ORIGINAL ARTICLE

The impact of a 6-week strength training program on physiological and hematological metrics in elite Ethiopian middle- to long-distance runners

Nigatu Worku Angasu . *Department of Sports Science. Addis Ababa University. Addis Ababa, Ethiopia.*
Zeru Bekele Tola. *Department of Sports Science. Addis Ababa University. Addis Ababa, Ethiopia.*
Aschenaki Taddese. *Department of Sports Science. Addis Ababa University. Addis Ababa, Ethiopia.*

ABSTRACT

This study examined the effects of a 6-week strength training (StT) program on elite middle- to long-distance runners (1,500m–10,000m). While strength training is recognized for improving athletic performance, its specific impact on physiological and haematological parameters in Ethiopia remains unclear. Twenty-one elite athletes underwent pre- and post-training assessments, measuring resting heart rate (RHR), maximal oxygen consumption (VO_{2max}), 5000m race time, 400m speed, and haematological markers, including red blood cell (RBC) count, white blood cell (WBC) count, haemoglobin (Hb), and haematocrit (Hct). Results showed that 5000m performance significantly improved ($p < .001$), demonstrating the positive effect of StT on endurance. Regression and ANOVA analyses revealed strong predictive relationships for VO_{2max} ($R^2 = 0.304$, $p = .010$), 5000m time ($R^2 = 0.719$, $p < .001$), 400m speed ($R^2 = 0.784$, $p < .001$), and Hct levels ($R^2 = 0.894$, $p < .001$). No significant changes were found in RBC, WBC, or Hb levels. These findings suggest strength training enhances endurance performance without significantly affecting haematological parameters, emphasizing the need for further research on long-term haematological adaptations. This research contributes valuable insights into the effectiveness of strength training interventions for enhancing athletic performance.

Keywords: Performance analysis, Exercise therapy, Strength training, Haematologic tests, Sport performance, Physiological processes, Endurance running.

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Corresponding author. *Department of Sports Science. Addis Ababa University. Addis Ababa, Ethiopia.*
E-mail: nafnat1973@gmail.com
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INTRODUCTION

Strength training (StT) has long been debated as a tool for improving endurance performance, particularly in middle- and long-distance athletes (MLDA) (Tomschi, Bloch, & Grau, 2018). Recent studies suggest that StT can significantly enhance running performance by improving key factors such as running economy, power, and endurance capacity (Gill, Williams, & Reifsteck, 2017). StT works by overloading the neuromuscular system, leading to better motor unit recruitment, increased firing frequency, musculotendinous stiffness, and improved intramuscular coordination, all of which contribute to enhanced running efficiency and performance metrics (Siddique et al., 2020; Škarabot, Brownstein, Casolo, Del Vecchio, & Ansdell, 2021).

Different modalities of StT, such as explosive and heavy StT, target various physiological adaptations. Explosive StT which includes bodyweight jumping and plyometric exercises, improves the rate of motor unit activation and muscular power (Liao et al., 2022). Although, heavy StT enhances anaerobic capacity and maximal speed is particularly useful for sprinting in competitive events (Gäbler, Prieske, Hortobágyi, & Granacher, 2018). These adaptations help delay fatigue and increase the MLDA's ability to sustain lower levels of exertion over time, which is critical for long-distance events (Midgley, McNaughton, & Jones, 2007).

Additionally, StT has been shown to improve haematological profiles, which are critical for endurance performance. Specifically, StT can increase red blood cell (RBC) counts, Hb, and Hct, all of which are essential for efficient oxygen delivery to working muscles (Ahmadizad & El-Sayed, 2005). While endurance training traditionally focuses on improving aerobic capacity, integrating StT offers a complementary approach, potentially boosting both muscular and haematological adaptations (Tomschi et al., 2018).

However, the specific effects of StT on the haematological profiles of elite runners remain underexplored (Zacháry et al., 2023). Existing research suggests that StT may positively influence these parameters, but further investigation is required to fully understand its impact, particularly in high-level MLDA (Tomschi et al., 2018). This study aims to fill this gap by examining how a structured StT program affects the haematological profiles, physiological adaptations, and overall performance of elite mid-to-long distance runners (Boullosa et al., 2020).

The study also explores the predictive role of pre-intervention Hb levels on post-StT outcomes, offering insights into how baseline physiological metrics may influence the effectiveness of StT interventions(Steiner, Maier, & Wehrlin, 2019). By addressing these factors, this research seeks to optimize training regimens for elite endurance MLDA, contributing to a more nuanced understanding of the relationship between ST, haematological adaptation, and performance improvement (Best, 2021; Mujika, Bourdillon, Zelenkova, Vergnoux, & Millet, 2024).

The effects of StT on endurance athletic performance have long been the subject of debate among athletes, coaches, and sports scientists. StT has a positive impact on middle- and long-distance running performance and its key determinants for different competitive levels (Blagrove, Howatson, & Hayes, 2018). StT modalities have been shown to elicit performance improvements in moderately-trained (Albracht & Arampatzis, 2013), well-trained (Alcaraz-Ibañez & Rodríguez-Pérez, 2018; Mujika et al., 2024), and highly-trained participants (Boullosa et al., 2020). This suggests that runners of any training status can benefit from ST.

StT provides an overload to the neuromuscular system, improving motor unit recruitment, firing frequency, musculotendinous toughness, and intramuscular coordination, potentially providing distance runners with a approach to enhance their RE and event-specific muscular power elements (Liao et al., 2022). StT includes both explosive and heavy ST, which promote different training adaptations (Aagaard & Andersen, 2010). Explosive StT involves bodyweight jumping exercises (Blagrove et al., 2018) and plyometric exercises, commonly used to increase short-tempered strength through the stretch-shortening cycle (Iaia & Bangsbo, 2010). This leads to adaptations such as an increased rate of activation of motor units (Coutts, Wallace, & Slattery, 2007).

StT contributes to enhancing endurance performance by improving the economy of movement, delaying fatigue, improving anaerobic capacity, and enhancing maximal speed. In running, the combination of these changes can provide an MLDA with tactical advantages, such as in attacks or final sprints, while also potentially affecting indices of aerobic capacity (Chen et al., 2023). Additionally, strength exercises that enhance endurance capacities are imperative in improving competitive running performance (Siddique et al., 2020; Škarabot et al., 2021).

The integration of StT into the regimen of endurance MLDA, particularly MLDA, has gained considerable attention due to its potential to enhance performance (Alcaraz-Ibañez & Rodríguez-Pérez, 2018; Mujika et al., 2024). StT not only augments muscular power and endurance but also induces beneficial physiological and haematological adaptations (Barnes & Kilding, 2015; Montero et al., 2017). Haematological parameters such as increased Hb concentration and RBC count have been associated with improved endurance capacity (Alcaraz-Ibañez & Rodríguez-Pérez, 2018; Schumacher, Schmid & Bültermann, 2002). The aim of this study is to examine the impact of a structured StT program on the haematological profiles, physiological adaptations, and performance metrics of elite mid-to-long distance runners. This study hypothesizes that StT modalities will show significant changes in MLDA haematological, physiological, and performance parameters, with RHR being the most affected physiological parameter. By addressing this gap in the literature, the study aims to provide a comprehensive understanding of how StT can be integrated into the training regimens of elite endurance MLDA to optimize performance (Steiner et al., 2019; Tomschi et al., 2018).

MATERIALS AND METHODS

Description of the sample population

This study was conducted in the Addis Ababa region of Ethiopia, focusing on an elite group of male middle- and long-distance athletes (MLDA) coached by the researcher. Participants were selected from athletes who primarily trained at high-altitude sites, including Intoto, Kenenisa's running tracks, and Dukum sand roads, with elevations ranging from 2,800 to 3,500 meters above sea level. These athletes were chosen due to their competitive status and representation of Ethiopia in international middle- and long-distance running events (1,500m to 10,000m).

Research design

This study employed a quasi-experimental design to investigate the effects of strength training on physiological and haematological factors influencing running performance. A purposive and convenience sampling technique was used to select 21 elite male MLDAs who met the inclusion criteria of competing at the national or international level.

Following a pre-test assessment, participants underwent a six-week strength training (StT) intervention, after which post-treatment effects on performance-related physiological and haematological determinants were evaluated. Ethical approval for the study was obtained from the Addis Ababa University College of Natural

Sciences Research Ethics Committee. All participants provided written informed consent, and the study adhered to the ethical principles outlined in the Helsinki Declaration for human research.

Experimental procedure

The intervention consisted of a six-week StT program, with 3–4 sessions per week. The study was conducted in three phases:

- Pre-test phase: Physiological and haematological parameters were assessed after four weeks of pre-intervention training.
- Intervention phase: A six-week StT program was implemented, focusing on endurance, strength, and speed training.
- Post-test phase: The same physiological and haematological parameters were measured immediately after the intervention.

The StT program included three hard training days, one moderate day, two easy days, and one rest day per week. Training variables (type, volume, and intensity) were strictly controlled, while extrinsic and intrinsic factors remained uncontrolled to minimize bias inherent in quasi-experimental designs

Strength training protocol

The StT program integrated hill running (3 × 200m) as the final station in a circuit of bodyweight exercises. The circuit comprised six sets of eight stations, with each station involving 1–2 minutes of work followed by a one-minute rest. Between sets, participants rested for three minutes. The program targeted muscle groups critical to running performance.

Training sessions were conducted three times per week (Tuesday, Thursday, and Saturday) over six consecutive weeks. Each session included: a 20-minute warm-up, 10 minutes of dynamic mobilization exercises, the main training session (duration determined by individual preliminary tests), and a 10-minute cool-down.

A preliminary test was conducted to establish each participant’s workload, set at 60–80% of their one-repetition maximum (1RM). The program followed the principle of progressive overload, with workload increasing by 10% weekly until reaching 80% of 1RM.

Data collection techniques

Blood samples were collected 48 hours after the final training session of each intervention phase. For the pre-test, participants were advised to refrain from strenuous activity for two days prior to sample collection. A total of 10 mL of blood was drawn from the antecubital fossa vein after a 12-hour fast. Post-StT blood samples were collected following the same procedure. Blood collection and analysis were performed by trained professionals in a certified laboratory.

Physiological data were collected through event-specific time trials, indirect VO_{2max} tests, 400m speed tests, and RHR measurements. Pre- and post-StT data collection adhered to standard laboratory protocols and established guidelines (Mackenzie, 2005).

Data analysis

Descriptive statistics, including mean (M), standard deviation (SD), and range, were calculated for pre- and post-StT data to identify general trends. Paired t-tests were conducted to assess statistically significant changes in physiological, performance, and haematological variables from pre- to post-StT.

Correlation analysis was performed to explore relationships between variables, and Analysis of Variance (ANOVA) was used to determine statistically significant differences in dependent variables (e.g., VO_{2max}, 400m speed, 5,000m run-time, RBC count, WBC count, Hb, Hct) before and after the StT intervention. Multiple regression analyses were conducted to evaluate the predictive power of pre- and post-StT metrics on post-StT haemoglobin (Hb) levels. Statistical significance was set at $p < .05$.

RESULTS

Physiological adaptations

The analysis of resting heart rate (RHR) revealed a mean pre-intervention value of 53.14 ± 3.82 beats per minute (bpm). Following the post-strength training intervention (PSTI), the mean RHR increased slightly to 54.10 ± 4.02 bpm. A paired t-test comparing pre- and post-StT RHR values (t = -1.00, *p* = .33) indicated no statistically significant change (Table 1).

For VO_{2max}, the pre-StT mean value was 78.37 ± 2.10 mL/kg/min, which increased marginally to 79.33 ± 4.70 mL/kg/min post-StT. The paired t-test revealed no statistically significant improvement in VO_{2max} (t = -1.11, *p* = .28) following the intervention (Figure 1).

In contrast, the 5000m running performance showed a notable improvement. The average time to complete the 5000m run decreased significantly from 13.78 ± 0.28 minutes pre-StT to 13.51 ± 0.03 minutes post-StT. A paired t-test demonstrated a statistically significant improvement in performance (t = 4.37, *p* = .0003), indicating a meaningful enhancement in running efficiency following the intervention.

The analysis of RHR revealed that before the intervention the mean RHR with a standard deviation (SD) was (53.14 ± 3.82) beats per minute (bpm). Post-strength training intervention (PSTI), the mean RHR increased slightly to 54.10 bpm (±4.02). A paired *t*-test comparing pre-and post-StT RHR yielded (*t* = -1.00, *p* = .33), indicating no statistically significant change (Table 1).

Table 1. The summary table of pre–post analysis.

Metric	Pre Mean	Post Mean	Change (%)	t	*p*	Cohen's d
Resting Heart Rate (bts/sec)	53.1	54.1	1.79	-1.0	.33	0.24
12-minute run (m)	4010.5	4017.1	0.17	-0.88	.39	0.07
VO_{2max} (mL/kg/min)	78.372	79.3	1.22	-1.11	.28	0.26
Speed test (sec)	57.079	55.8	-2.24	5.45	.00**	-0.54
Red Blood Cells (million/µL)	5.447	5.56	2.08	-2.48	.02*	0.3
White Blood Cells (WBC)	7.428	7.52	1.23	-1.06	.3	0.05
Hemoglobin (g/dL)	15.94	16.15	1.34	-2.49	.02*	0.21

*Note. Key: t-statistic (t), p-value (p), '**' sig.at 99% CI, and effect size (Cohen's d).*

For VO_{2max}, the pre-StT mean was 78.37 mL/kg/min (±2.10), which increased slightly to (79.33 ± 4.70 mL/kg/min) post-StT. The paired *t*-test resulted no significant improvement in VO_{2max} (*t* = -1.11, *p* = .28), post-StT (Figure 1).

In contrast, the 5000M showed a notable improvement. The average time to complete the 5000m run decreased from 13.78 minutes (±0.28) pre-StT to 13.51 minutes (±0.03) post-StT. A paired *t*-test revealed a statistically significant improvement in performance, (*t* = 4.37, *p* = .0003).

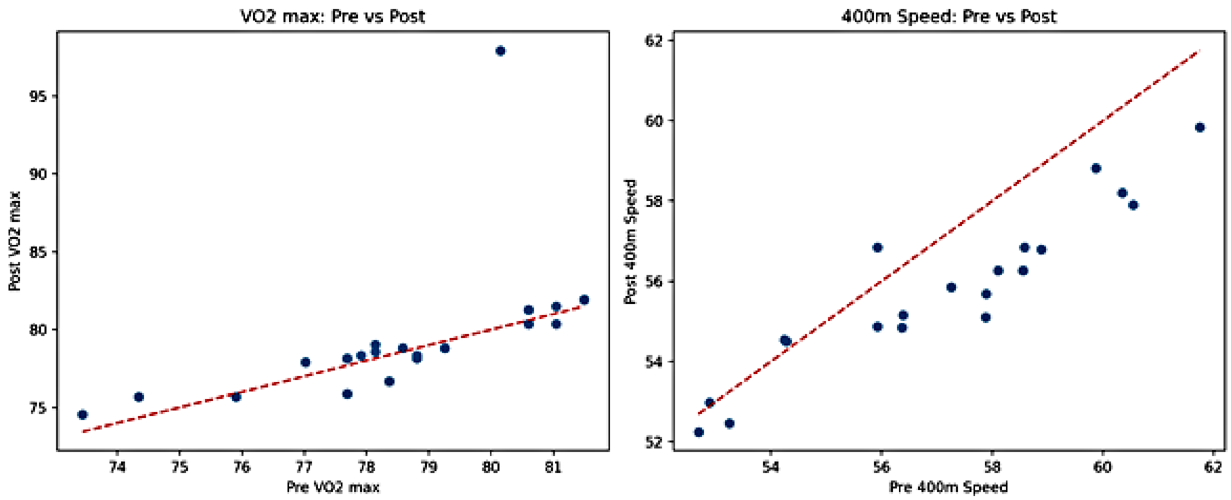

Figure 1. Linear regression.

Haematological changes

The intervention influenced several haematological parameters, as analysed through a violin plot (Figure 2). The post-StT result exhibited a slightly higher RBC mean count compared to the pre-StT, but with greater variability, as evidenced by the wider distribution. However, the ANOVA test indicated no significant impact of the intervention on RBC (p = .061).

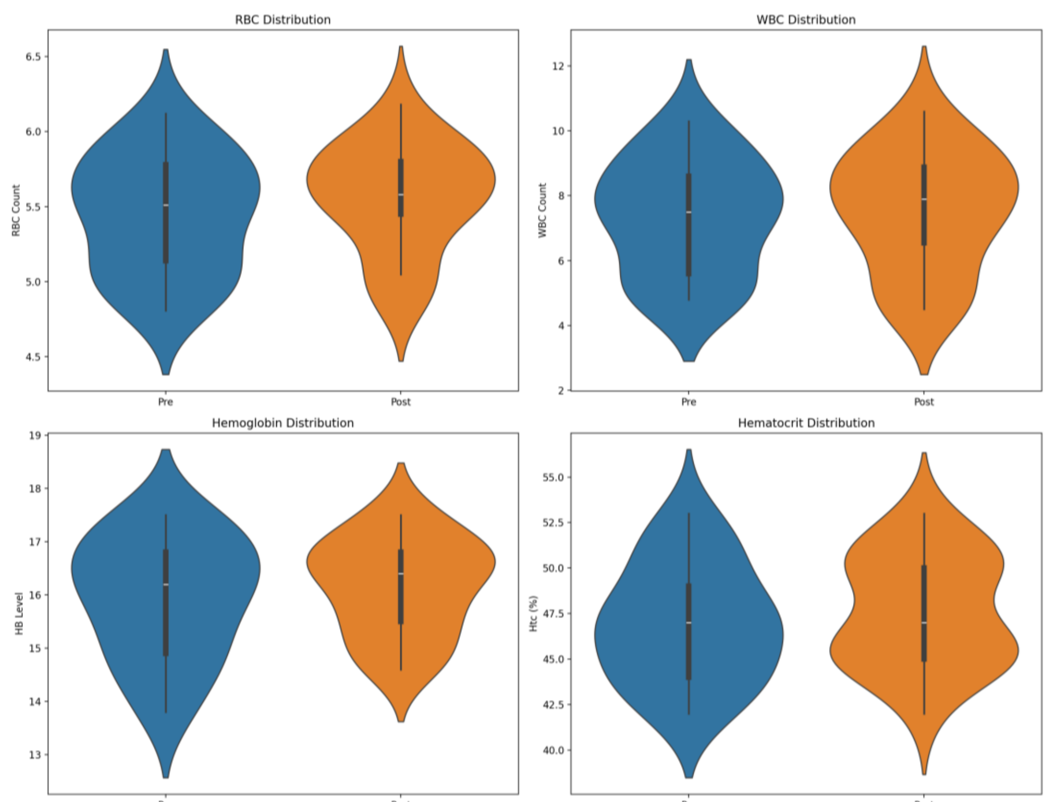

Figure 2. Statistical summaries of haematology.

PSTI, the Hb level showed a noticeable decline compared to pre-StT, as indicated by the violin plot (Figure 2). The variability in Hb levels was slightly lower post-StT. Regression analysis revealed a significant relationship between pre- and post-StT Hb levels (R^2 = 0.899, p < .001), but the ANOVA test confirmed no significant treatment effect (p = .158, Table 1). The mean WBC count remained similar between the pre- and post-StT groups. However, the distribution in the post-StT group was more concentrated around the median, indicating reduced variability. Regression analysis demonstrated a strong relationship between pre-StT and post-StT WBC counts (R^2 = 0.892, p < .001) and in RBC (R^2 = 0.848, p < .001) (Figure 3), but the ANOVA test showed no significant change in RBC (p = .218, Table 1).

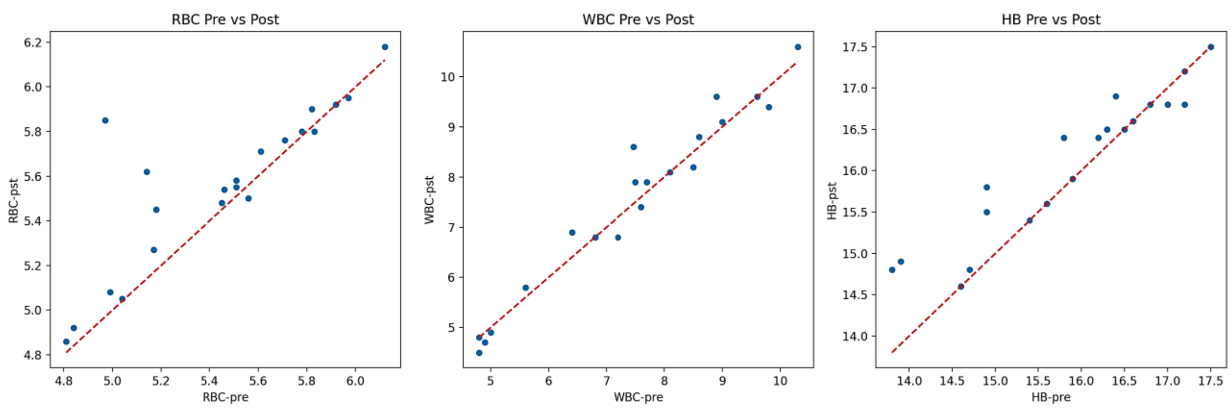

Figure 3. Linear regression of pre by post intervention.

Measures of association between anthropometry and strength training intervention (STI)

ANOVA results demonstrated a significant association between RBC count and age (F = 3.167, Eta² = 0.68, p = .03), with age explaining 19.3% of the variance and linearity being an important factor (p = .02) (Table 2).

Table 2. Summary of Post-haematological parameters.

Parameter	Variable	Between SS	Within SS	Total SS	F-Value	p	R²	Eta²
RBC	Age	3.2	1.5	4.7	3.17	.03	0.19	0.68
	Height	3.2	1.5	4.7	1.73	.21	0.13	0.68
	Weight	1.3	3.4	4.7	1.17	.40	0.06	0.28
WBC	Age	39.9	33.5	73.4	1.79	.17	0.07	0.54
	Height	25.2	48.2	73.4	0.43	.90	0.11	0.34
	Weight	18.1	55.3	73.4	0.98	.50	0.01	0.25
HB	Age	2.7	15.1	17.8	0.27	.96	0.02	0.15
	Height	12.1	5.8	17.8	1.72	.20	0.00	0.68
	Weight	1.0	16.8	17.8	0.19	.96	0.00	0.06
Htc	Age	88.9	97.2	189.0	1.33	.32	0.06	0.47
	Height	91.8	97.2	189.0	0.77	.70	0.07	0.49
	Weight	4.7	184.2	189.0	0.08	1.00	0.01	0.03
RHR	Height	247.1	76.7	323.8	2.64	.10	0.00	0.76
	Weight	108.1	215.7	323.8	1.50	.25	0.02	0.33

Note: Sum of Squares (SS), degree of freedom (df), Mean Square (M^2), estimated association (Eta),sig. at 95% CI (p)

No significant effects of age were observed for WBC, Hb, or Hct. RHR by height has high effect sizes (Eta² = 0.76) but is not statistically significant (p = .10). Height was marginally associated with RHR (F = 2.637, p

= .078), but no significant associations were observed between height and the haematological parameters. WBC by height show moderate effect sizes ($Eta^2 = 0.54$). Similarly, weight showed no significant effects on any of the studied parameters.

The data suggest that the intervention had limited significant effects across most parameters. While the 5000M showed a marked improvement, the haematological parameters and VO_{2max} remained largely unchanged. We found strong negative correlation (-0.71) between VO_{2max} and TT, Figure 4.

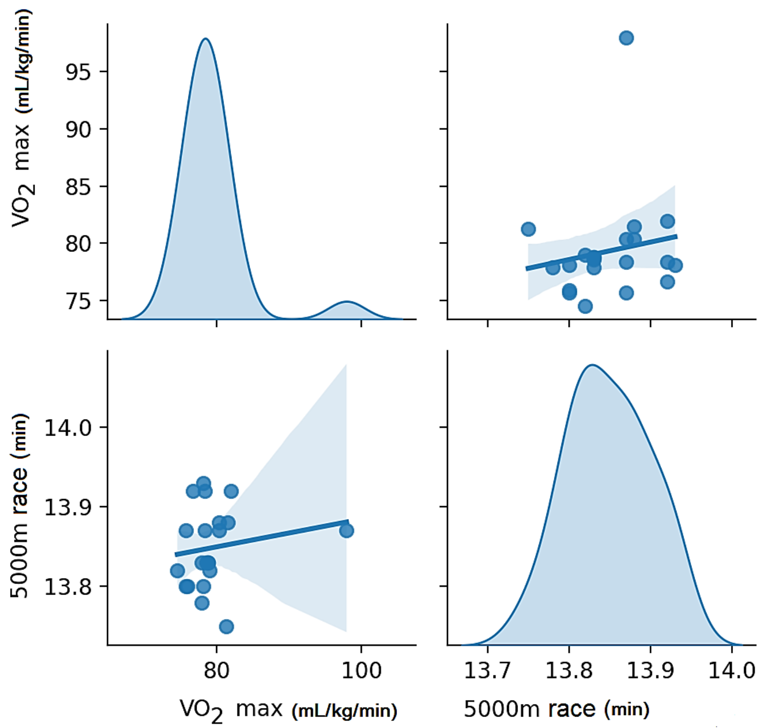

Figure 4. The relationships between key predictor.

DISCUSSION

The absence of significant change in RHR following the intervention aligns with findings from Thompson (Thompson, 2017), which reported that short-term exercise, particularly at moderate intensity, often does not alter RHR. This stability in RHR is consistent with our results, suggesting that the intervention had no significant impact on this variable.

The lack of significant change in VO_{2max} supports the observations of Sindall, who noted that improvements in VO_{2max} typically require longer training durations (Sindall, 2020). The short-term nature of this intervention was insufficient to produce a statistically significant difference in VO_{2max}, consistent with other finding (Saunders, Pyne, Telford, & Hawley, 2004).

The moderate R^2 (0.304) indicates that VO_{2max} is influenced by various factors, with the intervention showing a significant effect (p = .0096). Strong negative correlation between VO_{2max} and 5000M indicates better cardio fitness leads to faster times. This finding aligns with Sindall, who noted that VO_{2max} is a key predictor of long-distance performance (Sindall, 2020). However, the moderate R^2 suggests other factors, such as genetics or long-term adaptations, also play a role. The significant 5000M reduction in post-StT is in line with the study, which demonstrated that short-term interventions can improve distance running performance (Ives, Du, Etter, & Welch, 2005).

This result highlights the immediate performance benefits from the StT, reflecting enhanced running speed. The R^2 of 0.719 shows a strong predictive relationship between variables of pre-StT and TT. The significant treatment effect (p = .003) confirms the intervention's impact on performance. This aligns with similar study results (Das, 2013; Sindall, 2020), emphasized on the importance of VO_{2max} and aerobic capacity in long-distance running. The high R^2 (0.784) indicates a strong relationship between pre-StT variables and post-StT 400m speed test. The improvement in post-StT speed test, supported by comparable study (Raghuveer et al., 2020), highlights the role of both aerobic and anaerobic endurance in short-distance performance. Ethiopian MLDA' enhanced 400m speed is likely linked to improved cardiovascular fitness and training adaptations.

Age significantly influenced RBC post-StT, aligning with similar study that suggested age-related changes in haematopoiesis affect erythrocyte levels (Sheykhlouvand et al., 2018). However, no significant effects were observed for WBC, Hb, or Hct, consistent with study, which reported that these parameters are less sensitive to age (Bassett & Howley, 2000). The high R^2 (0.927) indicates that pre-intervention RBC levels strongly predict post-StT. However, the lack of significant change (p = .061) suggests that the intervention did not substantially affect RBC count, consistent with Mandić (2022) who found that significant changes in RBC often require longer training periods. Height showed marginal significance for RHR but no significant effect on RBC, WBC, Hb, or Hct, in line with the mixed findings in the literature. Some studies, suggest height influences cardiovascular metrics (Parmar, Jones, & Hayes, 2021), while others, show minimal direct effects (Rodríguez Zamora, 2013). The indirect influence of height, possibly mediated through body composition, is supported by (Liao et al., 2022; Tomschi et al., 2018). The R^2 of 0.892 reflects a strong relationship between pre- and post-StT WBC levels. The non-significant treatment effect (p = .218) is expected, as WBC counts are generally stable and less responsive to short-term endurance training (Nieman & Pence, 2020). Contrary to previous studies, weight did not significantly influence the haematological parameters (Sitkowski, Klusiewicz, Pokrywka, Jankowski, & Malczewska-Lenczowska, 2023). This discrepancy may be due to the lack of body fat percentage or distribution measurement, as highlighted by Nybo et al. (2010) which may better capture the relationship between weight and physiological outcomes. The stability of RBC and WBC measurements over time is supported by the previous findings (Koç, Özen, Abanoz, & Pulur, 2018), who reported minimal variation in these parameters after short-term exercise interventions.

The R^2 of 0.899 suggests that pre-StT Hb levels predict post-StT levels. The lack of significant treatment effect (p = .158) indicates that short-term interventions may not significantly alter Hb levels, consistent with similar works, who noted that Hb changes require longer training periods (Mandić, 2022; Wang et al., 2017). The R^2 of 0.894 indicates a strong relationship between pre-StT and post-StT Hct levels. The non-significant treatment effect (p = .061) suggests that short-term interventions may not substantially alter Hct, consistent with RBC and Hb findings.

CONCLUSION

This study underscores the impact of strength training (StT) on running performance, evidenced by significant improvements in 5000m run time and 400m speed, among elite male MLDA. The StT led to measurable improvements in running performance, its effects on physiological measures like RHR and Maximal oxygen consumption (VO_{2max}) were not statistically significant. Additionally, the intervention did not result in significant changes in haematological markers such as RBC, WBC, and Hb, likely due to the relatively short duration of the study.

The study suggests that while StT is effective in enhancing athletic performance, longer interventions may be necessary to elicit significant haematological adaptations. Short-term exercise can improve performance metrics while maintaining stability in physiological measures such as RHR and VO_{2max}. This study highlights the importance of baseline measures in determining exercise-related changes and supports the focus on pre-exercise blood metrics for predicting post-StT outcomes.

Future research should explore additional factors such as body composition and long-term training effects to provide a comprehensive understanding of the relationships. Moreover, studies should focus on extended training periods and incorporate a larger sample size to further investigate the long-term effects of StT on both performance and haematological parameters in elite runners.

AUTHOR CONTRIBUTIONS

Nigatu Worku conceptualized the study, conducted the literature review, designed the experiment, performed measurements and data analysis, and drafted the original manuscript. Aschenaki Taddese and Zeru Bekele contributed to the experimental design, provided supervision, assisted with visualization, and conducted the final review. All authors have read and agreed to the published version of the manuscript.

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DISCLOSURE STATEMENT

No potential conflict of interest was reported by the authors. The experiments comply with the current laws of the country in which they were performed. The authors state that the manuscript is honest, truthful, and transparent, that no key aspects of the investigation have been omitted, and that any differences from the study as planned have been clarified. This study followed all writing ethics.

INSTITUTIONAL REVIEW BOARD STATEMENT

The Ethical Committee of the Addis Ababa University, Ethiopia has granted approval for this study on 07 January 2023.

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