

# Effects of Altitude training on Ethiopian endurance athletes recovery heart rate and hematological variables

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## Abstract

**Background and Study Aim** A recent study indicates that Ethiopian middle- and long-distance athletes originate from diverse geographical regions, including areas of varying elevation. This study aimed to analyze the impact of altitude training on hematological parameters and recovery heart rates among young male endurance trainees training at sites located at different altitude levels.

**Material and Methods** The study employed a quasi-experimental, counterbalanced approach involving 15 male trainees. Five individuals from each training center experienced the standard training program across three distinct geographical locations and elevations. Pre- and post-test data were collected on red blood cells, hemoglobin, hematocrit, platelet count, and recovery heart rate before and after six months, from 6:00–8:00 AM. ANCOVA was utilized to analyze the data.

**Results** Following the intervention, the mean Red Blood Cell (RBC) count was observed to be higher in trainees from low altitude ( $5.18 \pm 0.33$ ) compared to those from moderate altitude ( $4.48 \pm 0.14$  and  $5.21 \pm 0.22$ ), with a significance level of  $p < 0.05$ . The mean Hemoglobin (HGB) count was found to be higher in moderate altitude trainees ( $17.00 \pm 0.70$  and  $16.31 \pm 0.65$ ) than in low altitude trainees ( $15.82 \pm 1.37$ ), although this difference was not statistically significant ( $p > 0.05$ ). Similarly, the mean Hematocrit (HCT) count was low for both low altitude ( $46.04 \pm 3.49$ ) and moderate altitude trainees ( $46.46 \pm 3.9$  and  $45.42 \pm 1.54$ ), with no significant difference noted ( $p > 0.05$ ). The mean Platelet (PLT) count was  $226.8 \pm 75.88$  for low altitude trainees and  $265.8 \pm 23.18$ ,  $276 \pm 53.96$  for moderate altitude trainees, with no significant difference between the groups ( $p > 0.05$ ). As for the recovery heart rate, mean values showed no significant difference between the pre- and post-test groups. In the pretest, the mean recovery heart rate was  $30.00 \pm 14.70$  for low-altitude trainees and  $43.20 \pm 8.90$ ,  $43.20 \pm 13.68$  for moderate-altitude trainees ( $p > 0.05$ ). In the post-test, the mean recovery heart rate was  $25.20 \pm 7.82$  for low-altitude trainees and  $32.40 \pm 10.04$ ,  $36.00 \pm 7.35$  for moderate-altitude trainees ( $p > 0.05$ ).

**Conclusions** The findings indicate that training at different altitudes impacts the hematological and cardiovascular systems of endurance athletes in varied ways. This underscores the importance of developing tailored training programs to optimize performance and recovery. These results are particularly relevant for coaches and athletes seeking to enhance endurance training outcomes through altitude training strategies.

**Keywords:** altitude training, red blood cell, Hemoglobin, hematocrit, recovery heart rate

## Introduction

The 1968 Summer Olympics were held in Mexico City at an altitude of approximately 2300 meters. This event sparked an interest in altitude and altitude training that persists today [1]. During the 1968 Olympics, the completion speed of endurance races was notably slower than usual, but records were

broken in sprint-oriented games [2]. Before the 1968 Olympics, training at moderate to high altitudes was not considered a significant factor in enhancing athletic performance or competition [1, 3]. However, subsequent research has demonstrated that the 1968 Olympic Games and the 1970 FIFA World Cup, hosted in Mexico City, prompted athletes to train at 2,300 meters above sea level [4, 5]. The inception of this initiative marked a significant turning point in the history of sports by paving the way for establishing

international standards for sporting events. Specifically, elevation limits were set to below 3,500 meters [1], a crucial development that has enabled athletes and coaches to recognize and embrace the benefits of high-altitude training. By optimizing their performance through this approach, athletes can gain a competitive advantage in the world of sports. This milestone has profoundly impacted the athletic community and helped establish a new era of excellence in sports.

Athletes have various ways to train and improve their physical fitness [1, 6] and have suggested combining various hypoxic training techniques, including intermittent hypoxic training, live low train high, live high-train low, and live high-train high approaches [6, 7, 8]. Endurance athletes use these methods to adapt better and improve their sea-level performance [6,7,9]. These methods also help improve hematological variables [8, 10, 11]. The optimal altitude range for these methods is between 1800 to 2700m and 2000 to 3000 meters above sea level and 1800 to 2,700masl [8, 12], respectively. Endurance running is a sport dominated by East African athletes, especially those from the middle and long-distance disciplines [13]. Depending on the length and duration of the endurance training, several elements, including hematological, environmental, sociological, psychological, physiological, anthropometrical, genetic endowment, inspiration, and training features, might affect endurance running performance [13, 14, 15, 16, 17, 18, 19]. Successful endurance runners share several traits, including a metabolic solid economy, a traditional diet, altitude training, and lifestyle, favorable skeletal-muscle-fiber composition, an oxidative enzyme profile, high maximum oxygen uptake, relatively high Hct and Hgb, and a drive for financial success [16, 20, 21, 22, 23].

Scheinfeldt et al. discovered that Ethiopian highlanders had different genes and genetic variants that contribute to adaption than those from other high-altitude places [24]. The Ethiopian runners tend to have a mesomorphic somatotype, demonstrate exceptional physiological economy, and appear independently through convergent evolution due to the strong selectivity of hypoxia, which is a potential factor contributing to their success [23, 25]. The elevation of several places in Ethiopia ranges from 1500 to 4550 meters, and the population is highly concentrated in plateau areas, especially at icy and moderate altitudes [26]. About 80% of the population mainly inhabits the highlands, where the athletes emerge from specific altitude areas, and the population is mainly from Arsi and Shewa or the central part of the country [23]. Depending on the subjective responses of these athletes, endurance training is carried out relatively at high altitudes.

Although many Ethiopians live in high altitudes, athletes grow at a precise area of altitude and population, mainly from Arsi and Shewa or the central part of the country [17, 23]. A recent study shows that Ethiopian middle- and long-distance athletes come from more than one geographical location or elevation [27]. However, the research investigation assessment focused only on live-high train-high approaches [11, 28] within the framework of Ethiopian athletics. As far as we know, no study has compared Ethiopian athletics training center trainees' hematological and recovery heart rate variables at a project level in moderate-train and low-train settings. Therefore, this study aimed to compare the hematological and recovery heart rate variables of Bekoji and Hagereselam from moderate altitude and Jinka athletics training center from low altitude. We hypothesized a significant difference between moderate and low-altitude trainees on selected hematological and recovery heart rates between Jinka, Bekoji, and H/selam athletics training centers of long-distance trainees.

This study aimed to compare the hematological parameters and recovery heart rates of athletes training at Bekoji and Hagereselam (moderate altitude) and the Jinka athletics training center (low altitude). We hypothesized significant differences in selected hematological parameters and recovery heart rates among long-distance trainees from Jinka, Bekoji, and Hagereselam training centers due to the varying altitudes.

## Materials and Methods

### *Participants*

The study involved 15 young male long-distance trainees, with five participants from each of the following training centers: Jinka, Bekoji, and Hagereselam.

### *Ethical Approval and Consent to Participate*

This study involves human participants and the study was reviewed and approved by the College of Natural and Computational Sciences Institutional Review Board (CNS-IRB) of Addis Ababa University with reference number CNCSDO/669/14/2022 dated June 02/2022. Informed consent was obtained from the parents or legal guardians of each participant.

### *Study Design*

The study was conducted in the South Ethiopia Region, which has Jinka athletics training center; the Sidama Region, which has Hagereselam athletics training center; and the Oromia Region, which has Bekoji athletics training center. The Jinka Athletics Training Center is in Jinka, a town in Southern Ethiopia. It is situated at a low altitude in the capital city of South Omo region [29] and is 1383masl. The Bekoji Training Center can be found in the Arsi Zone Oromia Region, 159 kilometers from Addis Ababa,

and at a moderate altitude of 2810 masl [17]. The Hagereselam training center is located in the Sidama Region, 284 km South of Addis Ababa, with an altitude of 2759 masl [30, 31]. A comparative quasi-experimental, particularly counterbalanced design [32] was employed to compare the hematological and recovery heart rate quantities of moderate-altitude and low-altitude trainees.

#### Procedures

The study data was taken twice: once at the start of the training period and again six months later, or by the end of the winter training session when athletes were starting to taper or ready for their final annual internal competition seasons, which EAF organized. All measurements and estimations of individuals' hematological and recovery heart rate variables were held during early morning sessions from 6:00–8:00 AM in their respective training centers to minimize variations. Recovery heart rate was measured using the portable FT1; Polar Heart Rate Monitor Kemple, Finland, and it was recorded after a submaximal 3-minute step test on the bench of 30 cm height for three minutes at the rate of 96 steps per minute [33]. The first minute's pulse rate immediately after stopping the step test was recorded as the recovery heart rate [34]. Blood was drawn under the guidelines provided by [35]. Before sampling, participants were allowed to sit for fifteen minutes. A tourniquet was applied, the area was cleaned, and then 5 ml of venous blood was extracted using a syringe from the ulnar vein of the non-dominant hand. Using a hematology analyzer (DIRUI BCC-3000B; China), the drawn blood was placed into a vacuum tube containing EDTA to measure the concentration of RBC, HGB, HCT, and PLT. The blood samples of Jinka trainees were transported to Jinka General Hospital Jinka Town, the Hagereselam trainees to Hula Primary Hospital

Hagereselam Town, and the Bekoji trainees to Bekoji General Hospital Bekoji Town.

Table 1 represents the weekly training schedule based on the FITT principle. The training was twice a day, five days a week. The training intensity was between 50 and 74% in each training center. Each session lasted at least 60 minutes and a maximum of 120 minutes. The type of training was endurance-based in all training centers. Hence, the frequency, intensity, time, and type of training were almost similar in all training centers.

#### Statistical Analysis

The Pearson normality test was used to determine whether all data were normal. For continuous and categorical variables, descriptive statistics were stated as mean ( $\bar{X}$ )  $\pm$  standard deviation (SD) and frequency (percentage), respectively. Statistical analysis was conducted using the software SPSS version 26.0 to examine how altitude affects recovery heart rate and hematological markers. The analysis included an analysis of covariance (ANCOVA) with LSD adjusted post hoc to evaluate the similarity of variance, source of variance, sum of squares, degree of freedom, mean sum of squares, and F-ratio. Any variable with a p-value of less than 0.05 was considered statistically significant.

### Results

Table 2 presents the participants' mean age, height, weight, and BMI.

Table 3 compares the hematological parameters, including RBC, HGB, HCT, and PLT counts, and the recovery heart rate between low and moderate-altitude trainees. In the pretest, there were no significant differences observed in mean RBC count between low-altitude trainees and moderate-altitude trainees ( $p > 0.05$ ). However, the mean HGB count was higher in moderate altitude trainees than

**Table 1.** Comparison of the FITT principles and their application between Jinka (low altitude) and Hagereselam and Bekoji (moderate altitude) training center

Variables	Jinka	Hagereselam	Bekoji
Frequency	2*/day 5days/week	2*/day 5days/week	2*/day 5days/week
Maximum Heart rate	50-74%	50-74%	50-74%
Time	60'-120'	70'-110'	70'-120'
Type	Endurance type	Endurance type	Endurance type

**Table 2.** Demographic characteristics between low-altitude and moderate-altitude trainees

Variables	Jinka		Hagereselam		Bekoji	
	Mean	St.Dev	Mean	St.Dev	Mean	St.Dev
Age	17.8	0.44	18.4	0.89	17.8	0.44
Height	162.4	11.11	170.2	6.72	166.4	6.54
Weight	58.4	8.14	60.2	4.20	59	4.24
BMI	19.87	0.57	20.11	0.39	19.91	0.75

**Table 3.** One-way ANOVA result for the comparison of RBC, Hgb, Hct, platelet count, and RHR between study groups

Variables	Jinka			Hagereselam			Bekoji			P-value	
	Pretest (Mean ± SD)	Post-test Mean ± SD)	p-value	Pretest Mean ± SD)	Post-test Mean ± SD)	p-value	Pretest Mean ± SD)	Post-test Mean ± SD)	p-value	Pretest	Post-test
RBC in (x10 <sup>6</sup> / μL)	5.08±.25	5.18±.33	.267	4.47±.6	4.48±.14	.972	4.99±.25	5.21±.22	.002	.074	.001
HGB in g/dL	13.88±1.14	15.82±1.37	.002	17.4±1.51	17±.7	.648	15.82±.80	16.31±.65	.080	.002	.196
Hct (%)	44.14±2.63	46.04±3.49	.027	39.52±5.18	46.46±3.9	.118	44.26±2.26	45.42±1.54	.026	.100	.873
PLT in (x10 <sup>3</sup> / μL)	243.4±13.57	226.8±75.88	.618	236.4±12.93	265.8±23.18	.108	247.4±88.39	276±53.96	.194	.945	.365
RHR	30.00±14.70	25.20±7.82	.242	43.20±8.90	32.40±10.04	.009	43.20±13.68	36.00±7.35	.109	.206	.165

RBC: red blood cell count, HGB: hemoglobin count, HCT: hematocrit, PLT: platelet, RHR: Recovery heart rate

in low altitude trainees ( $p < 0.05$ ). The mean HCT count showed no significant difference between the groups ( $p > 0.05$ ). Likewise, the mean PLT count did not significantly differ between low-altitude and moderate-altitude trainees ( $p > 0.05$ ). In the post-test, the mean RBC count was higher in low-altitude trainees than in moderate-altitude trainees ( $p < 0.05$ ). The mean HGB count was higher in moderate altitude trainees than low altitude trainees, but no significant difference was found ( $p > 0.05$ ). The mean HCT count did not significantly differ between the groups ( $p > 0.05$ ). Similarly, the mean PLT count did not significantly differ between low-altitude and moderate-altitude trainees ( $p > 0.05$ ).

For the recovery heart rate, mean values showed no significant difference between the pre-and post-test groups. In the pretest, the recovery heart rate for low-altitude trainees and moderate-altitude trainees did not differ significantly ( $p > 0.05$ ). Similarly, in the post-test, there was no significant difference in the recovery heart rate between low-altitude and moderate-altitude trainees ( $p > 0.05$ ).

### Discussion

In this study, we sought to evaluate the effects of altitude training on hematological parameters and recovery heart rates among young male endurance athletes from Ethiopia, who adhered to a regular training regimen across three distinct locations and altitudes. Our findings revealed that athletes training at both low and moderate altitudes experienced an increase in mean red blood cell count post-training. This result aligns with previous research conducted on elite endurance athletes, including Swiss national team cross-country skiers participating in Live High-Train Low (LHTL) programs [36], well-trained competitive runners from collegiate track and cross-country teams in the USA Track and Field circuit [37], and

comparisons between athletes from the Guna Athletics Sports Club and the Ethiopian Youth Sports Academy [11].

However, junior Ethiopian long-distance athletes showed no significant change in red cell mass after participating in Live High-Train High (LH-TH) and Live High-Train Low (LH-TL) programs [28]. Similarly, studies on French international swimming competitors and US collegiate track and cross-country runners revealed no significant alterations in mean values of hematocrit (Ht) and hemoglobin (Hb) in response to training [38, 39]. Despite these varied results, a meta-analysis indicated that elite athletes undergoing hypoxic training experienced more significant enhancements in red cell mass compared to those training at sea level. Additionally, short-term intermittent hypobaric hypoxia significantly increased red cell mass in moderately to highly trained individuals [40, 41]. Overall, this study reinforces the concept that altitude training, particularly LH-TH, substantially benefits long-distance athletes' red blood cell mass compared to a live low train low (LL-TL) approach [8].

Our research further explores the influence of altitude training on hemoglobin mass, with a particular focus on the outcomes of live-high train-high (LH-TH), live-high train-low (LH-TL), and combined live-high train-high train-low (LH-TH-TL) protocols. Our findings revealed that trainees at moderate altitudes exhibited higher mean hemoglobin levels compared to those training at lower altitudes. This observation aligns with results from [37], where the Swiss national orienteering teams saw an increase in Hgb levels following LH-TL training. Similarly, extensive research involving Australian endurance cyclists [43, 44], competitive cyclists [45], well-trained female cyclists [46], and Tokyo-based long- and middle-distance runners

[47], has consistently shown an enhancement in the hemoglobin mass of endurance athletes following LH-TL training.

Our results corroborate those of previous research, which has identified increased hemoglobin concentrations in highly-trained biathletes [10] and US endurance athletes [48], as well as among highly trained cyclists following altitude training [49]. Supporting these observations, a meta-analysis by [40] revealed that elite athletes training under hypoxic conditions at altitude showed more significant improvements in hemoglobin levels compared to those training at sea level, aligning with our findings. Contrarily, our study diverges from the results presented by [50], where no enhancements in hemoglobin levels were noted in trained athletes after altitude exposure. In contrast, studies by [51, 52] on live-high train-low protocols indicated hemoglobin mass increases even among well-trained athletes, a finding echoed by [53] in their investigation of elite or well-trained male and female distance runners undergoing LHTH training, which resulted in increased hemoglobin mass. Our study lends further support to the effectiveness of altitude training, particularly live-high train-low (LH-TL) and live-high train-high (LH-TH), in augmenting red blood cell mass in long-distance athletes.

The results of our study demonstrate an increase in hematocrit (Hct) levels among athletes training at both altitude and low/moderate altitudes. This enhancement in Hct count aligns with the findings of previous research [46, 47], which observed that elite endurance runners and cyclists, residing or training at altitude, exhibit elevated Hct counts. Furthermore, a meta-analysis by [40] revealed that elite athletes training at altitude could significantly improve their Hct levels compared to their sea-level counterparts, a conclusion that mirrors our observations. Chen et al. (2014), along with studies on male long-distance track and field athletes [54], highly-trained biathletes [10], intermittent hypoxic trainees [50], and the application of the live-high train-low (LH-TL) strategy in competitive off-road cyclists, have reported findings similar to ours, further validating the beneficial effects of altitude training on hematocrit levels.

Our research focused on investigating the impact of live-high train-high (LH-TH) altitude exposure on hematocrit (Hct) counts in elite distance runners [52]. We discovered that this specific altitude exposure significantly increased the Hct count. However, our results diverge from those reported by [55], where moderate altitude training sessions, or living and training at moderate altitudes, did not alter the hematocrit levels in male cyclists at the elite level. This discrepancy is further echoed by findings from a study on Ethiopian endurance runners engaged in LH-TH and live-high train-high train-low (LH-

THTL) programs, which indicated no significant hematocrit differences between experimental and control groups [28]. Conversely, our findings align with those of [48], which demonstrated a significant correlation in hematocrit levels between athletes training at lowland and those at high altitude, particularly among high-class long-distance cyclists with innate high-altitude training.

The results of our study indicate that trainees at moderate altitudes exhibit higher platelet counts compared to those training at lower altitudes. This observation is in line with findings from a previous study [56], which investigated the effects of altitude on platelet count among healthy, sports-engaged volunteers and reported an increase in platelet counts. Similarly, research conducted on young, healthy Bolivian airmen [57] found that short-term exposure to high altitude (just 48 hours) led to an increase in platelet count. Additionally, a study on healthy male volunteers [57] observed that strenuous exercise resulted in increased platelet aggregation, a result that mirrors our own. Exercise's effect on platelet activation was further supported by findings [58] that suggest training and exercise status influence platelet activation, with active individuals showing higher total platelet counts than their sedentary counterparts. Subsequent studies [59, 60, 61, 62] have consistently shown that physical activity can positively impact platelet function or counts. Despite these correlations, to date, no research has specifically demonstrated that altitude training variations for long-distance runners can enhance the athletes' platelet count, marking a notable area for future investigation.

The current study also investigated the mean recovery heart rate among trainees at low and moderate altitudes, finding that individuals in the low-altitude group exhibited a quicker recovery rate. This aligns with findings from previous studies involving well-trained male cyclists undergoing high-intensity training, physically active individuals across varying training intensities, and endurance athletes [63, 64, 65]. Additional research confirms that well-trained endurance athletes display more rapid heart rate recovery [66], and similar improvements in exercise capacity have been observed among recreational runners, physically active adults, and first-division soccer players [65, 67]. Moreover, studies focusing on young, healthy male soccer players [68], well-trained male basketball players [69], and participants engaging in maximal aerobic power exercises [70] have all demonstrated that aerobic training can significantly enhance the performance and recovery heart rate of endurance athletes, including elite cyclists.

In summary, the observed improvements in both hematological parameters and recovery heart rate among the athletes at the training centers

may be attributed to the unique characteristics of Ethiopian distance runners. These include genetic predispositions, a mesomorphic body type, and an outstanding physiological efficiency, which collectively contribute to their exceptional athletic performance.

## Conclusions

Based on the empirical evidence gathered, this study concludes that endurance athletes undergoing training regimens at both low (live-low train-low) and moderate (live moderate-train-moderate) altitudes exhibit statistically significant enhancements in hematological indices and recovery heart rate. The observed similarity in training intensity, frequency, duration, and type across both groups underscores the effectiveness of these training strategies. This research highlights the capability of both low and moderate altitude training to improve athletic performance and accelerate recovery, suggesting their valuable application in endurance sports training.

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## Conflict of interests

The authors have declared no conflicts of interest.

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