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Combined effects of aerobic and resistance exercises training on muscular endurance and related physiological variables of male middle-distance athletes

Gadisa Biranu Oljirra[1ABCDE], Dessalegn Wase Mola[1,2ACDE], Alemmebrat Kiflu Adane[3ACDE], Gemmechis Regaa Kabeta[1ABCDE], Haile Iticha Bulti[4ACDE], Mustafa Can Koc[5ACDE], Nugroho Susanto[6ACDE]

[1]Ambo University, Ambo, Ethiopia
[2]Postdoctoral Fellow, University of São Paulo, Brazil
[3]Addis Ababa University, Ethiopia
[4]Ethiopian Public Service University, Ethiopia
[5]Istanbul Gelisim University, Turkey
[6]Universitas Negeri Padang, Indonesia

Authors' Contribution: A – Study design; B – Data collection; C – Statistical analysis; D – Manuscript Preparation; E – Funds Collection

Abstract

Background and Study Aim Muscular endurance and physiological efficiency are relevant factors for middle-distance performance. While aerobic and resistance exercises improve these attributes, little is known about their combined effects among Ethiopian youth athletes. This study examined the impact of combined aerobic and resistance training on muscular endurance and physiological variables in male middle-distance athletes.

Material and Methods Eighteen (n = 18) male middle-distance athletes were selected using a census sampling technique. Participants were randomly assigned to an experimental group (EG, n = 9) and a control group (CG, n = 9). The experimental group completed an eight-week combined aerobic and resistance exercise program. Training was performed three days per week in addition to regular training. The control group continued routine training without receiving any additional intervention and served as a comparison group. Pre- and post-test data were collected for muscular endurance (squat and push-up tests), resting heart rate (RHR), hemoglobin level, and VO_2max. Data were analyzed using SPSS version 26. Paired-sample t-tests were conducted with a significance level of $p < 0.05$.

Results The experimental group demonstrated statistically significant improvements in muscular endurance and physiological variables. These included the squat test (MD = -3.44, p = 0.000), push-up test (MD = -3.67, p = 0.000), resting heart rate (MD = 4.89 beats/min, p = 0.000), hemoglobin (MD = -0.29 g/dl, p = 0.039), and VO_2max (MD = -3.59 l/min/kg, p = 0.000). In contrast, the control group showed no significant changes in any measured variables.

Conclusions The findings indicate that combined aerobic and resistance exercise training enhances muscular endurance and physiological performance indicators among youth male middle-distance athletes. Incorporating such combined training into regular athletic programs is recommended to improve performance outcomes.

Keywords: hemoglobin, VO_2max, resting heart rate, aerobic exercise, resistance training, muscular endurance

Introduction

Middle-distance running performance is influenced by the interaction of physical capacities and physiological responses developed through systematic training. Muscular endurance contributes to the ability to sustain repeated contractions during training and competition, while physiological responses such as cardiovascular efficiency and oxygen transport affect exercise tolerance over race distances. The simultaneous development of these components is associated with complex adaptations involving neuromuscular, metabolic, and hematological mechanisms. Training approaches that address multiple physical and physiological demands within a single program therefore represent a multifaceted process in the preparation of middle-distance athletes.

In context, regular participation in structured exercise programs is widely acknowledged as an important factor in improving physical and physiological functioning in athletes [1]. Exercise induces beneficial adaptations across multiple organ systems. These adaptations result in enhanced physical fitness, improved overall health, and better sport performance [2]. For competitive middle-

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distance runners, maintaining an appropriate level of physical fitness supports sustained high-intensity activity, delays fatigue, and promotes efficiency and alertness during training and competition [3]. Continuous and systematic training produces physiological adaptations, including increased maximal oxygen uptake (VO_2max), reduced resting heart rate, greater stroke volume, and higher maximal cardiac output. These adaptations contribute to improved performance capacity [4, 5].

Aerobic exercise is regarded as an effective training modality for improving cardiovascular fitness, muscular endurance, and oxygen utilization [6]. Because it relies primarily on aerobic metabolism, it enhances an athlete's ability to sustain prolonged activity and represents a central component of endurance training [7]. Resistance training is a fundamental component of athletic preparation worldwide. It contributes to increased muscular strength, improved neuromuscular coordination, and enhanced muscular endurance. These adaptations support the physical demands of sports that require a combination of strength and endurance [8]. Physiological adaptations resulting from consistent resistance training include enhanced muscle fiber recruitment and improved muscular efficiency. These adaptations are relevant for athletes engaged in middle-distance running [9].

Evidence indicates that combining aerobic and resistance training produces broader improvements in physical and physiological performance than either training modality alone [10]. For endurance athletes, supplementing aerobic conditioning with resistance training has been shown to increase maximal oxygen uptake (VO_2max), enhance endurance capacity, and improve overall exercise tolerance [11]. Similar effects have been observed among youth athletes. In these populations, combined training programs have produced improvements in muscular endurance, aerobic capacity, and general physical development [12, 14]. In addition to performance-related adaptations, exercise training has been associated with increases in hemoglobin concentration. This adaptation contributes to improved oxygen-carrying capacity and supports other physiological variables relevant to endurance sports performance [15, 16].

VO_2max is widely recognized as a primary predictor of performance in middle-distance running, particularly during early stages of athletic development [17, 18]. Experimental research examining the effects of combined aerobic and resistance training among youth middle-distance athletes in Ethiopia remains limited. Many existing studies have focused exclusively on aerobic training [19, 20] or have been conducted in non-athletic populations using less rigorous methodologies [21]. As a result, empirical evidence regarding the influence of combined training on muscular endurance, resting heart rate, hemoglobin levels, and VO_2max in youth athletic development settings remains insufficient. Although the effects of aerobic, resistance, and combined training have been documented in adult and elite athletic populations, evidence is less consistent among youth middle-distance athletes, particularly those training in high-altitude and resource-constrained environments. Previous studies have predominantly involved sea-level populations, mature athletes, or single-mode training interventions. This creates uncertainty regarding the effects of concurrent training on muscular endurance and physiological adaptations during early stages of athletic development. Furthermore, experimental studies involving East African youth athletic populations remain scarce, despite the region's global prominence in middle-distance running. In context, youth athletes enrolled in the Ambo University Athletics Project represent a distinct cohort due to chronic altitude exposure of approximately 2,101 m above sea level, early-stage athletic specialization, and limited access to structured resistance training programs. These contextual characteristics may influence physiological adaptation patterns differently from those reported in previous research.

Despite the documented physiological benefits of aerobic, resistance, and combined training approaches, their application within youth middle-distance development contexts remains complex. Variations in training background, physiological maturity, and environmental conditions may influence how muscular endurance and key physiological variables respond to concurrent training stimuli. In high-altitude youth training settings, these factors interact with chronic hypoxic exposure, potentially modifying cardiovascular, hematological, and neuromuscular adaptations. Within this context, combined aerobic and resistance training may influence muscular endurance, resting heart rate, hemoglobin concentration, and VO_2max in youth middle-distance athletes. Therefore, the aim of this study was to examine the effects of combined aerobic and resistance exercise training on muscular endurance and selected physiological variables in male youth middle-distance athletes..

Materials and Methods

Participants

The study was conducted at the Ambo University Youth Athletics Project in Ambo Town, West Shoa Zone, Ethiopia (8°59′N, 37°51′E; altitude 2,101 m). The sample included 18 male middle-distance athletes under 18 years of age. Participants were selected using a census sampling technique due to the small and homogeneous population. Eligible participants were male, under 18 years of age, free from injury and chronic illness, not using drugs or addictive substances, and willing to complete pre- and post-test assessments. Athletes older than 18 years, those with chronic or special health problems, those who sustained injuries during the study, or those who failed to complete the required measurements were excluded. Ethical approval was obtained from the Ambo University Research and Community Service Directorate. Permission was granted by the Department of Sport Science and Ambo University Referral Hospital. All participants and their guardians were informed about the study objectives, procedures, potential risks, and benefits. Voluntary participation, confidentiality, and the right to withdraw were ensured. Written informed consent was obtained from guardians, and participant assent was secured prior to data collection.

Research Design

Based on the reviewed literature, a conceptual framework was developed. It illustrates that the outcome variables are influenced by aerobic and resistance exercise, training intensity, dietary practices, altitude, and the training age of youth athletes (Figure 1).

A true experimental pretest–posttest control group design was employed to examine the effects of an eight-week combined aerobic and resistance training intervention on muscular endurance and physiological variables. Following baseline assessments, 18 eligible athletes were randomly assigned to an experimental group ($n = 9$) or a control group ($n = 9$) using simple randomization. The experimental group participated in an eight-week combined aerobic and resistance training program. Training was performed three times per week for 45 minutes per session. The control group continued with regular training.

The independent variable was the combined aerobic and resistance training program. The dependent variables were muscular endurance, resting heart rate, hemoglobin concentration, and maximal oxygen uptake (VO_2max). Muscular endurance was assessed using standardized squat and push-up tests. Resting heart rate was recorded manually from the radial artery in the early morning before physical activity. Hemoglobin concentration was analyzed from venous blood samples using a calibrated complete blood count (CBC) analyzer. Maximal oxygen uptake (VO_2max) was estimated using the equation $VO_2max = 15 \times (HRmax/HRrest)$, with HRmax predicted as 220 − age, as recommended and applied in previous studies [22, 23, 24]. Although indirect, this estimation method has been widely used in field-based research involving youth athletes when laboratory testing is not feasible.

All physiological and performance tests were conducted at the same time of day under standardized environmental conditions. The same trained assessors performed both pre- and post-intervention measurements. All measurements were conducted by trained healthcare and laboratory professionals using calibrated equipment and uniform procedures to ensure data reliability and accuracy.

An overview of the variables, measurement tools, and units of measurement is presented in Table 1.

Table 1. Variables and Measurement Tools

Variables	Test tools / procedures	Units of measurement
Muscular endurance	Squat and push-up tests	Number of repetitions
Resting heart rate	Radial pulse rate	Beats/min
Hemoglobin level	CBC analyzer	g/dL
VO_2max	Formula: 15 × (HRmax/RHR)	L/min/kg

As shown in Table 1, the selected variables and measurement tools represent standard field-based and laboratory-supported methods for assessing muscular endurance and key physiological characteristics in youth athletes. The combination of neuromuscular, cardiovascular, hematological, and aerobic indicators allows for a structured evaluation of training-related adaptations without reliance on a single physiological dimension.

Training Intervention

The experimental group followed an eight-week combined aerobic and resistance training program designed to improve cardiovascular fitness, muscular endurance, and physiological performance. Training

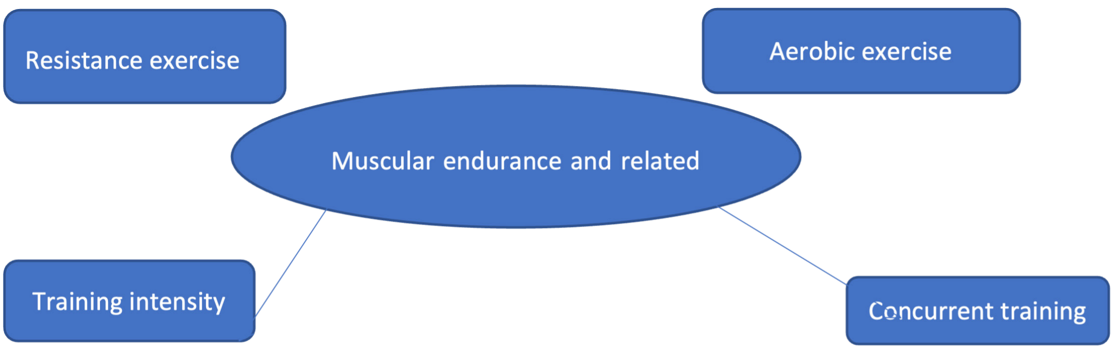

Figure 1. Conceptual framework.

was conducted three times per week for 45 minutes per session under the supervision of qualified coaches and sport science professionals. Each training session followed a fixed sequence in which aerobic exercise was performed first, immediately followed by resistance exercise. This sequence was selected based on evidence reported in previous studies indicating that aerobic exercise performed before resistance training supports cardiovascular adaptations without compromising muscular endurance development.

Each session began with a 10-minute warm-up consisting of light jogging, dynamic stretching, and mobility drills. The aerobic component lasted 15 minutes and included continuous running at 60–75% of HRmax during weeks 1–4. During weeks 5–8, intensity progressed to 70–80% of HRmax. Interval running was also included, consisting of 1–2-minute runs at moderate intensity alternated with 1-minute recovery periods. Hill running was incorporated on selected training days to support aerobic capacity and running economy.

The resistance component lasted 15 minutes and involved bodyweight and light-load exercises performed in a circuit format. Exercises targeted major muscle groups relevant to middle-distance running performance. Exercise intensity and duration were progressively increased across the eight-week intervention. Heart rate monitors were used to ensure adherence to prescribed intensity zones. One-repetition maximum (1RM) was estimated using submaximal testing procedures appropriate for youth athletes to ensure safety. Training intensity ranged between 40–60% of estimated 1RM and progressed every two weeks through increases in repetitions or resistance under qualified coach supervision. Exercises included squats, lunges, step-ups, push-ups, planks, core stabilization exercises, and medicine-ball functional drills. Resistance intensity was prescribed according to repetition maximum (RM) guidelines. Training began at 40–50% of 1RM or 12–15 RM during weeks 1–4 and progressed to 50–60% of 1RM or 10–12 RM during weeks 5–8. Each exercise was performed for 2–3 sets of 12–15 repetitions with 30–40 seconds of rest between stations. Progressive overload was applied weekly through incremental increases in repetitions, resistance, or circuit repetitions, as described in previous studies [25, 26, 27].

Sessions concluded with a 5-minute cool-down consisting of light jogging or walking followed by static stretching. Participants assigned to the control group continued their routine athletics training program. This program primarily included technical running drills, low- to moderate-intensity endurance running, and flexibility exercises. No structured resistance training or high-intensity aerobic conditioning was included during the intervention period.

An overview of the eight-week concurrent training program is presented in Table 2.

As shown in Table 2, the training intervention followed a structured and progressive format that integrated resistance and aerobic components within each session. The program illustrates how exercise selection, training volume, and intensity were systematically adjusted to ensure progressive overload while maintaining safety and consistency throughout the intervention period.

Adherence & Monitoring

Training attendance was recorded for each session using attendance logs maintained by supervising coaches. Participants who attended fewer than 85% of the training sessions were excluded from the final analysis. Training intensity compliance was monitored using heart rate monitoring and direct supervision to ensure adherence to the prescribed protocol.

Statistical Analysis

Data were analyzed using SPSS version 26. Descriptive statistics (mean ± SD) were computed for all variables. The Shapiro–Wilk test assessed normality. Pre–post differences within groups were examined using paired t-tests, and between-group

Table 2. Eight-Week Concurrent Training Program for Youth Middle-Distance Athletes

Week	Session	Resistance Component (15 min)	Aerobic Component (15 min)	Notes / Progression
1	Mon	Bodyweight squats: 2×12 Push-ups: 2×10 Lunges: 2×10 per leg	Continuous run 60% HRmax, 15 min	Base load
	Wed	Bodyweight squats: 2×12 Push-ups: 2×10 Plank: 2×30 s	Continuous run 62% HRmax, 15 min	Gradual intensity ↑
	Fri	Lunges: 2×12 per leg Push-ups: 2×12 Step-ups: 2×10	Continuous run 65% HRmax, 15 min	Slight volume ↑

Note. Resistance exercise intensity was expressed as a percentage of estimated one-repetition maximum (1RM), and aerobic intensity was prescribed as a percentage of maximum heart rate (HRmax = 220 − age). Training progression reflected gradual increases in repetitions, resistance, or running intensity under qualified supervision.

differences were evaluated using independent t-tests. Statistical significance was set at $p < 0.05$.

Results

As shown in Table 3, descriptive statistics were calculated to summarize the anthropometric characteristics of the study participants at baseline. Table 3 presents the demographic and anthropometric characteristics of the study participants. The experimental group had a mean chronological age of 16.67 ± 0.71 years and a mean height of 1.72 ± 0.01 m. Overall, the baseline data indicate that the experimental (EG) and control (CG) groups were comparable in age, height, weight, and BMI. The EG showed mean values of 16.67 years for age, 1.72 m for height, 51.89 kg for weight, and 17.58 for BMI. The CG demonstrated similar baseline characteristics, with mean values of 16.78 years, 1.70 m, 52.90 kg, and 18.58, respectively. These results indicate that both groups were demographically and anthropometrically homogeneous at the start of the study, providing an equivalent baseline for assessing the effects of the combined aerobic and resistance training intervention.

The pre- and post-test outcomes for muscular endurance and physiological variables in the experimental and control groups are summarized in Table 4. Table shows the paired-sample t-test results, indicating that the experimental group (EG) achieved significant improvements in muscular endurance, resting heart rate, hemoglobin concentration, and VO_2max after the eight-week combined training program ($p < 0.05$). In contrast, the control group (CG) showed no significant changes in any variables ($p > 0.05$).

The effects of the combined aerobic and resistance training intervention on muscular endurance and selected physiological variables are illustrated in Figure 2.

Table 5 shows the independent t-test results, indicating that the experimental group (EG) demonstrated significantly greater improvements in muscular endurance, resting heart rate, hemoglobin concentration, and VO_2max compared with the control group (CG) ($p < 0.05$). These findings indicate that the combined aerobic and resistance training intervention positively influenced physical fitness and physiological parameters in male youth middle-distance athletes. The observed differences in VO_2max and hemoglobin concentration reflect measurable physiological adaptations associated with combined training under high-altitude conditions.

Table 3. Descriptive statistics for anthropometric measurements of the study

Group	Variables	N	Mean ± SD	Std. Error
Age	EG	9	16.67 + 0.71	0.236
	CG	9	16.78 + 0.80	0.278
Height	EG	9	1.72 + 0.01	0.009
	CG	9	1.70 + 0.09	0.027
Weight	EG	9	51.89 + 2.47	0.824
	CG	9	52.90 + 3.43	1.144
BMI	EG	9	17.58 + 0.61	0.206
	CG	9	18.58 + 1.80	0.600

Key: N = number of participants; SD = standard deviation; BMI = body mass index.

Table 4. Summary of Pre- and Post-Test Results for Experimental and Control Groups

Variable	Group	Pre-test Mean ± SD	Post-test Mean ± SD	MD ± SD	t	df	p-value
Muscular Endurance (Squat)	EG	35.33 ± 1.50	38.77 ± 1.71	-3.44 ± 1.13	-9.141	8	0.000*
	CG	35.55 ± 2.00	35.88 ± 2.26	-0.33 ± 1.11	-0.894	8	0.397
Muscular Endurance (Push-up)	EG	30.00 ± 2.29	33.67 ± 1.50	-3.67 ±1.73	-6.350	8	0.000*
	CG	30.44 ± 2.65	31.00 ± 2.23	-0.56 ± 0.88	-1.890	8	0.095
Resting Heart Rate (beat/min)	EG	67.11 ± 3.66	62.22 ± 3.56	4.89 ± 0.33	44.00	8	0.000*
	CG	67.11 ± 3.96	66.67 ± 4.89	0.44 ± 1.67	0.800	8	0.447
Hemoglobin (g/dl)	EG	15.64 ± 0.37	15.93 ± 0.08	-0.29 ± 0.35	-2.465	8	0.039*
	CG	15.21 ± 0.79	15.33 ± 0.72	-0.12 ± 0.17	-2.050	8	0.074
VO_2max (l/min/kg)	EG	45.56 ± 2.41	49.15 ± 2.81	-3.59 ± 0.47	-22.77	8	0.000*
	CG	45.51 ± 2.76	45.83 ± 3.63	0.32 ± 1.40	-0.688	8	0.511

Notes: EG = Experimental Group; CG = Control Group; SD = Standard Deviation; MD = Mean Difference; df = Degrees of Freedom; *p < 0.05 indicates statistical significance

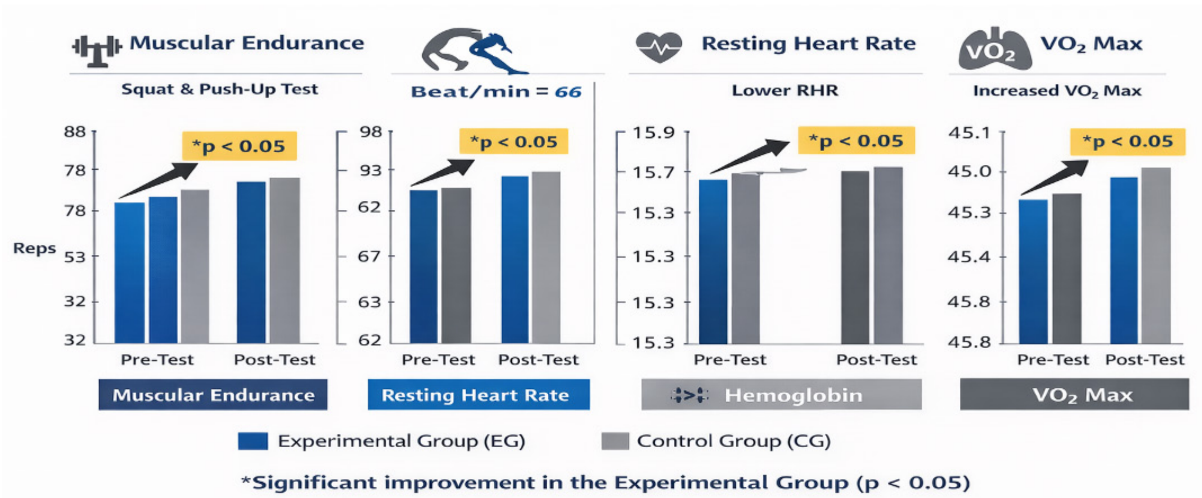

Figure 2. Effects of Combined Aerobic and Resistance Training on Youth Male Middle-Distance Athletes

Table 5. Between-Group Differences of Study Variables Using Independent t-Test

Variable	Test	EG Mean ± SD	CG Mean ± SD	t	p-value
Muscular Endurance – Squat	Post-test	38.77 ± 1.71	35.88 ± 2.26	4.11	0.001*
Muscular Endurance – Push Up	Post-test	33.67 ± 1.50	31.00 ± 2.23	3.63	0.002*
Resting Heart Rate (beat/min)	Post-test	62.22 ± 3.56	66.67 ± 4.89	-2.56	0.020*
Hemoglobin (g/dl)	Post-test	15.93 ± 0.08	15.33 ± 0.72	2.85	0.012*
VO_2max (l/min/kg)	Post-test	49.15 ± 2.81	45.83 ± 3.63	3.27	0.005*

Key: EG = Experimental group, CG = Control group; SD = Standard deviation; *$p < 0.05$ indicates statistical significance

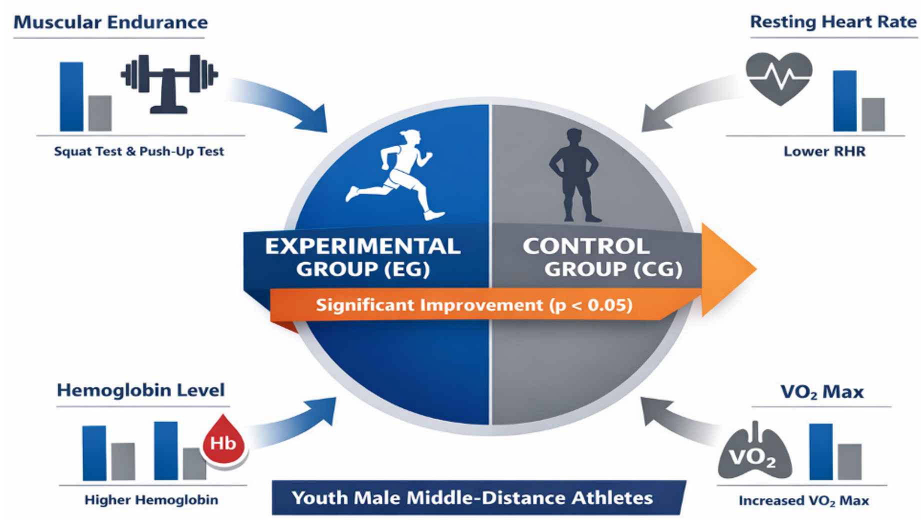

Figure 3. Exercise Program Effects on Youth Athletes

The overall structure and outcomes of the exercise program and its effects on youth athletes are further illustrated in Figure 3.

Discussion

This study examined the effects of an eight-week combined aerobic and resistance training program on muscular endurance and selected physiological variables in male youth middle-distance athletes. The observed improvements in muscular endurance, resting heart rate, hemoglobin concentration, and VO_2max in the experimental group are consistent with established evidence indicating that systematic exercise training induces beneficial physical and physiological adaptations in athletes [1, 2]. Similar adaptations, including enhanced aerobic capacity and cardiovascular efficiency, have been reported in middle-distance runners as a result of structured training programs aimed at supporting sustained high-intensity performance and delaying fatigue [3, 4, 5].

The present findings are also in agreement with previous studies demonstrating the positive effects of aerobic exercise on cardiovascular fitness, muscular endurance, and oxygen utilization [6, 7]. In addition, the observed adaptations align with evidence showing that resistance training contributes to improvements in neuromuscular coordination and muscular endurance, which are relevant for sports requiring both endurance and strength components, such as middle-distance running [8, 9].

Consistent with earlier reports, the combined application of aerobic and resistance training was associated with favorable changes across multiple performance-related and physiological variables [10, 11]. Comparable outcomes have been reported in youth athlete populations, where integrated training programs have been linked to improvements in muscular endurance, aerobic capacity, and general physical development [12, 14]. The observed changes in hemoglobin concentration further correspond with previous findings indicating that exercise training can influence hematological parameters related to oxygen transport and endurance performance [15, 16]. Given that VO_2max is widely recognized as an important determinant of middle-distance running performance during early stages of athletic development [17, 18], the present results are consistent with existing evidence supporting the role of combined training in shaping aerobic and physiological adaptations in young athletes.

Muscular endurance improved significantly in the experimental group. Squat performance increased from 35.33 ± 1.50 to 38.77 ± 1.71 repetitions (MD = −3.44, $p < 0.001$), and push-up performance increased from 30.00 ± 2.29 to 33.67 ± 1.50 repetitions (MD = −3.67, $p < 0.001$). These changes reflect improvements in neuromuscular coordination, local muscular oxidative capacity, and resistance to fatigue, which are relevant determinants of middle-distance running performance. The results are consistent with previous studies reporting that resistance training combined with aerobic exercise improves muscular endurance without negatively affecting endurance-related adaptations [21, 27, 28, 29]. The use of a circuit-based resistance format and progressive overload in the present study may have contributed to peripheral muscular adaptations and improved movement efficiency.

A significant reduction in resting heart rate was observed in the experimental group. Values decreased from 67.11 ± 3.66 to 62.22 ± 3.56 beats·min^{-1} (MD = 4.89, $p < 0.001$). No significant change was observed in the control group ($p = 0.447$). This reduction is indicative of improved cardiovascular efficiency, increased stroke volume, and enhanced parasympathetic modulation, which are commonly reported adaptations to endurance-oriented training. These findings are consistent with earlier studies showing that combined aerobic and resistance training induces cardiovascular adaptations comparable to those observed with aerobic training alone [30, 31].

Hemoglobin concentration increased significantly in the experimental group from 15.64 ± 0.37 to 15.93 ± 0.08 g·dL^{-1} (MD = −0.29, $p = 0.039$), whereas the control group showed no significant change ($p = 0.074$). Even small changes in hemoglobin concentration are associated with improved oxygen transport and endurance performance. This response may be related to exercise-induced stimulation of erythropoiesis and plasma volume regulation, which is relevant at the moderate altitude of the study site (2,101 m). Similar hematological responses following endurance or combined training have been reported in youth and adult athletes [28, 32, 33], supporting the association between structured training and oxygen delivery capacity.

VO_2max increased significantly in the experimental group from 45.56 ± 2.41 to 49.15 ± 2.81 ml·kg^{-1}·min^{-1} (MD = −3.59, $p < 0.001$). No significant change was observed in the control group ($p = 0.511$). Because VO_2max is a recognized predictor of middle-distance performance in developing athletes, this change is relevant for training outcomes. The results are consistent with previous studies reporting improvements in aerobic capacity when resistance training is incorporated into endurance programs [11, 34, 35]. Increases in muscular strength and endurance may lower relative exercise intensity at given workloads, improve running economy, and delay fatigue.

From a practical standpoint, these findings highlight the value of incorporating resistance training into aerobic conditioning programs for youth middle-distance runners. The use of bodyweight and circuit-based resistance exercises makes this approach feasible and cost-effective for youth development programs, particularly in resource-limited training environments. Such integrated training can simultaneously enhance muscular endurance, cardiovascular efficiency, hematological status, and aerobic capacity, all of which are essential for sustained middle-distance performance.

Limitations of the Study and Future Research Directions

Several limitations of the present study should be acknowledged. The small sample size, the short intervention duration, and the inclusion of only male athletes from a single training center limit the generalizability of the findings. In addition, only selected physiological variables were assessed. Other performance-related indicators, such as running time, lactate threshold, and biomechanical efficiency, were not measured. Lifestyle-related factors, including nutrition, sleep patterns, and daily physical activity, were not controlled and may have influenced training adaptations. Furthermore, VO_2max was estimated using a prediction equation rather than direct gas exchange analysis, which may have affected measurement accuracy. These limitations reflect practical conditions typical of youth athletic development programs and should be considered when interpreting the results.

Future research should involve larger and more diverse samples and include female athletes. Longer intervention periods are needed to examine long-term training adaptations. Additional studies should incorporate direct performance outcomes, biochemical markers, and biomechanical assessments to provide a broader evaluation of training effects. Greater control of dietary intake and recovery-related variables would strengthen causal interpretation. Further investigation of different training sequences and intensity distributions may contribute to the refinement of concurrent training approaches for youth endurance athletes.

Conclusions

Combined aerobic and resistance training improves muscular endurance and selected physiological variables in male youth middle-distance athletes. The findings support the integration of concurrent training programs within youth athletic development initiatives operating in high-altitude and resource-limited settings. The results indicate that structured concurrent training is associated with changes in cardiovascular efficiency, muscular strength, and endurance capacity within a single training framework. In addition, the findings emphasize the relevance of adapting training programs to contextual factors such as altitude and available resources. The application of such interventions in youth athlete programs may contribute to long-term performance development, injury risk management, and physiological adaptation.

Acknowledgment

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Conflict of Interest

The authors declare no conflict of interest related to this research.

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Information about the authors:

Gadisa Biranu Oljirra; https://orcid.org/0009-0002-4143-9880; gadisabiranu0924@gmail.com; Department of Sport Science, College of Natural and Computational Sciences, Ambo University; Ambo, Ethiopia.

Dessalegn Wase Mola; https://orcid.org/0000-0001-9688-0775; dessalegn.wasie@gmail.com; Department of Sport Science, College of Natural and Computational Sciences, Ambo University; Ambo, Ethiopia.

Alemmebrat Kiflu Adane; https://orcid.org/0000-0002-9298-1154; alemmebrat.kiflu@aau.edu.et; Department of Sport Science and Physical Education, College of Education and Language Studies, Addis Ababa University; Addis Ababa, Ethiopia.

Gemmechis Regaa Kabeta; https://orcid.org/0009-0008-5158-9675; gemechisregea869@gamil.com; Department of Sport Science, College of Natural and Computational Sciences, Ambo University; Ambo, Ethiopia.

Haile Iticha Bulti; https://orcid.org/0000-0002-6270-4041; bultihaile@gmail.com; Department of Physical Education and Sport Science, College of Social Science, Ethiopian Public Service University; Addis Ababa, Ethiopia.

Mustafa Can Koc; https://orcid.org/0000-0002-3007-5367; cankoc_01@hotmail.com; Faculty of Sport Sciences, Istanbul Gelisim University; Istanbul, Turkey.

Nugroho Susanto; (Corresponding author); https://orcid.org/0000-0002-9184-2769; nugrohosusanto@fik.unp.ac.id; Department of Sport Science, Faculty of Sports Science, Universitas Negeri Padang; West Sumatra, Indonesia.

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