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The effect of altitude training on physiological variables of endurance athletes in Ethiopia

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Abstract.

Purpose. Moderate-altitude training is widely accepted to enhance sports performance, particularly for endurance athletes, more than low-altitude training despite the lack of rigorous scientific studies at a project level in Ethiopia. This study aims to identify the effect of varied altitude training on physiological variables at varied altitudes in young project trainees in Ethiopia.

Material and methods: A quasi-experimental, particularly counterbalanced study design was employed using 15 male endurance project trainees, 5 individuals from each training center whose ages ranged from 16 to 20 years. Pre and posttests on Vo_{2max}, heart rate at rest, breath holding time, systolic blood pressure, and mean arterial pressure were made in early morning sessions in their training centers using standardized instruments from 6:00 -8:00 AM.

Results: The moderate-altitude trainees had better mean scores in $Vo_{2max,}$ systolic blood pressure, and breath-holding capacity, but in resting heart rate and mean arterial pressure, the low-altitude trainees were better than the moderate-altitude trainees. However, all training centers showed an improvement in mean score difference, but the result indicates no significant difference (P>0.05) between the moderate and low-altitude project training trainees.

Conclusion: The results show that training at various altitudes has distinct effects on endurance athletes' Vo_{2max}, systolic blood pressure, breath-holding capacity, resting heart rate, and mean arterial pressure. This emphasizes how crucial it is to create customized training plans to maximize output and recuperation. These findings are significant for athletes and coaches who want to use altitude training techniques to improve endurance training results.

Keywords: Vo_{2max}, resting heart rate, breath holding time, systolic blood pressure, mean arterial pressure.

Introduction

Altitude training has been developed to improve endurance at sea level and high altitude (Levine & Stray-Gundersen, 1997; Levine, 2002; Rusko et al., 2004; Wehrlin et al., 2006). Due to the success of African high-land athletes, mainly middle and long-distance runners, some countries have become interested in utilizing altitude training in various environments to gain additional physiological, hematological, and cardiovascular benefits. This exposure aims to enhance athletes' responses to training and promote adaptation (Mirrakhimov & Winslow, 1996; Hamlin et al., 2013). Studying human performance at altitude can provide advantages for competitions at sea level and may induce physiological stress in the body, while heat training can enhance performance in more relaxed environments (Saunders et al., 2009; Maiyanga et al., 2017; Saunders et al., 2019).

The studies have shown that training at moderate to high altitudes before the 1968 Mexico City Olympic Games did not significantly improve subsequent athletic performance (Bärtsch & Saltin, 2008). However, experts have cited sports competitions held at altitudes above 2,000 m, such as the 1968 Olympic Games and the 1970 World Cup in Mexico City at 2240 m, as evidence of the potential benefits of altitude training for improving athletic performance (Campos & Costa, 1999; Bärtsch & Saltin, 2008; Stray-Gundersen & Levine, 2008; Vargas, 2014). Altitude training has become increasingly popular in recent decades, with ongoing efforts to develop the most effective training programs for athletes (Garvican-lewis et al., 2013; McLean et al., 2013). Furthermore, studies have investigated the success of athletes from high-altitude regions, leading to growing interest in the effects of living and training in such areas to enhance athletic performance (Whyte, 2006).

The Torrid Zone, situated near the equator, faces hotter and more physically demanding conditions than the temperate or freezing zones. Approximately half of the world's population resides in this area (Harding, 2011). Consequently, many major athletic events are now scheduled to occur in locations situated at elevations of 1000-2000m above sea level, which experience hot and humid environments. Some of these notable competitions include the Olympic Games in Atlanta 1996 (Montain et al., 1996), Athens 2004, Beijing 2008 (Huijuan et al., 2013), the IAAF World Cross Country Championships in 2015 in Guiyang, China (elevated 1,275m), the 2017 event in Kampala, Uganda (elevated 1,210m), the 2019 IAAF World Athletics Championships in Doha, Qatar, the 2020 Olympic Games in Tokyo, Japan (Carr et al., 2022; Saunders et al., 2019), and the FIFA World Cup in Qatar 2022 (Chodor et al., 2021). These competitions are expected to have the highest hotness index in the history of those respective events, as they are near or below sea level and organized by international bodies.

Athletes who are not accustomed to the hot and humid weather of the Torrid Zone may need to prepare for heat-related conditions before competing in the region. Many sporting events are scheduled in hot and muggy weather, and athletes must acclimate for 10–14 days (Sawka, 2011). Heat acclimatization affects perspiration rate, pulse rate, skin and rectal temperature, and work capacity. These adjustments occur more rapidly in the first week and gradually in the following two weeks of heat acclimatization (Robinson et al., 1943; Ladell, 1951; Flouris et al., 2014). Highly skilled athletes develop these adjustments twice as quickly as untrained individuals (Pandolf et al., 1977). While even a few days of heat acclimatization can benefit athletes (Sunderland et al., 2008; Garrett et al., 2011; Chalmers et al., 2014), it can take six to ten days to achieve almost complete sudomotor and cardiovascular adjustments (Nielsen et al., 1993; Lorenzo et al., 2010; Karlsen et al., 2015). Consequently, it takes two weeks to enhance aerobic capacity in warm ambient settings.

According to Wishnizer et al. (2013), elite athletes' physiological characteristics and capabilities result from rigorous physical training and genetic predisposition (Scott et al., 2005; Ruiz et al., 2009). While these physiological factors are significant predictors of athletic success, it is essential to recognize that biomechanical, psychological, tactical, nutritional, and environmental factors may also impact performance. Success in athletics also encompasses factors such as traditional diet, living and exercising at altitude, oxidative enzyme profile, high maximum oxygen absorption development, good metabolic economy, and the drive to succeed financially (Wilber & Pitsiladis, 2012). Additionally, improvement in resting heart rate (Divya, 2017), heart rate recovery (Álvarez-Herms et al., 2012; Botonis et al., 2020), breath holding time (Bagavad et al., 2014; Lone & Hurah, 2018), mean arterial pressure, (Cornelissen & Smart, 2013; Muthuraj, 2017) and systolic blood pressure are also essential factors (Wishnizer et al., 2013).

Most Ethiopians reside in the plateau areas, particularly in icy and moderate altitudes. The lowlands have a sparse population. However, the dominance of Ethiopian long-distance runners has been challenged in recent international competitions, such as the 2020 Tokyo Olympics and the 2023 Hungary Budapest World Athletics Championship, which took place at low altitudes. This is attributed to the athletes' training in high altitudes and the temperature difference. As a result, there is a need to consider modifying the training zones to address this issue. The Ethiopian population is highly concentrated in the plateau areas, especially at icy and moderate altitudes, but only some are alive in the lowlands and are sparsely populated [50]. However, due to the majority of Ethiopian athletes training and their background at high altitudes and the most recent international competition organized at low altitudes, Ethiopia started to lose the dominant power of its long-distance winning capacity by other nations in the 2020 Tokyo Olympics and 2023 Hungary Budapest World Athletics championship due to its temperature. So, the training zone needs to be modified.

Materials and methods

Study setting

The study was conducted in the following regions: Bekoji Athletics Training Center in Oromia, Hagereselam Athletics Training Center in the Sidama Region, and Jinka Athletics Training Center in the South Ethiopia Region. The Jinka Athletics Training Center is situated in Jinka, the capital city of South Omo in Southern Ethiopia, at a low altitude of 1383 miles (Mesfin et al., 2017). The Bekoji Training Center is located in the Arsi Zone Oromia Region at a modest elevation of 2810masl (Assefa & Getachew, 2015). The Hagereselam training center is also situated at 2759 meters above sea level in the Sidama Region (Kiflu et al., 2016; Seyoum, 2015). It was conducted with 15 male long-distance trainees from Jinka, Bekoji, and Hagereselam and five individuals from each training center. Before starting the research, each member provided written, fully informed consent and was free to terminate the involvement.

Study design and training protocol

A counterbalanced comparative quasi-experimental design (Sarkies et al., 2019) was employed to compare the physiological variables of moderate-altitude and low-altitude trainees. Table 1 represents the weekly training plan based on the FITT principle. It shows five days a week, twice a day. In every training center, the training intensity ranged from 50 to 74%. Each session had a minimum of 60 and 120 training minutes. Every training center used an endurance-based training approach. As a result, all training centers offered nearly identical frequency, intensity, time, and type of training.

Table 1. Comparison of the FITT principles and their application between low-altitude and high-altitude training center

Variables	Jinka	Hgereselam	Bekoji
Frequency	2*/day 5days/week	2*/day 5days/week	2*/day 5days/week
Intensity	50-74%	50-74%	50-74%
Time	60’-120’	70’-110’	70’-120
Type	Endurance type	Endurance type	Endurance type

Procedures

The study data was collected twice, at the beginning of the training season and after six months or by the end of the training season when athletes were starting to taper or ready for their final annual internal competition seasons, which EAF organized. All measurements and estimations of the physiological parameters of individuals were held during early morning sessions from 6:00–8:00 AM in their respective training centers to minimize any dissimilarities. So, the $Vo_{2\ max}$ was estimated using a maximum exercise test using a 20-meter multistage shuttle run test, known as the beep test measures cardiorespiratory endurance. It is an accurate system to estimate $Vo_{2\ max}$ in young adults with (r = 0.9). It was taken at 8.5 km/ hr (level-1) and increased by 0.5km/hr at each level. The calculator appears to be accurate within 0.1 ml/kg/min of values. The result gained was calculated through an online beep test calculator (BTC) based on the number of shuttles that reached the individual level (Kaya, 2016). A portable FT1 Polar Heart Rate Monitor from Kemple, Finland, assessed the subjects' resting heart rates. The heart rate was measured after 15 minutes of resting in the supine position (Manadhar et al., 2021). Systolic and mean arterial blood pressure was measured by a sphygmomanometer (accutracker II automatic noninvasive ambulatory BP monitor Suntech Medical Instrument, Inc). The procedures were applied when the person relaxed, sat on the chair with feet flat on the floor, back supported, and was quiet for 5 min. and have an empty bladder, avoid exercise before the test, and remove clothing from their arm. After 3 successive measurements agreed within 5 mmHg of auscultatory values (Syme et al., 2006; Kaya, 2016). Nose clippers measured breath-holding time. The participants were instructed to seal their lips and nose, avoid taking more breaths, and hold their breath for as long as possible using a nasal clip (Shingai & Kanezaki, 2014; Kerti et al., 2018). The study was 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 and was carried out under the Declaration of Helsinki.

Statistical analysis

The Pearson normality test was utilized to assess the data's normal distribution. Descriptive statistics represented continuous variables as mean ($\bar{x}$) ± standard deviation (SD) and categorical variables as frequency (percentage). Using the Statistical Package for Social Sciences (SPSS) version 26.0, an analysis of covariance (ANCOVA) with LSD adjusted post hoc was conducted to evaluate the impact of altitude on physiological parameters. A p-value of less than 0.05 determined statistical significance.

Results

To ascertain the average age, height, weight, and BMI of the participants, a demographic characteristic was explained in table 2.

Table 2. Demographic characteristics between low-altitude and high-altitude trainees

Variables	Jinka		Hgereselam		Bekoji	
	Mean	St.Dev	Mean	St.Dev	Mean	St.Dev
Age	17.8	0.44	18.4	0.89	17.8	0.44
Height	166.4	6.34	170.6	7.19	169.8	4.38
Weight	55.2	5.71	58.6	4.46	57.5	4.24
BMI	19.87	0.57	20.11	0.39	19.91	0.75

Table 3 displays Vo_{2max}, resting heart rate (RHR), breath holding time (BHT), systolic blood pressure (SBP), and mean arterial blood pressure (MAP) between study groups. The pretest mean in Vo2max was (46.52±3.30) in low and (48.26±6.40; 48.28±3.65) moderate altitude trainees, and the p-value was (P>0.05) and no significant difference. However, the posttest mean was (51.88±3.25) in low and (54.66±7.60; 56.08±4.99) in moderate altitude trainees, and it implies no significant difference mean while the p-value was (P>0.05). The low altitude trainees also had better Vo2max mean in pre- and posttest compared with moderate altitude trainees. The moderate altitude trainees had notably higher mean levels in resting heart rate (54.00±9.33, 60.20±9.01) than low altitude trainees (65.40±9.66) in the pretest. However, the p-value was P>0.05, with no significant difference. However, in the posttest, the mean was highly improved in low altitude (53.60±6.66) than in moderate altitude (63.60±10.62, 55.40±3.85), and no significant difference among them since the p-value was P>0.05.

The mean breath holding time in the pretest (32.89±5.65) was low (48.42±24.83; 30.30±9.55) in moderate altitude, and no significant differences were seen since the p-value was P>0.05. However, the posttest was low (56.30±13.45) and (71.07±32.56; 60.07±10.87) in moderate altitude trainees, but no significant difference was observed since the p-value was P>0.05**.** The pretest means systolic blood pressure in the study group of low altitude trainees was (127.80±5.93), and the moderate altitude trainees resulted (124.60±6.99; 121.60±7.96), and no significant difference was seen since the p-value was P>0.05. Meanwhile, the posttest result of the trainees in the study areas also indicated that (119.60±9.07) in low altitude (117.80±5.89; 108.40±10.60) and in moderate altitude trainees and no significant difference was detected since the p-value was P>0.05. The pretest mean arterial pressure was (88.86±4.98) in low and (87.16±4.73; 82.60±8.31) in moderate altitude trainees, and the p-value was (P>0.05) with no significant difference. However, the posttest mean was (94.40±9.45) in low and (94.00±4.95; 97.40±7.37) in moderate altitude trainees, and it implies no significant difference; meanwhile, the p-value was (P>0.05).

Table 3. One-way ANOVA result for the comparison of Vo_{2max}, RHR, BHC, SBP, and MAP between study groups

Variables	Jinka			Hagereselam			Bekoji			P-value	P-value
	Pretest	Posttest	p-value	Pretest	Posttest	p-value	Pretest	Posttest	p-value	Pretest	Posttest
Vo2max	46.52±3.30	51.88±3.25	.000	48.26±6.40	54.66±7.60	.001	48.28±3.65	56.08±4.99	.001	.794	.501
RHR	65.40±9.66	53.60±6.66	.112	54.00±9.33	63.60±10.62	.080	60.20±9.01	55.40±3.85	.138	.197	.126
BHC	32.89±5.65	56.30±13.45	.014	48.42±24.83	71.07±32.56	.003	30.30±9.55	60.07±10.87	.002	.185	.540
SBP	127.80±5.93	119.60±9.07	.133	124.60±6.99	117.80±5.89	.031	121.60±7.96	108.40±10.60	.018	.404	.136
MAP	88.86±4.98	94.40±9.45	.218	87.16±4.73	94.00±4.95	.053	82.60±8.31	97.40±7.37	.032	.295	.740

Vo_{2max} = maximal oxygen consumption, RHR = resting heart rate, BHC = breath holding time, SBP = systolic blood pressure, MAP = mean arterial blood pressure

Discussion

This study aims to compare the physiological parameters of Jinka's low-altitude trainees, who live and train between 500 and 1500 masl, and moderate-altitude trainees, Hagereselam and Bekoji, who live and train between 1500 and 3000 masl. The present result revealed that both low- and moderate-altitude trainees had an increase in mean Vo_{2max}. Our finding agrees with the result obtained by (Levine & Stray-Gundersen, 1997; Saunders et al., 2004; Wehrlin et al., 2006; and Saunders et al., 2013). The $VO_{2\ max}$ of endurance performance runners has increased significantly compared to LL-TL and LL-TH. Contrary to expectations, Jensen et al. (1993) found that the SL trainees demonstrated an increase while the LHTH group did not show improved $VO_{2\ max}$. However, other studies showed either LL-TL or LH-TH with no enhancement in $VO_{2\ max.}$ Additionally, Gore et al. (1998) and Schmidt et al. (2002) observed that male track cyclists at high altitudes and sea levels did not experience improved $VO_{2\ max}$ in their respective endurance groups. Similarly, Chen et al. (2014) found no differences in V_{O2max} between the experimental and placebo groups of male endurance track and field competitors.

Our result showed the resting heart rate of low altitude trainees and moderate mean improvement to moderate altitude trainees. Whatever the mean was improved, no significant difference was seen between the trainees. In line with our study (Czuba et al., 2018), the live high, train low approach on endurance training and sports performance in off-road cyclists under normoxia and intermittent hypoxic training, a meta-analysis by (Reimers et al., 2018) diverse kinds of sports or training in the training groups compared to the control group and a meta-analysis by (Huang et al., 2005) and (Cramer et al., 2014) endurance or aerobic exercise training, aerobics training, and yoga training are vital for decreasing the resting heart rate of the trainees. Whereas (Bhattarai et al., 2018) contradicted the LL-TL protocol in their study between highlanders and lowlanders by delivering submaximal exercise, the highlanders showed better-resting heart rates than the lowlanders.

This study showed no significant difference in the mean breath-holding capacity of trainees at low and moderate altitudes. This is similar to a study that showed by (Lone & Hurah, 2018) the effect of weight training (Santoshi, 2011) breathing exercises on school-going children and (Dasarathan, 2016) circuit trainees have produced an improvement in breath-holding time. Moreover, (Vishan & Mishra, 2017) revealed that breath-holding capacity was significantly impacted by Swiss ball training. The result on means systolic blood pressure in our study area showed that both low and moderate-altitude trainees improved, but no significant difference was seen between the trainees. In agreement with our study (Abergel et al., 2004) explores professional cyclists who participated in the Tour de France, a meta-analysis by (Cornelissen & Smart, 2013) endurance training, dynamic resistance training, and isometric resistance (Cornelissen & Smart, 2013) isometric handgrip training and isometric leg training of endurance athletes demonstrate lower resting systolic function. Similarly, endurance exercise training (Baggish et al., 2008), moderate exercise (Gerche et al., 2009), prolonged intense training for elite rowers (Mantziari et al., 2010), combined resistance and endurance training (Figueroa et al., 2011) decrease systolic blood pressure. In addition, a study by (Collier et al., 2008) on aerobic or resistance exercise training and a meta-analysis by (Kelley, 1997) on dynamic resistance training exercise reduced systolic blood pressure.

Our study revealed that the low and moderate-altitude trainees showed better improvement in posttest mean arterial blood pressure, but statistically, no significant difference was seen between the training groups. In line with our study (Muthuraj, 2017), strength and endurance training (Figueroa et al., 2011) was combined with resistance and endurance exercise training, and both studies showed an improvement in mean arterial pressure. Similarly, (Collier et al., 2008) aerobics and endurance exercise training and (Vedam et al., 2009) noted that acute and short-term exposure to normobaric hypoxia decreased the MAP of the participants.

Conclusion

In conclusion, this study suggests that endurance athletes who train at low (live-low train-low) and moderate (live moderate-train-moderate) altitudes show statistically significant improvements in physiological indicators based on the empirical evidence gathered. The efficacy of these training methods is highlighted by the similarities in training intensity, frequency, duration, and type that were seen amongst the groups. This might be due to the uniqueness of Ethiopian distance runners in genetic endowment, mesomorphic somatotype, and exceptional physiological economy. This study demonstrates how low- and moderate-altitude training can enhance an athlete's physiology and athletic performance, indicating a valuable application for these techniques in endurance sports training.

Authors' contributions

Conceptualization: Tesfaye Moges, D. Mathi Vanan, Dr. Mulay Gebretensay; Data curation: Tesfaye Moges, D. Mathi Vanan; Formal analysis: Tesfaye Moges, Mulay Gebretensay; Funding acquisition: Tesfaye Moges; Investigation: Tesfaye Moges; Methodology: Tesfaye Moges, D. Mathi Vanan, Mulay Gebretensay, Alemmebrat Kiflu, Efrem Kentiba; Project administration: Tesfaye Moges; Supervision: D. Mathi Vanan; Validation: D. Mathi Vanan, Mulay Gebretensay, Alemmebrat Kiflu, Efrem Kentiba; Visualization: Efrem Kentiba; Writing – original draft: Tesfaye Moges, Mulay Gebretensay; Writing – review & editing: Tesfaye Moges, D.Mathi Vanan, Mulay Gebretensay, Alemmebrat Kiflu, Efrem Kentiba.

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Conflict interests

The authors declare no competing interests.

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During this study, the co-author (TM) was an Exercise Physiology Ph.D. candidate at Mekelle University. Mekelle University, College of Natural and Computational Sciences, Mekelle, Ethiopia, supported the study.

Data access

Original data can be accessed upon reasonable request.

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