*$ ± 4.4	57.2$* ± 4.5	2482.69 (0.866) [<0.001]	18.96 (0.090) [<0.001]	13.30 (0.065) [<0.001]
RL (mmol/lit)	2.0 ± 0.5	2.1 ± 0.5	2.1 ± 0.5	2.0 NS ± 0.9	2.2 NS ± 0.9	2.1NS ± 0.9	0.00 (0.00) [0.989]	0.003 (0.000) [0.997]	0.14 (0.001) [0.865]
PL (mmol/lit)	16.5 ± 2.2	16.8 ± 2.5	17.1 ± 2.1	9.5$ ± 1.8	9.6$ ± 1.4	9.8$ ± 1.3	1335.99 (0.777) [<0.001]	0.56 (0.003) [0.573]	1.08 (0.006) [0.339]

[Data presented as Mean ± SD, Two-Way ANOVA followed by post-hoc tests (Bonferroni) was performed. * when compared to 0 week $p\leq0.05$, # when compared to 8 week $p\leq0.05$, $when compared to control group $p\leq0.05$; 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 (ηp^2) and p value; SD = standard deviation, ANOVA= Analysis of Variance, 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, FEV1= force expiratory volume in 1st sec, PEFR= peak expiratory flow rate, VO_{2max} = maximal aerobic capacity, RL= resting lactate, PL= peak lactate]

Training's effects on middle-distance runners' performance and physical fitness metrics:

Training produced improvements in numerous physical fitness metrics between middle-distance running athletes. Following 8 and 12 weeks of instructions, middle-distance runners showed decrease in reaction time, 30 meters as well as 1500 meter running times; also an improvement in speed of running. In addition, significant increase in strength (handgrip, back, and leg muscles), explosive power (SBJ and VJ scores), muscular endurance (eg- push-ups and sit-ups scores), anaerobic power and flexibility were observed among the middle-distance runners after the training when compared to the baseline data. The middle-distance runners outperformed control group participants in various fitness determinants. The runners had significantly reduced reaction time, 30m sprint time, 1500m running time; and increased speed, handgrip strength, back strength, leg strength, explosive power (SBJ and VJ scores), muscular endurance (push-ups and sit-ups scores), anaerobic power and flexibility in contrast to those in the control group (Table 4).

Training's effects on middle-distance runners' performance and Physiological metrics:

The athletic training produced notable gains at various key physiological variables among the middle-distance runners. The runners demonstrated increase in aerobic capacity (VO_{2max}), pulmonary function (FVC, FEV1 and PEFR) after the training when compared to the baseline data. Middle-distance runners out performed control group participants with considerably higher ($p\leq0.05$) VO2max, FVC, FEV1, and peak expiratory flow rate (PEFR) indicators, which indicates respiratory and aerobic performance has been improved. On the other hand, decrease in different heart rate measured and blood presser were noted among the middle-distance runners after the training when compared to the baseline data. The runners showed significantly declining in resting blood pressure, heart rates and peak lactate levels compared to control group participants indicating improved cardiovascular efficiency and improved lactate clearance. No significant changes were found in resting and peak lactate levels among the middle-distance runners following training (Table 5).

Correlation studies:

In this study, running event time revealed a substantial negative connection ($p<0.05$) with VO_{2max}, back strength, leg strength, flexibility, speed, power max; significant ($p<0.05$) positively correlated with percentage of body fat, WHR, and peak lactate. Further, VO_{2max} showed negatively correlated with BMI, and fat mass ($r = -0.725$); positively ($p<0.05$) correlated with flexibility, and speed. Speed was found positively correlated with back strength, leg strength, and flexibility. Lung functions had significant ($p<0.05$) negative correlation with body fat and peak lactate levels (Table 6).

Table 6: Correlation between different Variables of Control and Middle Distance Runners group

Variables Name	r value	P value	Significance
VO2 max Vs BMI	-0.753*	p<0.05	High significant negative correlation
VO2 max vs Fat mass	-0.725*	p<0.05	High significant negative correlation
VO2 max vs. Flexibility	+0.788*	p<0.05	High significant positive correlation
V O2 max vs Speed	+0.846*	p<0.05	High significant positive correlation
Speed vs BS	+0.863*	p<0.05	High significant positive correlation
Speed vs LS	+0.815*	p<0.05	High significant positive correlation
Speed vs Flexibility	+0.723*	p<0.05	High significant positive correlation

3.2 DISCUSSION

The results demonstrated that athletic training produced meaningful improvements in body composition in middle-distance runners. Body weight, body mass index (BMI), and the body surface area (BSA), ponderal index, body fat percentage, and fat mass all decreased significantly following the training period, suggesting positive physiological adaptations to the endurance-focused program. These findings are consistent with research indicated that aerobic training enhances energy expenditure, increases fat oxidation, and causes reductions in body fat in trained athletes [24, 25]. The reduction in body fat percentage and fat mass reflects enhanced metabolic efficiency and substrate utilization. Middle-distance running relies on both aerobic and anaerobic energy systems; therefore, a leaner physique is advantageous for optimizing running economy and improved performance [26]. Additionally, athletes may maintain greater speeds with less exertion when they lose body fat since it lowers the energy cost of locomotion. Similar findings have indicated a high correlation between aerobic performance and decreased body fat [27]. Additionally, the study found a modest decrease in lean body mass after training, which might be the result of both high training volume and low calorie consumption [28]. This suggested that lean body mass might be increased with physical strength exercise and suitable dietary practices. The non-significant variation in limb lengths anticipated because they are determined by developmental and genetic factors rather than adult training. This implied that after maturation, skeletal measurements do not alter [29]. The trained runners had considerably lower body weight, body mass index (BMI), ponderal index, percentage of body fat, and fat free mass, fat mass and waist-to-hip ratio than control group. These variations demonstrated how athletic training affects body composition over time. A lower waist-to-hip ratio is crucial because it shows less central adiposity, which is linked to athletes' better health and productivity [30]. Runners' increased mid-calf and mid-upper arm circumferences were indicative of training-induced muscle adaptations. Rather than hypertrophy in the conventional sense, increased muscle girth in certain areas represents functional changes [31].

The result showed that training for middle-distance running athletes for more than 8 and 12 weeks can improve the physical metrics significantly. The decrease on reaction time, 30 m sprint time, and 1500 m running time; along with increased running speed, suggested improved neuromuscular coordination, acceleration capacity, and endurance performance. These adaptations are due to combined endurance and speed training, which improves motor unit recruitment, nerve conduction velocity, and movement efficiency [6, 32]. The reduction in reaction time indicates increased neuromuscular efficiency and faster stimulus-response processing, which are critical for running events. It can be suggested that training-induced neural adaptations contribute to such improvements [33]. The significant increase in muscular strength (handgrip, back, and leg strength) was observed following training among the runners, which shows the efficacy of strength training program. It can be said that middle-distance running is an endurance activity, but muscular strength is important in maintaining running economy, speed, and lowers injury risk. Recent study suggested that strength development enhances musculotendinous stiffness and improves force production, which contributes to better running performance [5, 34]. Muscular endurance (indicated by increased push-up and sit-up performance), also increased significantly after training. It is suggested that improved muscular endurance supports prolonged running and delays fatigue. Previous study suggested that endurance training increases mitochondria number, oxidative capacity and delayed fatigue in skeletal muscles [35]. The improvements in explosive power (indicated by increased standing broad jump and vertical jump scores), suggested an increase in anaerobic capabilities. It can be suggested that plyometric and high-intensity training may be responsible for these adaptations [36]. The increase in anaerobic power observed in this study might be due to high-intensity training among the runners. Although aerobic metabolism predominates in events such as the 1500 m, anaerobic energy systems contribute substantially during high-intensity phases of the race [37]. Further, increase in flexibility was noted after the training, which contributes to optimal stride length, reduced injury risk, and improved biomechanical efficiency. It can be suggested that dynamic and static stretching during training may enhance joint range of motion and muscle-tendon compliance [38]. In addition, the higher performance of middle-distance runners compared to the control group across all measured fitness parameters suggested the cumulative effect of systematic training. The present study also showed positive correlations of speed with strength of leg and back and with also flexibility. Further emphasize importance for strength and mobility in enhancing sprinting ability within middle-distance events. The running time showed negative correlations with back strength and leg strength which indicated the role of muscular strength in middle-distance running [6, 32]. Strength contributes to greater force application, while flexibility facilitates efficient stride mechanics, both of which are essential for achieving higher running speeds [32]. Further, the running time had negative relationships with and speed, flexibility, and maximal power indicated that neuromuscular and biomechanical factors are essential contributors to middle-distance performance [5, 34].In contrast, the running time showed significant positive correlations with body fat percentage, and waist-to-hip ratio suggest that higher adiposity are associated with poorer performance [26, 27].

The current investigation revealed that athletic training may effect for improvements in key physiological variables including in aerobic capacity, pulmonary function, cardiovascular efficiency, and metabolic responses among middle-distance runners. The significant increase in maximal oxygen uptake (VO_{2max}) was noted after training, which is a determinant factor of middle-distance running performance. Improvement of VO_{2max} may because of enhanced cardiac output volume, increased stroke volume, greater capillary density, and improved mitochondrial enzyme activity in skeletal muscles. Contemporary literature indicated VO_{2max} as a primary indicator of endurance performance, with training-induced increases linked to improved oxygen delivery and utilization [39, 40]. The higher VO_{2max} values observed in runners compared to controls further confirm the effectiveness of endurance training.Forced vital capacity (FVC), forced expiratory volume in one second (FEV_1), and peak expiratory flow rate (PEFR) were significantly improved. It suggested an increased respiratory muscle strength and lung function. It can be suggested that, regular endurance training may improve ventilatory efficiency, respiratory muscle endurance, and alveolar-capillary diffusion capacity. The respiratory adaptations facilitate enhance oxygen uptake and carbon dioxide removal during exercise [41]. The greater pulmonary functions observed in trained runners compared to controls indicated the importance of long term training. The significant reduction in different heart rates, indicated an improved autonomic regulation, characterized by increased parasympathetic (vagal) tone and decreased sympathetic activity. The lower resting and submaximal heart rates are widely recognized markers of cardiovascular efficiency and training adaptation, reflecting an increased stroke volume and more efficient cardiac function [42]. Additionally, faster heart rate recovery suggests improved autonomic balance and enhanced recovery capacity, which are important for repeated performance and training tolerance. The reductions in systolic and diastolic blood pressure observed following training supports, beneficial role of training in cardiovascular adaptations. Lower peripheral resistance and blood pressure may result from endurance training's potential to improve endothelial function, which decreases the arterial stiffness, and increases the vascular compliance [43].Both long-term cardiac health and sports performance are enhanced by these modifications. Metabolic adaptations can be inferred from the blood lactate responses. Increased mitochondrial activity, lactate capacity for transport, and stabilizing processes may be the cause of the trained runners' noticeably lower peak lactate levels as compared to controls, indicating enhanced lactate clearance and utilization. There is no significant change in athletes' resting and peak lactate levels after training, however, suggested that the length or intensity of the exercise was inadequate to cause detectable changes in lactate production limits. Previous research has indicated that training intensity and specificity affect lactate adaptations [44, 45]. The negative correlation of VO_{2max} with BMI and fat mass further reinforces the detrimental impact of excess body fat on aerobic performance. Higher adiposity reduces relative oxygen uptake when expressed per unit body mass and impairs endurance capacity. Conversely, the positive correlations of VO_{2max} with flexibility and speed indicate that athletes with better aerobic fitness also tend to exhibit superior neuromuscular and biomechanical characteristics. The negative correlation between 1500 m running time and VO_{2max} indicated that higher aerobic capacity is strongly associated with better performance [39, 40]. In contrast, the running time showed significant positive correlations with peak lactate suggest that greater metabolic stress are associated with poorer performance. The significant negative correlations between body fat percentage and lung function parameters (FVC and PEFR) suggest that increased adiposity may impair respiratory mechanics, possibly due to reduced chest wall compliance and increased work of breathing. Additionally, increased respiratory efficiency is linked to better metabolic control and less lactate build up during exercise, according to the negative associations between peak lactate levels and pulmonary function (FVC, PEFR).

Result of this investigation suggests 8 to 12-weeks of structured training program can bring about a noticeable improvements in body composition, physical metrics for fitness, and several important physiological parameters among these runners. Coaches can program well to include a mix of endurance work, strength training, and plyometric exercises to help runners to perform better while keeping unwanted body fat under control. Nutrition also plays a big role. Proper dietary strategies are essential not just for maintaining lean muscle mass but also for supporting good recovery between hard training sessions. Keeping an eye on markers like VO_{2max}, heart rate, and lactate levels can really help coaches and athletes adjust training intensity and track how the body is responding. Adding flexibility and strength exercises into the mix further helps to improve running economy, reduces injury risk, and makes running feel smoother and more efficient overall. Ultimately, a well-planned, periodized training approach combined with smart nutrition is key to unlocking the best possible performance in middle-distance running.

It is important to recognize the limitations of the current investigation. The sample size was somewhat tiny and the training period was only for 8–12 weeks, which makes it difficult to generalize the findings and may not have been long enough to capture long-term physiological adaptations, especially in lactate responses. Also, it couldn't strictly control the athletes' dietary intake or daily training load outside the supervised sessions, so these factors could have influenced the small changes observed in body composition and physiological variables. Future studies would benefit from recruiting larger and more diverse groups of runners, also extending the intervention period, and implementing a tighter monitoring of both the nutrition and training loads. Also to include more advanced assessments such as muscle biopsies, hormonal profiling, and longer follow-up measurements can be done. These steps could offer a clearer and deeper understanding of the metabolic and neuromuscular adaptations that occur in middle-distance runners over a long time.

4. CONCLUSION

The study shows that a well-organized training program can make a real difference in middle-distance runners. It leads to better anthropometric variables, improved physical fitness, and noticeable gains in overall physiological performance. The reductions in body fat along with clear improvements in strength, speed, endurance, and flexibility was observed, all of these helped the athletes run more efficiently and perform better. On the physiological side, there were noticeable changes like increases in VO_{2max}, better pulmonary function, improved cardiovascular efficiency, and more favorable lactate responses. The results also highlight that how important optimal body composition and good neuromuscular coordination are for running performance in middle distance runners. Overall, the findings suggest that a smart, well-planned training approach — backed by proper nutrition — is crucial for maximizing performance and supporting long-term development in middle-distance runners.

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