LONG DISTANCE RUNNING IN ETHIOPIAN ATHLETES: A SEARCH FOR OPTIMAL ALTITUDE TRAINING.

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DECLARATION

I, Mr Zeru BekeleTola, declare as follows:

1. That the work described in this thesis has not been submitted to UKZN or other tertiary institution for purposes of obtaining an academic qualification, whether by myself or any other party.
2. That my contribution to the project was:
   Principal investigator for all studies - developed proposal, conducted all testing, organized and interpreted all data, as well as wrote the whole thesis.
3. That the contributions of others to the project were as follows:
   Associate Professor Andrew James McKune:- Primary supervisor for all studies
   Dr Nenad Naumovski: - Co-supervisor for the nutrition study (Manuscript two)
   Dr Michal Botek: - Co-supervisor for the altitude study (Manuscripts three to seven)
   Dr JakubKrejčí (Professional statistician): – Assisted with analysis of all data from altitude study (Manuscripts three to seven)

Signed ______________________ Date August, 2018

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LIST OF ACRONYMS AND ABBREVIATIONS

µ	Microlitre
AAU	Addis Ababa University
ACE	Angiotensin Converting Enzyme
ACTN3	Alpha-actinin-3
ANS	Autonomic Nervous System
a.s.l.	above sea level
AU	Arbitrary Unit
$a\text{-}Vo_{2diff}$	Arteriovenous oxygen difference
BL	Baseline
BM	Body Mass
BMI	Body Mass Index
BMR	Basal Metabolic Rate
CA	Caucasian
CHO	Carbohydrate
CL	Confidence Limit
CMJ	Counter Movement Jump
CNCS	College of Natural and Computational Sciences
Con	Control
CR	Categorical Ratio
D	Day
DALD	Daily Analysis of Life Demands

DNA	Deoxyribonucleic Acid
EE	Energy Expenditure
EI	Energy Intake
ES	Effect Size
ET	Ethiopian
EUR	Eccentric Utilisation Ratio
Exp	Experimental
g	Grams
$g.dL^{-1}$	grams per decilitre
$g.kg^{-1}$	grams per kilogram
$g.L^{-1}$	grams per litre
GPS	Global Positioning System
Hct	Haematocrit
Hgb	Haemoglobin
HR	Heart Rate
HRR	Heart Rate Recovery
HRV	Heart Rate Variability
IAAF	International Association Athletics Federation
IHE	Intermittent Hypoxic Exposure
IHT	Intermittent Hypoxic Training
IOC	International Olympic Committee

kg	kilogram
$kg.m^{-2}$	kilogram per metre squared
KJ	kilojoule
Km/h	kilometre per hour
L	Litre
LH-TH	Live High Train High
LH-THTL	Live High Train High Train Low
LH-TL	Live High Train Low
LL-TH	Live Low Train High
LnRMSSD	Natural logarithm of root mean square of the successive differences
LTAD	Long Term Athlete Development
M	metre
MET	Metabolic Quotient
ms	microsecond
NFOR	Non- Functional Overreaching
PAL	Physical Activity Level
PAR	Physical Activity Ratio
PNN50	Proportion of difference between adjacent normal R-R intervals that are greater than 50
RBC	Red Blood Cell
RESTQ	Recovery Stress Questionnaire
RHR	Resting Heart Rate

RMSSD	Root Mean Square of the Successive Differences
RPE	Rating of Perceived Exertion
s	second
SB	Seasonal Best
SD	Standard Deviation
SDANN	Standard Deviation of Averaged NN
SDNN	Standard deviation of all normal R-R intervals
Session-RPE	Session Rating of Perceived Exertion
SJ	Squat Jump
SSC	Stretch - Shortening Cycle
SW	Seasonal Worst
tHgb	Total Haemoglobin mass
TL	Training Load
TLR	Training Load Responses
TQR	Total Quality Recovery
TRIMP	Training Impulse
UKZN	University of KwaZulu-Natal
$\dot{V}O_2$ Max	Maximum Oxygen Consumption
WADA	World Anti-Doping Agency

ABSTRACT

Background

The extended dominance of Ethiopian and Kenyan middle- and long- distance athletes in world athletics has resulted in researchers proposing numerous explanations to explain this success. Genetic predisposition, anthropometric, physiological, biochemical and biomechanical characteristics, environmental factors like living and training at high altitude, active lifestyles during childhood as well as nutritional practices, have all been major focus areas of past studies that involved east African endurance athletes. Of all the proposed variables, researchers have acknowledged the positive role of environmental factors in the success of these athletes. Despite the past attempts to investigate the major factors that contributed to the successes of east African athletes, to the best of the authors' knowledge, limited studies have addressed each of the proposed physiological and environmental variables in the Ethiopian athletes, compared with the number of studies conducted on Kenyan athletes**.**

Purpose

The primary purpose of this research was to test a natural altitude training model and examine whether it enhanced the long-distance performance of junior Ethiopian athletes. The research also examined a variety of environmental factors associated with these junior athletes that included daily distance travelled to and from school, mode of transport to and from school as well as physical activity patterns after school. These factors were compared between the junior athletes who participated in the altitude training study, current and retired World and Olympic level long-distance Ethiopian athletes. The energy intake, macronutrient breakdown and energy expenditure of the junior athletes during the altitude training camp were also analysed.

Methods

Demographic Characteristics Study*:* A total of 83 endurance runners were involved in this study. The athletes were classified into three separate groups based on their current performance status and age as retired elite (n = 32), current elite (n = 31) and academy junior athletes (n = 20). The average ages of the athletes in the three groups were 38±7.6, 25±4.5, and 18±1.2 years for retired elite, current elite and junior group athletes, respectively. The study primarily employed a

questionnaire survey design to gather the demographic characteristics of the athletes. Along with the questionnaire, the altitudes where the athletes were born and trained, as well as the home to school distance of the athletes were measured. Data were collected from the retired athletes through both self- and interviewer-administered questionnaires and forms. Self-administered questionnaires were used to collect data from the current elite and academy junior athletes. Only 46.8% of the retired elites (n=15) filled in the questionnaire and the rest 53.2% (n=17) of the retired elite athletes responded to the questionnaire via telephone. The home to school distance of 71.8% (n = 23) and 58.1% (n = 18) of retired and current elite athletes, respectively, was measured physically using a watch with Global Positioning System (Garmin forerunner, 910X).

Macronutrient Intake and Energy Balance Study*:* In this study, twenty (male = 16 and female = 4) junior long-distance athletes participated. The athletes were attending an eight-week training in the camp where they were living in and training in and around Tirunesh Dibaba National Athletics Training Centre (TDNATC) located at an altitude of 2500m (7°57′N latitude and 39°7′E longitude). The study used the three-day direct dietary record method. Nude body weight measurements were taken before and after the three assessment days.

All food measurements were carried out when the three meals were served: breakfast (8:00 – 9:00am), lunch (12:00 am – 1:00pm), and dinner (6:00 – 7:00pm). All the measurements were taken and recorded by the principal investigator, together with the head coach of the athletes, using a digital weighing scale readable to 1 gram (Salter Housewares LTD, England) and the dietary analysis of each individual athlete, including the total energy intake, and the energy contribution and gram values for carbohydrate, fat and protein from the consumed foods was performed using the nutritional software package Nutritics (v3.7, University Edition).

Training type, intensity and duration, as well as external load, including distance, time covered and speed of the training were recorded in a daily training diary over the three consecutive days. Total energy expenditure of each study participant was calculated from basal metabolic rate (BMR) using the Schofield equation (1985) and the physical activity ratio (PAR), and physical activity level (PAL).

Altitude Training Study: A total of 20 (male = 16 and female = 4) junior long distance athletes lived and trained in and around the Athletes Tirunesh Dibaba National Athletics Training Centre were recruited for the study. The study applied the balanced, randomised, experimental design. Before the athletes were randomly assigned to the live high - train high (LH-TH) control (n = 10) and live high - train high train low (LH-THTL) experimental (n = 10) groups, they were tested on a 5km track race at baseline (end of four pre-experimental weeks) and then assigned equally into the two groups based on their 5km performance (time) and gender. The study lasted for a continuous eight weeks where all the athletes lived in every day of the week, and trained light and moderate intensity sessions at an altitude of 2500m a.s.l. four times per week. In addition, the LH-TH and LH-THTL groups trained separately at 2500m and 1470m a.s.l. in high intensity sessions two days per week, respectively. During the study time, different haematological, autonomic, neuromuscular, subjective training monitor and five kilometre performance time trial tests were conducted.

Resting haematological tests were conducted three times (baseline, week four and week eight). Sample blood was drawn from a cubital vein under standard conditions (off-training days, between 08:30 and 09:30 a.m. before breakfast and after a 10 minute rest period in a sitting position) in the haematology laboratory of the College of Health Sciences of Arsi University, Ethiopia at the specified time for complete blood count (CBC) analysis. Like the haematological tests, three consecutive vagal related heart rate measurements (heart rate variability and one- and two-minute heart rate recovery measurements) were taken at baseline, week 4 and week 8. The heart rate variability measurements were taken early in the morning, before the athletes left for training, in their bedrooms (before leaving their beds). The one- and two-minute heart rate recovery tests were taken as soon as the three 5km time trials were completed at baseline, week 4 and week 8. Along with the CBC and vagal-related heart rate measurements, five consecutive neuromuscular fitness tests (at baseline, week 2, week 4, week 6 and week 8) using the common vertical jump tests (counter movement (CMJ) and squat jump (SJ) test) were conducted after 10 hours of light intensity training. For a total of 47 training sessions, subjective training load responses were collected using a session rating of perceived exertion (session-RPE) methods within 30 minutes after the end of the day’s workout. At baseline, week four and week eight three 5km endurance performance tests were conducted on a 400m standardized synthetic track under standard conditions (at 2500m a.s.l. and between 07:00 – 08:00 a.m.).

Results

Demographic Characteristics Study: Although the demographic characteristics study identified significant difference between the three groups in the age at which formal training started ($p < 0.001$), no significant difference was identified between the groups ($p > 0.05$) regarding the altitudes where the athletes were born and raised. Moreover, the study reported no significant difference in the daily distance covered to and from school between the three groups during their primary education ($p > 0.05$) but not during their secondary education ($p < 0.05$). The study also revealed that there were significant regional distribution differences in the three groups ($p = 0.002$) where 81.3% of retired athletes and 55% of academy junior athletes were from central Ethiopia. There was also no significant difference ($p = 0.05$) between the three groups in the mode of transportation used to cover the daily distance to and from school. In addition to the above findings, this study also found no statistically significant difference in the types of major out-of-school activities between the three groups of athletes during their childhoods ($p > 0.05$).

Macronutrient Intake and Energy Balance Study: There was a significant difference between the mean total energy intake (14593±895KJ.day^{-1}) and mean total energy expenditure (13423± 1134 KJ.day^{-1}, $p < 0.001$) during the three days' dietary assessment. Moreover, the daily total energy intake (EI) and energy expenditure (EE) throughout the three days for all subjects were also compared in the same way as the total EI and EE. In comparison to the daily energy expenditure, on day one there was a mismatch between EI (15682 ± 1599 KJ.day^{-1}) and EE (12823 ± 1397KJ.day^{-1}, $p = 0.000$), and a positive energy balance was calculated. On day two there was no substantial difference between daily EI (14368 ± 1516KJ.day^{-1}) and EE (13688± 1618 KJ.day^{-1}, $p = 0.146$). Similarly, there was also no significant difference between the EI (13728±412KJ.day^{-1}) and EE (13757± 1390KJ.day^{-1}, $p = 0.919$) on day three. This study also confirmed no significant differences in the daily energy expenditure between the three days ($p = 0.091$). As compared to fat and protein, it appears that CHOs were the major energy source consumed during the three days. The overall proportion of the energy derived from the foods revealed that CHO provided 65.7% (±11.7 %); protein 18.7% (±6.9 %) and fat 15.4% (±4.9 %).

When the overall proportions of energy intake (KJ) derived from the three macronutrients were analysed on a daily basis, there were statistically significant differences in CHO, protein and fat consumption across the three days, ($p < 0.001$). Moreover, substantial differences were identified in the day-to-day fat ($p < 0.001$) and protein ($p < 0.001$) consumption during the three dietary assessment days.

Altitude Training Study

Haematological Study: No statistically significant difference in RBC count was observed between the LH - TH and LH - THTL study groups following eight weeks of endurance training (Δ0.05; CL ±0.029; $p = 0.741$; ES = 0.12). After eight weeks of endurance training no significant difference was observed in the haemoglobin concentration ($p = 0.926$), but substantially declined from baseline to week eight in both groups (Experimental: Δ-0.48; CL±0.46; $p = 0.040$; ES = -0.35 and control: Δ-0.51; CL± 0.46; $p = 0.030$; ES = -0.37). This study also identified no substantial difference in haematocrit value between the two study groups following eight weeks of endurance training (Δ0.2; CL±1.9; $p = 0.832$; ES = 0.06).

Vagal-Related Heart Rate Response: The resting HRV (RMSSD) measurements revealed no meaningful differences between the LH-TH and LH - THTL groups (Δ-0.18; CL±0.43; $p = 0.407$; ES = -0.29) from baseline to week eight in the experimental (Δ0.05; CL±0.31; $p = 0.761$; ES = 0.08) and control (Δ0.22; CL±0.31; $p = 0.145$; ES = 0.37) groups; although the changes in both groups were positive. The difference between the experimental and control groups, however, was negative and small (Δ-0.29). The regression analysis also revealed no significant differences, both in the one-minute (Δ4.4; CL±10.8; p = 0.413; ES = 0.47) and two-minute post-exercise heart rate recovery (Δ3.1; CL±10.4; $p = 0.550$; ES = 0.31), between the experimental and control groups.

Neuromuscular Fitness/Fatigue Response: The CMJ test results revealed no significant difference between the two study groups following eight weeks of endurance training (Δ0.5; CL±4.8; $p = 0.829$; ES = 0.06), although meaningful changes were identified both in the experimental (Δ8.3; CL ±3.4; $p = 0.001$; ES = 0.92) and control (Δ7.8; CL ±3.4; $p = 0.001$; ES = 0.86) groups from baseline to week eight. Significant changes in squat jump ability were observed, both in the experimental (Δ4.8; CL±2.8; p = 0.001; ES = 0.69) and control (Δ2.9; CL±2.8; p = 0.039; ES = 0.42) groups, following eight weeks of endurance training; but not between the groups (Δ1.8; CL±3.9; p = 0.353; ES = 0.26). This study also confirmed no significant difference between the two study groups in the eccentric utilisation ratio following eight weeks of endurance training (Δ-0.05; CL±0.16; p = 0.511; ES = -0.39).

Training Load Response: The results of the analysis identified significant differences between the groups, and for all weekly training load responses of all training sessions, i.e., light, moderate and high-intensity training sessions (p = 0.019) and high intensity training sessions (p = 0.000). However, no substantial difference was identified between groups (p = 0.133) in the weekly load responses to the light and moderate intensity training sessions. Based on the results of the least significant difference, post-hoc meaningful differences were identified between the groups in their weekly load response to the total intensity training at week seven and eight; as well as at weeks one, five, seven and eight for the high intensity training sessions. Out of the 47 training sessions, light intensity sessions (< 4 RPE, less than the first ventilatory threshold) made up 87.2% of sessions in the experimental group and 68.1% in the control group, while 12.8% (Experimental group) and 31.9% (Control group) of the training sessions were completed at RPE > 4 < 7 RPE (between first and second ventilatory threshold).

Five Kilometre Endurance Performance: After eight weeks of endurance training no significant difference in the 5km endurance performance was identified between the LH-TH and LH-THTL study groups (Δ-12; CL ±25s; p = 0.335). Even though times for the 5km decreased significantly in the experimental group (Δ-19; CL±18s; p = 0.037) from baseline to week eight, performance in the control group did not improve significantly (Δ-7; CL ±18s; p = 0.440).

Conclusions

Demographic Characteristic Study: Significant difference was observed between the three groups in the age at which formal training started. However, no significant differences were identified between the three groups in the altitudes where the Ethiopian long-distance athletes were born and raised, the daily distance travelled to and from school, the mode of transportation and the major out-of-school activities during their childhood. Thus, the findings of this study confirmed that the 20 junior athletes who were involved in the study shared common demographic characteristics with the retired and current elite Ethiopian long-distance athletes.

Macronutrient Intake and Energy Balance Study: In line with the previous studies conducted on Kenyan and Ethiopian endurance athletes, the young long-distance Ethiopian athletes met the recommended daily macronutrient intake for carbohydrates and protein for endurance athletes. However, the study also identified that the athletes' dietary fat consumption was below the recommended amount for endurance athletes. Moreover, based on the three-day dietary assessment results, the young Ethiopian endurance athletes were found to be in a state of positive energy balance one week before their first major competition of the year (albeit during the preparation phase of their yearly training plan).

Altitude Study: The overall results of the current altitude study revealed that in most of the study variables (i.e., haematological, autonomic, neuromuscular, and endurance performance), except the subjective based training load response, statistically insignificant results were identified between the two study groups. However, when the results of the altitude study variables across time (baseline to week eight) were examined, athletes in the LH-THTL experimental group showed better progress in neuromuscular and lower training load responses which were accompanied with significant five kilometer endurance performance change; and lower or similar progress in haematological and autonomic regulation responses as compared with the LH-TH control group. It is noted that the ultimate purpose of any type of altitude training is enhancing the running performance while minimizing athlete's susceptibility to injury. Taking these core concepts of athletic training and the physiological and performance changes of the current study in to consideration, the LH-THTL altitude training model was potentially the preferred optimal altitude training model to further enhance the past and existing long-distance performance of Ethiopian endurance athletes although further comprehensive studies are required to confirm the results.

Future Directions

In order to exhaustively investigate optimal altitude training models that better enhance the long-distance performance of athletes' native to high altitude, more comprehensive, similar studies should be designed. Moreover, to achieve stronger results, further studies should be conducted using larger sample sizes with balanced gender proportions, along with more subjective and objective training monitoring methods. Furthermore, future studies should consider additional altitude training models, be conducted over longer periods and during different phases of the yearly training plan (preparation, pre-competition, and competition). It is also recommended that future studies should design endurance performance tests at different altitudes (low and high) to enhance the local and international competition performance of Ethiopian long-distance athletes.

CHAPTER ONE: INTRODUCTION

1.1 Introduction, Context and Problem

The success story of high altitude native Ethiopian athletes in middle- and long - distance events traces back to the 1968 Mexico Summer Olympics. Since then and including the recent 2016 Rio Olympics as well as the 2015 IAAF World Championships, athletes from Ethiopia highlands have dominated the medals on offer for both middle and long distance events (IAAF, 2017). The top twenty male all-time lists include 6, 3, and 9 Ethiopians for the five and ten kilometre and marathon, respectively. Similarly for females, the top twenty all-time list includes 9, 9 and 5 Ethiopians for the five and ten kilometre and marathon, respectively (IAAF, 2016). Due to this dominance of East African runners over the last six decades, scientists have spent their time and resources studying the secret behind the long distance running success of athletes originally from high altitude nations like Ethiopia and Kenya.

Research into altitude training and sports performance was sparked by the awarding of the 1968 Summer Olympic Games to Mexico City, a city found at an altitude of ~ 2300m above sea level (a.s.l.) (Hamlin, Draper, & Hellemans, 2013; Fulco, Rock, & Cymerman, 2000). Because of the altitude of the city, some countries exposed their athletes to different altitudes in an attempt to induce some form of acclimatisation (Balke, 1964). However, in general, performance declines in middle- and long-distance events were observed at the Mexico City games compared with previous Olympic Games. On the other hand, athletes who came from high altitude nations like Kenya and Ethiopia dominated in most of the middle- and long-distance events (International Association of Athletics Federation [IAAF], 2017a; 2015). Anecdotal evidence and research results suggested that, because east African athletes are born, live and train at high altitude, they find it easier to compete and perform at sea-level or low altitude areas. The dominance of these east African athletes, native to high altitude, has continued to the present day. Based on their successes, different altitude training models have been introduced and are now typically included in the yearly training plan of athletes living at sea level and in low altitude countries (Vargas Pinilla, 2014).

Over the past five decades, the focus of altitude training research has been to find the optimal altitude training models that can enhance sea level endurance performance (Wishnizer, Inbar, Klinman, & Fink, 2013; Stray-Gundersen & Levine, 2008). Based on the altitude training studies conducted to date, different artificial (Saugy et al., 2014; Chapman, 2013; Hamlin et al., 2013; Wilber, 2007) and natural (Saugy et al., 2014; Hamlin et al., 2013; Garvican et al., 2012; Stray-Gundersen & Levine, 2008; Stray-Gundersen, Chapman, & Levine, 2001; Levine & Stray-Gundersen, 1997) altitude training models have been proposed and used, despite the fact that no consensus has been reached regarding the performance and physiological benefits of these models. The majority of the altitude-based studies were conducted using artificial altitude settings (Robertson et al., 2010; Brugniaux et al., 2006; Saunders, Telford, et al., 2004; Roberts et al., 2003).

When the target population of the altitude-based research is critically examined, it can be seen that, in most studies, the objective was to enhance the performance of athletes native to sea-level and low altitude. Despite the performance and physiological benefits that can be obtained from altitude training for these athletes living at low altitude, very few studies over the last five decades (Wishnizer et al., 2013; Saltin, Kim, et al., 1995; Saltin, Larsen, et al., 1995) have involved high altitude native athletes. Importantly, these (few) studies were not designed to enhance the endurance performance of athletes native to high altitude. Rather, the studies compared the physiological and performance responses of the east African endurance athletes with those of athletes living at low altitude.

As anecdotal evidence and research results show (Hamlin, Hopkins, & Hollings, 2015; Hamlin et al., 2013; Wehrlin & Hallén, 2006; Kayser, 2005), there are performance differences when endurance athletes compete and/or train at high and low altitudes. These differences have been observed in endurance athletes living at both low and high altitude. Variations in environmental stress have been observed when Ethiopian athletes (high altitude native athletes) train in various parts of the country in moderate to high altitude environments. Based on the subjective responses of these athletes, endurance training at relatively high altitudes (2300m - 2700m a.s.l.) is associated with a heavier load response than at lower altitudes (1300m - 1500m a.s.l.). The differences in the athletes' responses while training at these different altitudes are presented in the chapter discussing training load response differences between the two study groups of the current study (Chapter Eight).

Previous studies have reported the effects of different altitude training models on the physiological and performance characteristics of sea-level and low altitude native athletes. These altitude training models include the classic live high - train high (LH-TH), live high - train low (LH-TL), live high - train high train low (LH-THTL) and live low - train high (LL-TH) models. Most of the existing studies that used these altitude training models reported physiological and biochemical responses to altitude training, including red blood cell count (volume); haemoglobin concentration (haemoglobin mass); haematocrit values; iron status and aerobic capacity (Wehrlin & Hallén, 2006; Niess et al., 2003; Stray-Gundersen et al., 2001; Saltin, Larsen, et al., 1995); as well as non-haematological characteristics like muscle fibre type and size; lactate resistance level and muscle oxidative capacity (Gore, Clark, & Saunders, 2007; Pitsiladis, Bale, Sharp, & Noakes, 2007; Saltin, Kim, et al., 1995); and performance outcomes (Bohner et al., 2015; de Paula & Niebauer, 2012; Stray-Gundersen & Levine, 2008; Stray-Gundersen et al., 2001). Apart from these objective physiological assessments, there is limited research in altitude training models about the autonomic nervous system (ANS), immune and other subjective responses (e.g. session ratings of perceived exertion (session-RPE)).

Anecdotal evidence and cumulative data revealed that most international middle- and long-distance running events have been organised at sea level or low altitude venues (IAAF, 2017a; 2015). From the time east African athletes native to high altitude started to participate in international competitions, they have been using the live high - train high compete low approach. Unlike the east African athletes, middle- and long-distance athletes native to sea-level have usually been living, training and competing at the same altitude (live, train and compete at sea level). A variation in the actual day-to-day training and competition is common in the high altitude native athletes. In the past, numerous altitude-based studies have been conducted to enhance the performance of middle- and long-distance athletes native to sea-level and low altitudes. To the best of the author's knowledge, there has been no altitude-based study using any of the training models (LH - TH, LH - TL, LH – THTL, LL – TH) conducted on east African athletes native to high altitude.

Because of logistical problems, a shortage of adequate training venues, and time constraints, most altitude-based studies have used altitude simulations and devices in a laboratory setting to access the benefits of natural altitude training (Hamlin et al., 2013). While altitude simulation methods and devices have been widely used in altitude-related research, as well as in training programmes to enhance endurance performance, for the past few years the use of these methods and devices has not been fully accepted by the World Anti-Doping Agency (WADA) and International Olympic Committee (IOC). Although studies have shown that altitude simulation methods and devices enhance athletic performance; due to their effects on the health of athletes, and in violation of the spirit of sport, WADA and the IOC have been debating the issue and opening it up for research (Wilber, 2017; James, 2010; Wilber, 2007). Although WADA and IOC have discouraged the use of artificial altitude training models, the topography of most countries does not allow athletes or coaches to use natural altitude training models to enhance the performance of their athletes. However, there are some countries, like Ethiopia, where the natural topography is suitable for the implementation of different altitude training models, particularly in endurance training. Although the altitude varies noticeably across the country, no altitude training studies using these natural conditions have previously been conducted in Ethiopia to enhance the endurance performance of Ethiopian athletes.

Taking the above research gaps and the potential advantages of the country's topography into consideration, the focus of the present research was to determine the physiological and performance benefits of natural altitude training on athletes native to high altitude areas. Specifically, the aim was to identify an optimal natural altitude training model that enhances the long-distance performance of junior Ethiopian athletes who lived and trained at two different altitudes. The study employed the LH-TH and LH-THTL altitude training models. A total of 20 junior long-distance athletes (5 and/or 10km runners) were recruited and assigned into the two study groups: LH-TH (control, n=10) and LH-THTL (experimental, n=10). Unlike previous studies, this study applied both objective and subjective training monitoring methods to address the five specific objectives that focused on the eight weeks altitude study (No.3 -7) and other two specific objectives (No.1 and 2) to identify the deviation in some selected environmental factors (demographic characteristics) by the athletes involved in the altitude study (junior academy long-distance athletes) as compared with the retired and current elite Ethiopian long-distance athletes. The specific objectives of the current study were:

1. to identify differences in the demographic characteristics between retired, current elite, and the junior, Ethiopian long-distance athletes who participated in the altitude training study.
2. to assess the macronutrient intake and energy balance of young Ethiopian long-distance athletes living in a training camp at higher altitudes: To meet this objective, a three-day macronutrient intake, as well as the energy intake and expenditure assessments were measured.
3. to identify differences between the two study groups in their haematological responses: To meet this objective, red blood cell (RBC) count, haemoglobin concentration (Hgb) and haematocrit (Hct) tests were conducted.
4. to identify vagal-related heart rate differences between the two study groups: To meet this objective, resting heart rate variability (HRV) and one- and two-minute post-exercise heart rate recovery (HRR) measurements were obtained.
5. to identify neuromuscular performance/fatigue differences between the two groups: To meet this objective counter-movement jump (CMJ) and squat jump (SJ) performance were determined and the eccentric utilisation ratio (EUR) was calculated.
6. to identify the subjective training load response differences between the two study groups: Session-RPE was obtained to determine the subjective responses of the two groups.

7. The primary focus of any altitude training model in endurance sports is to enhance the endurance performance of athletes. Therefore, the final objective of the current study was to identify the endurance performance differences between the two study groups following eight weeks of endurance training. The endurance performance differences between the experimental and control groups were assessed using 5km time trial tests.

The study participants (athletes) were recruited from Tirunesh Dibaba National Athletics Training Centre based in the town of Asella at an altitude of 2500m (7°57′N latitude and 39°7′E longitude). Once the athletes had been recruited, they were assigned into two study groups: experimental and control. For the study, two training areas were identified and used for endurance training that lasted for eight weeks. The altitudes of the locations used for high and low altitude training were at Asella (2500m) and Dodota-Awash (1470m). To test the five altitude study hypotheses derived from the specific objectives of the study (No.3 - 7), a balanced, randomised experimental design was employed. The athletes who were assigned to the control group trained following the classic altitude training model (LH-TH); whereas the athletes in the experimental group trained following the LH –THTL altitude training model. Throughout the eight study weeks, the LH-TH groups lived and trained at ~2500m a.s.l. However, athletes in the experimental group lived at ~2500m a.s.l., and performed all light and moderate intensity training sessions at ~2500m a.s.l; while high intensity interval training sessions occurred at ~1470m a.s.l.

Haematological measurements, vagal-related heart measurements (HRV and HRR) and 5km time trials were assessed three times: at baseline, week 4 and week 8. Neuromuscular performance/fatigue testing was conducted at five times: at baseline, week 2, week 4, week 6 and week 8. Apart from these tests, subjective training load responses were collected from the athletes at the end of every training session (47 sessions) throughout the study using the session-RPE method. All the study hypotheses were tested using regression analysis and two-way repeated measure ANOVA (training load response) with post-hoc analyses. Effect size, the magnitude of the differences between the two groups, was also calculated for the selected variables.

All the study approaches, methodology, results, discussions and conclusions are organised and presented separately in a format based on the specific objectives of the study. Finally, the major study findings and conclusions of the overall specific objectives of the study are synthesised and presented in a separate chapter at the end of this thesis (Chapter Ten).

In parallel to the current study, two additional studies that assessed the demographic characteristics as well as the macronutrient intake and energy balance of the athletes involved in the current study were conducted. The demographical characteristics study mainly focused on the altitude where the athletes were born and lived in childhood, early childhood home-to-school distance, mode of transportation used to travel to and from school, geographical distribution and major out-of-school activities of the athletes at childhood. Specifically, the demographic characteristics of the athletes in the current study were compared with those of retired senior and current elite, long-distance athletes. The three-day nutritional assessment mainly focused on assessing the macronutrient intake and energy balance of the athletes, both in the control and experimental groups, during the last week of the study (a week before the athletes' first official competition).The rationale behind these studies was to investigate how far the early lifestyle and nutritional practices of the junior athletes deviate from the retired and current elite long-distance athletes, based on the results of the previous studies, and how the deviation in selected factors might affect the current altitude study.

This thesis is organized and submitted in a manuscript format based on the University of Kwazulu-Natal's academic requirements for a Doctorate in Philosophy. The thesis consists of ten chapters. The first chapter deals with the problem identification and study approaches. The narrative literature review is presented under chapter two of the thesis. From chapter three to chapter nine separate but interdependent studies are presented in a manuscript format. The two small scale studies that are aimed at supporting the altitude studies are presented under chapter three and four and deal about the demographic characteristics and macronutrient intake and energy balance studies respectively. The altitude studies that aimed at identifying haematological, autonomic (vagal-related heart rate response), and neuromuscular performance differences between the two study groups are presented in a manuscript form under chapter five, six and seven respectively. The last two manuscripts, training load and endurance performance responses are presented under chapter eight and nine. The final chapter (Chapter Ten) presents the synthesis, conclusion and recommendations part of the study.

CHAPTER TWO: REVIEW OF RELATED LITERATURE

2.1 Introduction

There is limited literature on the effects of altitude training on high altitude-living native athletes. This part of the thesis presents a narrative review of altitude-based studies that directly or indirectly related to middle- and long-distance events. Specifically, the review discusses the major factors that affect endurance performance; training adaptations to endurance training; altitude training and endurance performance; and altitude training and long distance running success of high altitude native athletes from east African nations.

2.2 Factors affecting endurance performance

Although the underlying training principles for enhancing sporting performance do not differ from sport to sport, the rate and the mechanisms which cause performance changes may vary from person to person as well as from sport to sport (Lorenz, Reiman, Lehecka, & Naylor, 2013; Bompa & Haff, 2009; Richardson, Andersen, & Morris, 2008).

For endurance sports like long distance running and cycling, there are a number of interacting factors that influence performance. Nutritional factors (Heydenreich, Kayser, Schutz, & Melzer, 2017); psychological factors (Baker & Horton, 2003); genetic predisposition (Kikuchi & Nakazato, 2015; Guth & Roth, 2013; Tucker, Santos-Concejero, & Collins, 2013; Scheinfeldt et al., 2012); haematological characteristics (Brocherie et al., 2015); biochemical (Saltin, Kim, et al., 1995) factors; anthropometric considerations (Mooses & Hackney, 2016; Lorenz et al., 2013; Wilber & Pitsiladis, 2012; Lucia et al., 2006; Saltin, Kim, et al., 1995); biomechanical (Lucia et al., 2006; Enomoto & Ae, 2005) and training characteristics (Wilber & Pitsiladis, 2012; Davids & Baker, 2007; Smith, 2003) and environmental factors (Davids & Baker, 2007) are the commonly proposed factors that can determine the success of endurance athletes.

In relation to genetic predisposition, original studies (Kikuchi & Nakazato, 2015; Guth & Roth, 2013) and a review article (Wilber & Pitsiladis, 2012) have reported advantageous genotypes, specifically mitochondrial DNA, Y-chromosome, and alpha-actinin-3 (ACTN3) genes that, potentially, can identify successful endurance athletes. As far as the physiological variables are concerned, the majority of research supports $\dot{V}O_2$ Max, running economy, lactate threshold and fractional utilisation of VO_2 as key determinants of endurance performance (Lorenz et al., 2013; Billat, Demarle, Slawinski, Paiva, & Koralsztein, 2001).

Oxygen transport and utilisation ability of the body are responsible for enhancing aerobic power and capacity in endurance sports like long-distance running and cycling (Lundby & Robach, 2015; Lorenz et al., 2013; Lucia, Oliván, Bravo, Gonzalez-Freire, & Foster, 2008). The physiological mechanism underlying $\dot{V}O_2$ Max, which is defined as the maximum amount of oxygen that the body can consume during intense exercise, is the extraction of sufficient oxygen from the air to supply to the blood and blood vessels to reach the working muscle (Lorenz et al., 2013). In previous studies (Laursen & Rhodes, 2001), $\dot{V}O_2$ Max was considered the only major factor that determined endurance performance. However, recent studies (Lorenz et al., 2013; Lucia et al., 2008) have disproved the sole and dominant role of $\dot{V}O_2$ Max in predicting endurance performance in elite athletes, and reported that $\dot{V}O_2$ Max, along with fractional utilisation of $\dot{V}O_2$ Max and running economy, are better predictors of endurance performance (Lundby & Robach, 2016; Lorenz et al., 2013; Lucia et al., 2006).

There is growing support for the role of haematological variables like total haemoglobin mass, haemoglobin concentration, red blood cell count and blood volume in determining endurance performance (Brocherie et al., 2015; McLean, Buttifant, Gore, White, & Kemp, 2013; Wilber & Pitsiladis, 2012; Prommer et al., 2010). In addition to these haematological variables, studies (Gore et al., 2007; Saltin, Kim, et al., 1995) revealed the role of non-haematological variables like muscle fibre types, size and composition; oxidative enzymes; and muscle buffering capacity in affecting endurance performance positively.

Apart from the effects of physiological, haematological, and biochemical variables on endurance performance, studies have also identified the role of anthropometric characteristics in performance (Mooses & Hackney, 2016; Mooses et al., 2013; Wishnizer et al., 2013; Lucia et al., 2008). Height, body mass, body mass index, body composition, length of limbs, length of the upper leg, thigh girth, total skin fold and skinfold thicknesses of the lower limbs are some of the anthropometric variables that directly or indirectly affect endurance performance (Knechtle, Knechtle, Andonie, & Kohler, 2007). Another study by Maldonado, Mujika, and Padilla (2002) demonstrated the role of body mass and height in determining middle- and long-distance endurance performance. The other crucial factor that determines endurance performance is the type of training (Lorenz et al., 2013). Specifically, the effects of training frequency, training quality and quantity (the combination of volume and intensity), load distribution, training periodisation, the use of resistance and plyometric training, the balance between training stress and recovery (Manzi et al., 2015; Lorenz et al., 2013; Smith, 2003) must all be considered.

2.2.1 Physiological adaptation to long-term endurance training

Many adaptations occur in response to optimal, balanced endurance training. Haematological, autonomic, neuromuscular, biochemical and other physiological adaptations are the most commonly reported physiological adaptations following endurance training (Schmitt, Regnard, & Millet, 2015; Meeusen et al., 2013; Elloumi et al., 2012). Although training adaptation is a general concept in exercise and sport science, the pattern and rate of adaptations to given training stimuli differ, based on individual genetic predisposition (Guth & Roth, 2013; Tucker et al., 2013); the volume and intensity of training (Lundby & Jacobs, 2016; Montero et al., 2015); nutritional practices (Heydenreich et al., 2017; Kato, Suzuki, Bannai, & Moore, 2016; Phillips, 2012); physiological readiness (Lundby & Jacobs, 2016; Lorenz et al., 2013; Wishnizer et al., 2013); age; gender and other environmental conditions (Knechtle et al., 2015; Lepers, Rüst, Stapley, & Knechtle, 2013). Below some of the physiological variables that have mostly been studied in relation to adaptation to long-term endurance training are presented.

2.2.1.1 Haematological adaptations

Optimal and consistent endurance training enhances the ability of the heart to deliver a sufficient amount of oxygen-rich blood to the working muscle. It enhances glycogen stores and fat utilisation; improves the quality and quantity of mitochondria (mitochondria density); increases muscle capillarisation; improves arteriovenous oxygen difference (a-

vO_{2diff}); and enhances the functions of oxidative enzymes (Rusko, Tikkanen, & Peltonen, 2004).

Since endurance performance is influenced by the availability of oxygen to skeletal muscle, it is important to monitor haematological parameters in endurance athletes (Mairbäurl, 2013). In this regard, haemoglobin (Hgb) concentration, haematocrit (Hct), total haemoglobin mass (tHgb), and total red blood cell (RBC) volume have been the most widely monitored haematological parameters to detect the oxygen transport capacity of endurance athletes (Mairbäurl, 2013; Hu & Lin, 2012). In the past, attempts were made to establish normal values for Hgb concentration, Hct, and RBC volume in athletes, although great variation in ranges have been reported due to changes in load of training within the same training and competition season (Banfi, Lundby, Robach, & Lippi, 2011; Vergouwen, Collee, & Marx, 1999).

The most common haematological indices that can be altered, either by phases of training or training load are RBC, Hct, and Hgb(Mairbäurl, 2013; Banfi et al., 2011). In different sports, except soccer, Hct and Hgb typically decrease during intense training weeks (Banfi et al., 2011). The reported decrease in Hgb in these sports ranged between 3-8% during the competition season, compared with other seasons (Banfi et al., 2011). Blood dilution, a higher rate of RBC turnover and RBC destruction due to continuous muscle contraction and foot strike are the major causes for a decrease in the haematological indices as athletes' time spent training and their training load increase (Banfi et al., 2011; Peeling, Dawson, Goodman, Landers, & Trinder, 2008; Telford et al., 2003). Along with Hgb and Hct, a decrease in RBC count was observed at the onset of the racing season, compared with the preparation phase in road cyclists (Rietjens, Kuipers, Hartgens, & Keizer, 2002; Schumacher, Jankovits, Bültermann, Schmid, & Berg, 2002). In elite cyclists, Hct decreased from 45% to 42% when moving from low intensity/low volume training to an intense training/competition phase (Mørkeberg, Belhage, & Damsgaard, 2009). Haemoglobin decreased from $15.2 g.dL^{-1}$ to $14.0\ g.dL^{-1}$, moving from preparation phase to peak, competition phase (Mørkeberg et al., 2009). In elite soccer players there was a significant reduction in Hgb concentration (15.7 ± 3.9 to $15.2\pm2.1\ g.dL^{-1}$) and Hct percentage (48.2±1 to 46.2±0.5%) after 90 days of training, compared with baseline; although there was no meaningful change (5.4±1 to 5.3±0.5 x 10^{12}/L) in red blood cell count (Anđelković et al., 2015). A longitudinal study (Mørkeberg et al., 2009) conducted on professional cyclists revealed significant season-based haematological changes following endurance training. In this study, the average Hct and Hgb decreased by 4.3% and 1.3 $g.dL^{-1}$, respectively. However, the Hct and Hgb levels returned to baseline levels at the end of the competition phase. In comparison with the out-of-competition, preparation period, lower Hct and Hgb (43.2 % and 15.0 $g.dL^{-1}$, respectively) values were observed during the in-competition period (40.9 % and 14.1 $g.dL^{-1}$) in these road cyclists (Mørkeberg et al., 2009). Haematocrit values increase during exercise because of a reduction in plasma volume triggered by fluid loss during exercise. However, blood and plasma volume may also increase very rapidly after training sessions, with RBC volume remaining unchanged for several days (Schmidt et al., 2002; Sawka, Convertino, Eichner, Schnieder, & Young, 2000). This situation (elevated blood and plasma volume) can cause a decrease in Hct for a certain period (Mairbäurl, 2013). However, after few weeks of training, Hct returns to pre-training levels. One of the explanations for the post-exercise increase in plasma volume in highly trained athletes is aldosterone dependent renal sodium ion reabsorption and water retention stimulated by elevated antidiuretic hormones to compensate for the water loss during each training session (Mairbäurl, 2013).

In addition to the effects of training load and seasonal variation, the effects of altitude and/or training at different altitudes on haematological variables has been investigated. A comparative study (Schmidt et al., 2002) that involved lowland and highland native elite endurance (cycling) athletes showed no statistically significant difference in Hgb concentration (15.8 $g.dL^{-1}$ ±0.07 vs 15.8 $g.dL^{-1}$ ±0.07) and Hct (47.7±1.9% vs 47.8± 1.5%, low vs high, respectively) after endurance training during the preparatory season. A study that conducted frequent haematological testing during 53 days of altitude training at different altitudes revealed some variations in Hgb and Hct(Wachsmuth et al., 2013). Importantly, the study found no significant change in Hgb concentration from pre- to post-altitude training in females (14.0 ±0.6 $g.dL^{-1}$ to 14.5± 0.7 $g.dL^{-1}$, p = 0.21); but found a significant change in male athletes (15.6 ±0.9 g.dL^{-1} to 16.1 ± 0.7 g.dL^{-1}, p = 0.04). However, Hct did not change (42.2 ± 2.2 % to 43.0 ± 2.0 %, p = 0.53 for females and 45.5 ± 2.2 % to 46.3 ± 2.1 %, p = 0.13 for males). When the same athletes trained at a relatively low altitude (1360m), there were no significant changes in Hgb or Hct after 43 days of training (Hgb, 13.1 ± 0.6 g.dL^{-1} to 13.2 ± 0.5 g.dL^{-1}, p = 0.69 for females and 14.7 ± 0.7 g.dL^{-1} to 15.0 ± 0.4 g.dL^{-1} for males; and Hct, 38.4 ± 1.8 % to 40.4 ± 1.5 %, p = 0.09 for females and 43.0 ± 1.4 % to 45.0 ± 1.4 % for males, respectively).

2.2.1.2 Autonomic adaptations to endurance training

In addition to haematological variables, autonomic adaptation to endurance training is the other widely studied variables in sport. Resting bradycardia, a decrease in heart rate (HR) during submaximal exercise, fast heart rate recovery (HRR) and increased vagal-related heart rate variability (HRV) indices were the most widely reported indices of improved endurance training (Bellenger et al., 2016; Hynynen, Vesterinen, Rusko, & Nummela, 2010). These HR related changes are associated with changes in the autonomic nervous system (ANS) (Vesterinen, 2016). Each provides information regarding the different physiological aspects of training adaptation (Buchheit, 2014).

The physiological relationship between the ANS and HR can be explained in relation to sympathetic and parasympathetic activities (Stanojević, Stojanović-Tošić, & Đorđević, 2013). Exercise and resting HR are predominantly controlled by the co-ordination of the sympathetic and parasympathetic nervous system (Bellenger et al., 2016). The parasympathetic nervous system plays a limited role during exercise, with the sympathetic nervous system preparing the body for physical activity by increasing heart rate, blood pressure and respiration (Buchheit, 2014). On the other hand, increases in measurements of resting HRV and faster post-exercise HRR, due to increases in parasympathetic HR modulation or decreases in sympathetic activation, are the result of positive adaptations to endurance training (Bellenger et al., 2016).

Different studies have reported the chronic effects of endurance training on the sympathetic and parasympathetic nervous system (George et al., 2012) and used the most common heart rate indices like resting heart rate (Vesterinen, 2016), heart rate recovery (Bellenger et al., 2016; Cornforth, Robinson, Spence, & Jelinek, 2014; Daanen, Lamberts, Kallen, Jin, & Van Meeteren, 2012), maximal heart rate (Whyte, George, Shave, Middleton, & Nevill, 2008), as well as heart rate variability (Saboul, Balducci, Millet, Pialoux, & Hautier, 2016; Schmitt et al., 2015; Reichert & Picanço, 2014; Makivić, Nikić Djordjević, & Willis, 2013) to track the possible effects on well trained endurance athletes.

In addition to increased cardiac vagal activity with exercise training, the reduction in RHR may be due to an increase in stroke volume (Wang, Solli, Nyberg, Hoff, & Helgerud, 2012). In response to endurance training, an important adaptation is a decrease in submaximal exercise HR. Lower submaximal HR may result from improved stroke volume, increased parasympathetic and decreased sympathetic activity, and decreased metabolite production (Wang et al., 2012). In contrast, Borresen and Lambert (2008) indicated that an increase in average HR during submaximal exercise is a marker of training maladaptation or overtraining.

Despite some studies reporting a relationship between positive training adaptation (enhanced performance) and increases in HRV, a number of studies have reported that increased HRV is associated with negative adaptation to training (Meeusen et al., 2013; Meeusen et al., 2006). Studies that have focused on HRV responses in over-trained or over-reached athletes reported equivocal findings (Bellenger et al., 2016). For example studies have reported no change in HRV among non-functional and over-trained athletes (Bosquet, Papelier, Leger, & Legros, 2003; Hedelin, Wiklund, Bjerle, & Henriksson-larsÉn, 2000; Uusitalo, Uusitalo, & Rusko, 2000). While others reported a decrease (Uusitalo et al., 2000) or increase (Hedelin, Wiklund, et al., 2000) in HRV non-functional over-reached (NFOR) and over-trained athletes.

Studies have reported faster HRR and improved performance following endurance training (Buchheit et al., 2010; Lamberts, Swart, Noakes, & Lambert, 2009). A recent review indicated a small to moderate relationship between improved HRR and endurance performance (Bellenger et al., 2016). Aubry et al. (2015) also reported improvement in one-minute HRR after the end of maximal aerobic power exercise among well-trained triathletes during a period of functional over-reaching. In contrast, a study reported an improved post-exercise HRR but a decrease in performance (Dupuy, Bherer, Audiffren, & Bosquet, 2013). Taking these opposing findings into consideration, the recent review by Bellenger et al. (2016) highlighted the need to use other markers, in addition to HRR, to monitor changes in endurance performance. Moreover, it was also suggested that faster HRR does not always predict better endurance performance and that interpretation should consider the phases of endurance training as well the subjective/perceived fatigue level of athletes (Aubry et al., 2015).

2.2.1.3 Endurance training and muscular and metabolic adaptation

Besides the above mentioned haematological and autonomic responses, numerous muscular and metabolic adaptations have been reported following endurance training (Lundby, 2016; Lundby & Jacobs, 2016; Cormack, Newton, & McGuigan, 2008). Endurance training improves skeletal muscle oxidative capacity through enhancing mitochondrial volume density (Lundby & Jacobs, 2016). The change in mitochondrial density is associated with two mitochondrial sub-populations called the intermyofibrillar mitochondria and subsarcolemmal mitochondria (Carsten Lundby & Jacobs, 2016). Recent studies reported a strong association between mitochondrial volume density and endurance performance (Lundby & Jacobs, 2016; Montero et al., 2015).

Montero et al. (2015) reported that after six weeks of endurance training, the skeletal muscle capillary-to-fibre ratio increased by 18% ($p < 0.05$); total mitochondrial volume density, intermyofibrillar and subsarcolemmal mitochondria increased by 43% ($p < 0.05$), 184% ($p < 0.05$) and 35% ($p < 0.05$) from pre- to post-training, respectively. Skeletal muscle adaptations were also associated with the intensity of exercise. For example, high intensity training and moderate intensity continuous endurance training have been associated with skeletal muscle (Jacobs et al., 2013) and haematological/respiratory (Montero et al., 2015) adaptations, respectively.

Although scientific data in support of skeletal muscle adaptation in response to training at different altitudes are minimal, enhanced capillarisation, increased concentration of myoglobin, increased mitochondrial oxidative enzyme activity and a greater number of mitochondria are some of the changes that enhance the rate of aerobic energy production following altitude training (Wilber, 2004). There are studies that have reported non-haematological adaptations following endurance training. These changes include augmented muscle efficiency at the mitochondrial level, greater muscle buffering capacity,

and higher lactic acid tolerance (de Paula & Niebauer, 2012; Gore, Clark, & Saunders, 2007). A recent study reported changes in muscle fibre types following endurance training at altitude (Montero et al., 2015). This study reported significant percentage changes in fast twitch type IIx (increased from 6.77±5.2 % to 11.13±5.24%, from pre- to post-endurance training, $p < 0.05$); and slow twitch type I decreased from pre- to post-endurance training (56.93±10.91% to 49.02±12.30%, $p < 0.05$) in muscle fibre cross-sectional area; but not in fast twitch type IIa muscle fibre from pre- to post- (36.29±11.07 to 39.85±11.67%, $p>0.05$) six weeks of endurance training.

2.3 Training monitoring in endurance training

When monitoring training load or training-load responses, many variables representing internal or external load can be obtained from athletes. In most studies, RHR, HRR (Bellenger et al., 2016; Daanen et al., 2012), HRV (Hynynen et al., 2010; Aubert et al., 2003; Pichot et al., 2000), blood lactate concentration (Manzi et al., 2015), and different hormonal and biochemical data have been used to objectively measure or monitor the training load responses (Meeusen et al., 2013). Increased or decreased RHR, slow or fast HRR, high or low HRV, increased or decreased blood lactate concentration, and biochemical substances in the blood or other body fluids can provide information regarding acute and chronic responses to training (Meeusen et al., 2013).

When planning training programmes, coaches and sport scientists typically apply three distinct external training loads that may vary significantly in a training programme. These external loads are: the load planned before the season (or study) starts, the load prescribed on a daily basis, and the actual load completed by each individual athlete (Mujika, 2017). Of these three, the actual load completed during the training session is the most important load to be measured and recorded by coaches and sport scientists (Mujika, 2017).

Internal and external training load quantification is now a priority task for coaches and athletes (Hernández-Cruz et al., 2017; Mujika, 2017; Sanders, Abt, Hesselink, Myers, & Akubat, 2017; Halson, 2014). Appropriate load monitoring can aid in determining whether an athlete is adapting to a training programme and in minimising the risk of developing non-functional over-reaching, illness, and/or injury (Haddad, Padulo, & Chamari, 2014; Halson, 2014). In addition to minimising the risk of training-related injury, non-functional over-reaching and over-training syndrome, monitoring training and/or training load can provide a scientific explanation for training responses, competition readiness and overall performance changes (Haddad et al., 2014).

2.3.1 External training load responses

In order to monitor the training of elite and sub-elite athletes, researchers have used a variety of external and internal load monitoring methods (Halson, 2014). External training load monitoring uses time, distance and speed measurements, which have been regarded as the foundations for understanding internal load data (Halson, 2014). External load is defined as the work completed by an athlete and is measured independently of the athlete's internal characteristics (Mujika, 2017). Power output sustained for a given duration, the weight lifted, total distance covered, the vertical height covered, speed and acceleration are the most common external load variables measured (Mujika, 2017). In endurance sports, especially in long-distance events, prescribing training load using external load monitoring of duration, distance, speed and/or pace of running, assisted by the relatively recent development of global positioning systems (GPS), has been widely used by athletes and coaches (Midgley, McNaughton, & Jones, 2007). Currently, different digital watches are being linked to GPS with a wireless signal connection, and the distance covered by the athlete, as well as the average and maximum speed, is calculated using triangulation (Karboviak, 2005).

2.3.2 Measurable internal training load responses

Numerous methods have been introduced to monitor the training load (TL) and training load responses (TLR) in endurance sports. Unfortunately, most of the methods are inconvenient for daily training use and no single acceptable method to directly measure the

TL and TLR has been reported (Roos, Taube, Brandt, Heyer, & Wyss, 2013). Many studies have examined the value of internal load measurements for exercise programming. Rating of perception of effort (RPE) and session RPE (Haddad et al., 2014; Halson, 2014; Egan, Winchester, Foster, & McGuigan, 2006); HR-based monitoring tools like training impulse (TRIMP) which uses duration efforts in categorised HR zones (Sanders et al., 2017; Comyns & Flanagan, 2013); HRR (Javorka, Zila, Balharek, & Javorka, 2002); HRV (Schmitt et al., 2015; Pichot et al., 2000); blood lactate concentration; hormonal, immunological and biochemical measurements (Cunha, Ribeiro, & Oliveira, 2006); training logs/diaries; questionnaires based on psychological responses (Hernández-Cruz et al., 2017; Kenttä & Hassmén, 1998) like stress-recovery balance (Recovery Stress Questionnaire, RESTQ) and mood disturbance (Profile of Mood States, POMS); total quality recovery (TRQ); daily analysis of life demands (DALD); sleep quality and quantity are the most abundantly used tools to monitor the physiological and psychological stresses imposed by external loads (Halson, 2014; Kenttä & Hassmén, 1998). Not all methods are practical for everyday use in sports training. For example, hormonal, biochemical and immunological measurements are expensive, time consuming and complicated internal load training monitoring methods to apply in day-to-day training (Comyns & Flanagan, 2013; Reilly & White, 2005). There are also difficulties associated with HR monitoring to quantify the training load responses of athletes, although it is far cheaper than the biochemical and hormonal testing. Most studies monitoring TL and TLR recommend perception of effort measurements along with training logs and diaries, as these are cost effective and manageable methods to monitor training and prevent training and non-training related stresses and loads from being imposed on athletes. Amongst the methods, RPE or session-RPE stand out because they are cheap and easy to implement, reliable and valid (Sanders et al., 2017; Manzi et al., 2015; Saw, Main, & Gastin, 2015; Haddad et al., 2014; Halson, 2014; Comyns & Flanagan, 2013).

In conclusion, most coaches and sport scientists recognised the importance of training load monitoring (Halson, 2014). Preventing injury, assessing training effectiveness, maintaining performance, and preventing over-training were the major reasons for monitoring training provided by coaches and sport scientists (Saw et al., 2015; Halson, 2014; Roos et al., 2013). In order to benefit from training load monitoring, most researchers recommend not relying on a single training monitoring method (Saw et al., 2015; Roos et al., 2013; Egan et al., 2006). Rather, they suggest using use both external and internal load quantification methods to improve reliability and validity in order to make informed decisions (Mujika, 2017).

2.4 Altitude training and endurance performance

2.4.1 Altitude classifications

Although altitude training is a most extensively studied area, no consensus has been reached as far as the classification of altitude is concerned. According to the America College of Sport Medicine (2013), altitude is classified as low (below 1524m), moderate (1524 – 2438m), high (2438 – 4267m), and very high (above 4267m). Most studies in altitude training consider locations below 1500m as low, higher than 1500m and lower than 2500m as moderate, and higher than 2500m as high (de Paula & Niebauer, 2012; Lundby, Millet, Calbet, Bärtsch, & Subudhi, 2012; Levine & Stray-Gundersen, 1997). On the other hand, Bärtsch and Saltin (2008) reported that altitude is classified as near sea level (0 to 500 m), low (>500 to 2000m), moderate (>2000 to 3000m), high (>3000 to 5500m), and extreme altitude (>5500 m).

2.4.2 Altitude and altitude simulation models

Currently, different altitude training approaches (Figure 2.1) and devices are being used under the two major altitude training models called natural/terrestrial and artificial/altitude simulation (Hamlin et al., 2013; Wilber, 2007). Along with the classic LH-TH altitude training model, the LH-TL, LH-THTL, and LL-TH altitude training models are the altitude training models most practised by coaches and athletes. Following the introduction of different natural altitude training models, attempts were made to introduce more convenient and time-efficient artificial altitude simulations. These altitude simulations include LH-TL via nitrogen dilution, LH-TL via oxygen filtration, LH-TL via supplemental oxygen; as well as the LL -TH intermittent hypoxic exposure (IHE) and LL-TH intermittent hypoxic training (IHT) (Wilber, 2017).

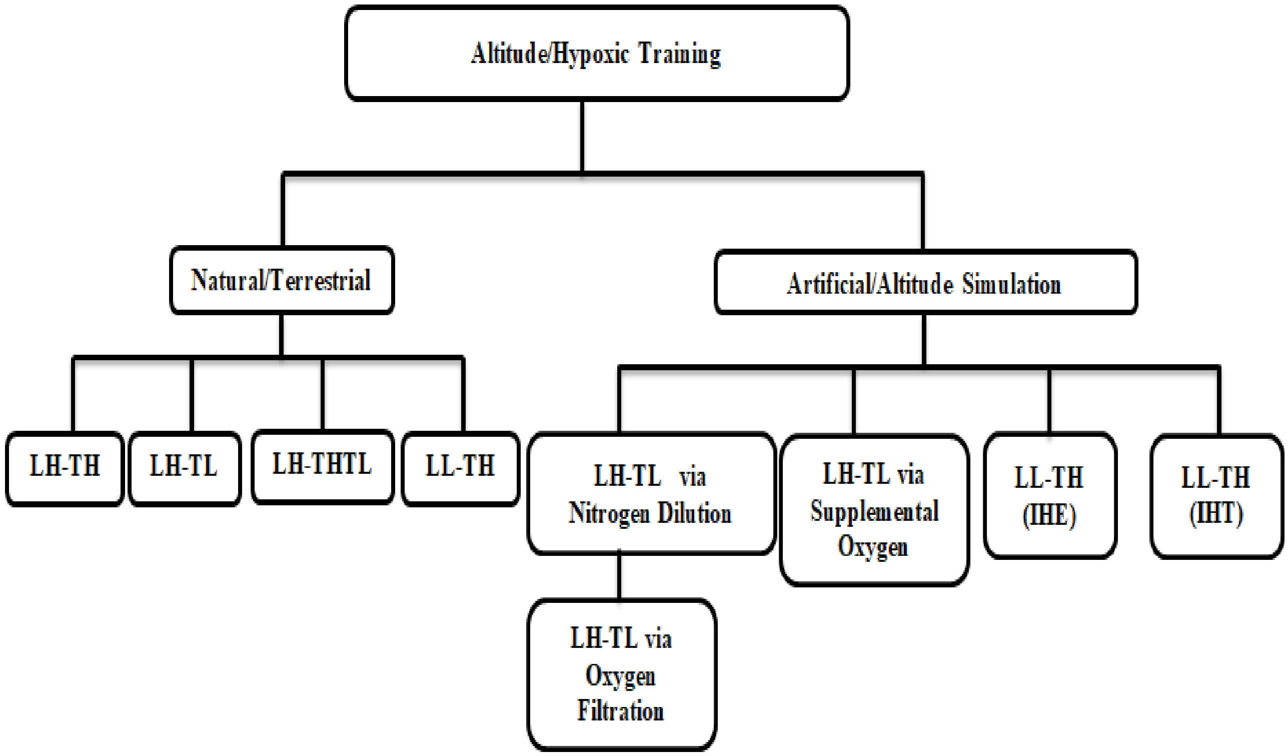
The LH-TH altitude training model was the first type of altitude training model (classical altitude training) adopted by western athletes, following the dominance of east African middle- and long- distance running athletes at the 1968 Olympic Games (Lundby et al., 2012). The general intention of this training model is to increase the total volume of RBC and Hgb mass to improve oxygen delivery by increasing arterial blood oxygen-carrying capacity, and thus increase $\dot{V}O_2$ Max and improve performance both at sea level and at altitude (Rusko et al., 2004). The second type of altitude training model is the LH-TL model. The LH-TL model was developed in the early 1990s by Drs Benjamin Levine and James Stray-Gundersen of the United States (Levine & Stray-Gundersen, 1997). It was introduced as a potential solution to the 'training intensity' limitation that appears to be inherent in the LH-TH altitude training model. The LH-TL is based on the premise that athletes can simultaneously experience the benefits of altitude acclimatisation (i.e., increased erythrocyte volume) and sea level training (i.e., maintenance of sea level training intensity and oxygen flux), which result in positive haematological, metabolic and neuromuscular adaptations (Stray-Gundersen & Levine, 2008; Wehrlin, Zuest, Hallén, & Marti, 2006; Stray-Gundersen et al., 2001; Wilber, 2001; Levine & Stray-Gundersen, 1997).

Although the LH-TL altitude training model has been accepted by athletes and coaches for its dual physiological and training benefits, due to its logistic difficulties and financial implications, and the fatigue and stress imposed on the athletes when travelling to high and low altitude locations every day, the model was not accepted as the best altitude training model for athletes and coaches (Vargas Pinilla, 2014). Taking all these drawbacks into consideration, another altitude training model with a slight modification to the LH-TL model, called the live high-train high train low model (LH-THTL) was introduced and researched along with other altitude training models (Hamlin et al., 2013; Wehrlin et al., 2006; Stray-Gundersen et al., 2001). In the LH-TL altitude training model, athletes live at high altitude for the sake of acclimatisation for most of the day and complete all their (different types of) training at low altitude (Stray-Gundersen et al., 2001). However, in the newly modified LH-THTL altitude training model, athletes live at high altitude, performing light and moderate intensity endurance training at high altitude, and then go down to a lower altitude for high intensity training, two to three times per week. Therefore, athletes who use this model do not travel up and down throughout the week but rather spend a few hours a week at low altitude, compared with the LH-TL model where athletes travel every day for all types of training at low altitude. One of the few studies (Stray-Gundersen et al., 2001) that examined this altitude training model reported a performance improvement in athletes (Stray-Gundersen et al., 2001). Another study that used a similar LH-THTL altitude training model required endurance athletes to live at 2456m and perform light and moderate intensity training at 1800m and high intensity training at 1000m. These athletes improved their 5km times compared with a control group that trained between 600m and 1600m (Wehrlin et al., 2006).

The limitations of the LH-TL altitude training model also motivated researchers to come up with different artificial altitude training models and scientific devices. These included normobaric hypoxia via nitrogen dilution (e.g., nitrogen apartment); normobaric hypoxia via oxygen filtration (e.g., hypoxic tent); and normobaricnormoxia via supplemental oxygen, which are the most common artificial altitude training models being used to substitute for the natural LH-TL model (Lancaster & Smart, 2012; Wilber, 2011; Saunders, Pyne, Telford, & Hawley, 2004; Wilber, 2001).

Normobaric hypoxia via nitrogen dilution was developed in Finland by Dr.HeikkiRusko in the early 1990s to create the natural LH-TL altitude training environment (Wilber, 2007). This simulated LH-TL altitude training model was developed for the purpose of simulating an altitude environment equivalent to approximately 2000m to 3000m a.s.l. through the manipulation of the oxygen concentration. The adjustment is made by introducing a gas composed of 100% nitrogen, thereby reducing the composition of the oxygen concentration from 20.9% to 15.3%, while nitrogen increased from 79.0% to 84.7%. Athletes who use the normobaric hypoxia (nitrogen tent) method typically live and sleep in the tent for 8 to 18 hours and complete their training at sea level (Wilber, 2007, 2004). The LH-TL altitude training model via oxygen filtration is the second simulated altitude training method that uses a form of the ‘hypoxic tent’. The purpose of this method is to creat a normobaric hypoxia environment for living and sleeping. This method uses an oxygen-filtration membrane and reduces the molecular oxygen concentration in the ambient air drawn from outside of the tent and the oxygen-reduced air is pumped into the tent with the help of a generator (Wilber, 2007). The other simulated altitude training model is the LH-TL via supplemental oxygen. The method allows athletes to live in a naturally high altitude/hypobaric hypoxic environment and train at a simulated sea level environment or created hyperoxic conditions for high intensity training at high altitude (Wilber, 2004).

In addition to the above LH-TL simulated altitude training models, other simulated altitude training methods were introduced to creat the LL-TH altitude training models. Athletes use the simulated LL-TH altitude training model in the form of intermittent hypoxic exposure (IHE) during rest and intermittent hypoxic training (IHT) during exercise (Wilber, 2004). Unlike the three models mentioned above, the LL-TH IHE method is used for the purpose of enhancing athletic performance through brief exposures to hypoxia (usually 1.5 to 2 hours with a 9 - 15% oxygen reduction; equivalent to ~ 6600m to 2700m a.s.l.), alternated with exposure to sea level atmospheric pressure, where the concentration of oxygen is 21%, with the intention of increasing serum erythropoietin and red blood cell concentration that ultimately increase $\dot{V}O_2$ Max and improve endurance performance (Hamlin et al., 2013; Wilber, 2007). As far as the IHT is concerned, the LL-TH training environment is created via the use of the IHE during training sessions (Wilber, 2007).



IHE (Intermittent Hypoxic Exposure), IHT (Intermittent Hypoxic Training), LH -TH (live high - train high), LH - TL (live high - train low), LH – THTL (live high – train low train high), LL - TH (live low - train high)

Figure 2.1 Contemporary altitude training models (Wilber, 2007)

Although endurance athletes in many countries are using altitude simulation methods to enhance their endurance performance, the World Anti-Doping Agency (WADA) and the International Olympic Committee (IOC) were debating the issue from the standpoint that using altitude simulation might violate the spirit of sport (Wilber, 2017; James, 2010; Møller, 2009; Wilber, 2007). In Italy, for example, the use of simulated altitude training practices is prohibited by law (Wilber, 2007). As far as the use of these altitude simulations or artificially induced hypoxic conditions by endurance athletes is concerned, WADA considered it a health risk if not properly implemented under medical supervision; and a violation of the spirit of Olympic sport, which celebrates natural talents and their virtuous perfection (Møller, 2009). In line with this, the IOC has prohibited the use of simulated altitude devices within the boundaries of the Olympic village since the 2000 Sydney Olympics (Wilber, 2017). In addition to the above limitations, the additional expense of construction, maintenance and use of simulated altitude devices/equipment and the inconvenience of living and sleeping for a specified number of hours for physiological benefit, which might interfere with the lifestyle of the athletes, are considered as the other drawbacks to using simulated altitude devices for the LH-TL training models (Wilber, 2017).

As indicated in the above figure (2.1), previous studies have tested different natural and simulated/artificial altitude training models in athletes. However, these training models have not been tested on east African athletes. Taking into account the challenges and availability of facilities and experts to test the effect of artificial/hypoxic training models on east African athletes, the current study intended to test the effects of the LH-THTL and LH-TH natural altitude training models on some selected physiological and endurance performance variables of Ethiopian junior long-distance athletes.

2.5 Altitude training models and their effects on sea level/low altitude native endurance athletes

2.5.1 Live High - Train High

Many coaches of athletes native to low altitudes firmly believe that preparation for a major sea level competition is incomplete unless a runner has undertaken a period of altitude training (Simpson & Bosch, 2014). By living and training at altitude, athletes expect to increase their RBC andHgb mass (Moran et al., 2004; Rusko et al., 2004; Wilber, 2004; Ge et al., 2002). In turn, increases in RBC and Hgb mass have been shown to enhance an athlete's oxygen-carrying capacity and allow the athlete to train and perform more effectively upon returning to lower elevations (Wilber, 2011; Saunders, Pyne, & Gore, 2009; Moran et al., 2004; Wilber, 2004; Levine & Stray-Gundersen, 1997).

Studies have reported drawbacks in the classic altitude training model. The LH-TL model was shown to induce negative effects causing performance determinants, thus masking and preventing the benefits from increased RBC (Wilber, 2004; Wilmore, 1999; Bailey & Davies, 1997). One probable reason for the absence of a positive altitude training effect was that even moderate hypoxia during exercise may substantially compromise training pace and decrease mechanical and neuromuscular stimuli, leading to gradual weakening of some specific determinants of endurance performance (Wehrlin & Hallén, 2006; Kayser, 2005; Niess et al., 2003). In addition to the above studies, there was also a recent study (Garvican-Lewis, Halliday, Abbiss, Saunders, & Gore, 2015) that assessed the total haemoglobin mass, red blood cell count, haematocrit and iron profile of low altitude native distance runners. This study applied the live high - train high (1800m a.s.l.) and live low - train low (600m a.s.l.) altitude training models at 1800m for three consecutive weeks and reported a significant change in total haemoglobin mass by the LH-TH group at week two (3.1% Vs. 0.4% , $p = 0.01$) and week three (3.0% Vs. -1.1%, $p < 0.02$), and in haematocrit at week two ($p = 0.01$) and week three ($p = 0.04$), as compared to the LL-TL group. Unlike the total haemoglobin mass and haematocrit percentage, no significant change in haemoglobin concentration ($p = 0.06$) was reported. After three weeks of the LH-TH altitude training at 1800m a.s.l., a substantial increase in total haemoglobin mass was identified among the runners in the LH-TH group. In this study, data of the haemoglobin index contradicted these results. Studies have indicated that haemoglobin concentration measurements are a bit misleading, due to changes in body fluids, and recommend using a more reliable total haemoglobin mass measurement using the carbon monoxide (CO) rebreathing method (Lombardi et al., 2013; Otto, Montgomery, & Richards, 2013; Schmidt & Prommer, 2005).

2.5.2 Live High - Train Low

Over the last decade, a significant number of studies have compared the effects of the four most common altitude training models (LH – TH, LH – TL, LL-TL and LL – TH) on endurance performance (Wehrlin et al., 2006; Saunders, Pyne, et al., 2004; Levine & Stray-Gundersen, 1997). In comparison with the LL-TL and LL-TH, significant improvements in runners' RBC mass, Hgb concentration and Hct percentage, and $\dot{V}O_2$ Max and thereby a positive acclimatisation effect and increase in the oxygen transport capacity of the blood was observed among subjects using the LH- TH and LH-TL altitude training models. However, only the LH-TL altitude training model results in a translation of the physiological adaptations into a better maximum running speed or endurance running performance (Humberstone-Gough et al., 2013; Lancaster & Smart, 2012; Lundby et al., 2012; Wilber, 2011; Wehrlin et al., 2006; Rusko et al., 2004; Wilber, 2004; Ge et al., 2002; Stray-Gundersen et al., 2001; Aulin, Svedenhag, Wide, Berglund, & Saltin, 1998; Levine & Stray-Gundersen, 1997).

2.5.3 Live High - Train High Train Low

As far as LH-TL altitude training is concerned, there is also a modified, natural live high - train high train low (LH-THTL) altitude training model. In this altitude training model, athletes live at high altitude and train basic endurance training at high altitude, while training high intensity, interval training at low altitudes (Stray-Gundersen & Levine, 2008; Wehrlin et al., 2006; Rusko et al., 2004; Stray-Gundersen et al., 2001).

In addition to the 3000m performance increase, a study by Stray-Gundersen et al. (2001) reported significant changes in haemoglobin concentration (13.3±1.1 $g.dL^{-1}$ to 14.3±1.1 $g.dL^{-1}$, $p \leq 0.05$) and haematocrit (41.0±2.5 % to 42.8±2.8 %, $p \leq 0.05$) from baseline to week four by the athletes in the LH-THTL study group. The relative positive changes in haemoglobin concentration and haematocrit in the four study weeks by the LH-THTL altitude training group were 7.51% and 4.4%, respectively. In this study, the four weeks of hypoxic exposure was the possible explanation for the observed haematological changes among athletes who lived and trained light and moderate altitude training at higher altitude. However, the haematological results from this study were contrary to other findings that reported drops in haemoglobin concentration and haematocrit values due to training load and/or training season variations.

2.6 Altitude training and the long-distance running success of athletes from east African nations native to high altitude

To the best of the author's knowledge, currently there is limited research available regarding the use of, or benefits from, altitude training models in successful Ethiopian and Kenyan endurance athletes born, raised and living at high altitude. According to Brutsaert (2008), high altitude natives are defined as individuals born, raised, and living above 2500m a.s.l. Based on this definition and anecdotal reports, most east African athletes are categorised as high altitude natives. In addition to the success of Ethiopian and Kenyan middle- and long-distance runners, athletes from Eritrea and Uganda have also demonstrated their outstanding long-distance running ability (IAAF, 2017a; 2015; Lucia et al., 2008; Lucia et al., 2006).

Interestingly, the birth places of most of the best east African endurance athletes are not evenly distributed throughout east Africa (Pitsiladis et al., 2007). Rather, they are concentrated in distinct high altitude regions of Kenya and Ethiopia, named Nandi and Arsi, respectively (Pitsiladis et al., 2007). Over the past five decades these areas have been serving as the training grounds for many endurance athletes who have dominated the Olympics and World Athletics Championships in distances ranging from 800m to the marathon (Pitsiladis et al., 2007).

2.6.1 The reasons behind the long-distance running success of east African athletes

The success of east African middle- and long-distance athletes is still an exceptional phenomenon in the world of athletics. Starting from the 1968 Mexico City Olympic Games, until the recent 2016 Rio Olympics, as well as IAAF World and Cross Country Championships, athletes from east African countries, mainly Ethiopia and Kenya, have topped the medal tables in middle- and long-distance events (IAAF, 2017a; 2015).

Researchers continue to pose the question: ‘Why do east African athletes dominate the world middle- and long-distance running?’ (Tucker, Onywera, & Santos-Concejero, 2015; Harm et al., 2013; Wilber & Pitsiladis, 2012; Pitsiladis et al., 2007; Hamilton, 2000). Based on this question, researchers have investigated many possible explanations underlying the success of these athletes, including genetics; haematological, physiological, biomechanical, biochemical, sociocultural, economical, psychological and nutritional factors, and training (Wilber & Pitsiladis, 2012) .

Despite numerous explanations proposed for the dominance of east African running (Wilber & Pitsiladis, 2012; Pitsiladis et al., 2007; Pitsiladis, Onywera, Geogiades, O'Connell, & Boit, 2004), to date no single factor has been identified that is solely responsible for the ever-growing middle- and long-distance running successes of these athletes. Based on this, it is generally accepted that successful athletic performance requires the optimal interaction of multiple factors, although most studies agree on the vital role of genetics (Ahmetov et al., 2015; Vancini et al., 2014; Tucker et al., 2013). However, research investigating the role of genetic predisposition has not been able to find a unique genetic explanation for the success of east African middle- and long-distance athletes (Ash et al., 2011; Scott & Pitsiladis, 2006; Scott et al., 2005; Scott, Moran, Wilson, Goodwin, & Pitsiladis, 2004).

A recent review by Vancini et al. (2014) reported that, to date, there is no single result that supports the genetic basis for the success of east African middle- and long-distance athletes (Lorenz et al., 2013; Wilber & Pitsiladis, 2012). In line with these studies, a review by Tucker et al. (2013) highlighted the important role of genetics in positively affecting endurance performance. In this article (Tucker et al., 2013), it was indicated that attempts have been made in the past to identify the genetic difference between east African and other endurance athletes; but no particularly responsible gene was isolated. Even though no study has reported a unique gene that is responsible for the exceptional east African running success, this recent review raised different points, including the possible limitations of the past genetic studies that involved high altitude native east African athletes (Ethiopia and Kenya). According to Tucker et al. (2013), the results of the previous studies were considered as incomplete, since they only focused on two candidate genes (Angiotensin Converting Enzyme, ACE and Alpha-actinin-3, ACTN3) and involved a small sample size. Other performance factors like environment and training were not properly controlled; and the genetic study did not compare east African athletes with other world-class distance runners worldwide. Based on the summary of this article, the successes of middle- and long-distance runners of east African origin might be attributed to the exposure of their optimal genetic factors to an optimal training environment; although the existing studies have not yet unveiled a single endurance gene that characterised elite east Africa endurance runners. In this regard, taking the limitations of the existing studies into consideration, it is difficult to fully accept the conclusions that the superior middle- and long-distance performances of east African athletes are not genetically mediated (Tucker et al., 2013).

In support of the above findings, a review (Wilber & Pitsiladis, 2012) reported no genetic traits but proposed some physiological ($\dot{V}O_2$ Max, skeletal-muscle-fibre characteristics, enzymatic profile, diet) and haematological advantages (total haemoglobin mass, total blood volume) of east African runners. The authors presented a hypothetical model to explain the success of Kenyan and Ethiopian distance runners (Figure 2.2). The model included biomechanical and physiological superiority; consistent aerobic training during childhood as a means of transport to and from school; moderate-volume, high-intensity training at altitude (2000-3000m); and psychological (high motivation to succeed for the purpose of improving socioeconomic status and a tradition of running excellence) characteristics as the factors proposed for the successes of east African middle- and long-distance athletes (Wilber & Pitsiladis, 2012).

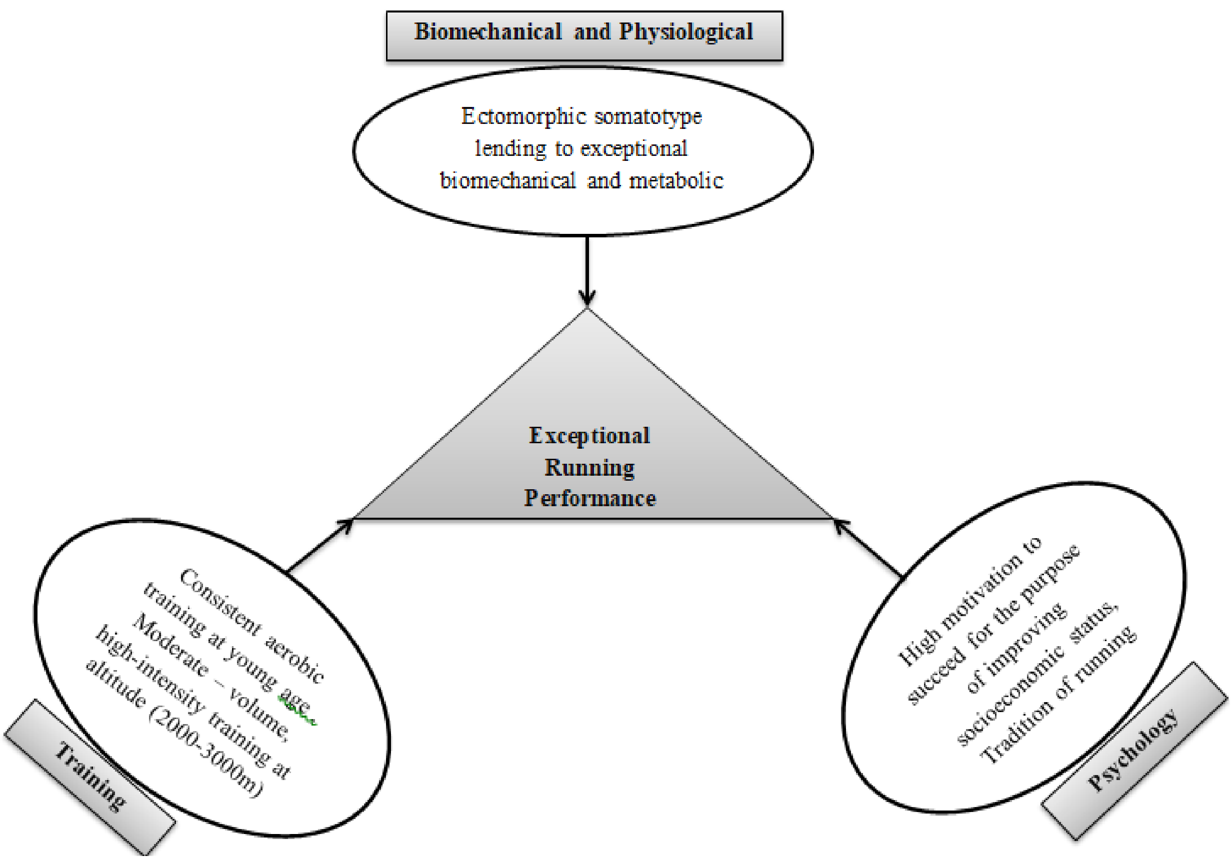


Figure 2.2 Hypothetical models to explain the extraordinary success of Kenyan and Ethiopian distance runners (Wilber & Pitsiladis, 2012)

As indicated in the above figure (2.2), different explanations have been provided for the successes of east African long-distance athletes. However, limited efforts have been made to investigate the majority of these proposed explanations using original research in the areas where the athletes live and train. Therefore, the major objective of the current study was to identify the effects of LH-THTL and LH-TH natural altitude training on some selected physiological and endurance performance variables in relation to one of the proposed explanations (Figure 2.2), i.e., moderate volume-high intensity training at altitude (2000-3000m a.s.l).

2.6.2 Anthropometric, haematological and physiological characteristics of east African athletes native to high altitude

Despite the successes of east African middle- and long-distance runners, studies investigating the contributory factors for their success have only been conducted recently. While the two earlier studies by Saltin, Larsen, et al. (1995) and Saltin, Kim, et al. (1995)are considered as the ground-breaking altitude-based research on athletes of east African origin, there are a few other published comparative studies that discuss some anthropometric, haematological and physiological characteristics of east African native high altitude and sea level endurance athletes (Wishnizer et al., 2013; Prommer et al., 2010; Pitsiladis et al., 2007; Lucia et al., 2006; Hamilton, 2000; Weston, Mbambo, & Myburgh, 2000; Saltin, Kim, et al., 1995).

A few studies have examined the role of anthropometric variables in the successes of east African endurance athletes (Mooses & Hackney, 2016; Wishnizer et al., 2013; Maldonado et al., 2002). In one of the first studies, high altitude Kenyan athletes were reported to be lighter and shorter than Scandinavian athletes (Saltin, Larsen, et al., 1995) Similar comparative studies between Kenyan and German (Prommer et al., 2010); Eritrean and Spanish (Lucia et al., 2006) and Ethiopian and Israeli (Wishnizer et al., 2013) athletes showed that east African athletes were lighter and shorter than athletes native to sea level. In support of these findings, a study by Mooses and Hackney (2016) described how these anthropometric variables may benefit east African athletes in the middle- and long-distance events. They suggested that body mass and height should not be overlooked and mentioned simply as descriptive parameters in performance studies, as these variables are considered major determinants of good running economy. Another study (Wishnizer et al., 2013) was conducted over two to six months and compared the anatomical, physiological and endurance performance differences of Ethiopian (ET) and Caucasian (CA) long-distance runners (over 10km) at sea-level. This study identified significant differences in selected anthropometric variables: the Ethiopian runners were lighter and shorter ($p < 0.001$) and were characterized by a lower body mass index ($p < 0.05$) than Caucasian athletes. Moreover, the study reported significant differences in running economy measured at maximal treadmill test (ET: $161.8 \pm 24.5^{-0.75kg}$/min Vs CA: $184.6 \pm 17.4^{-0.75kg}$/min, $p < 0.05$) and 10 km performance (ET: 30:36±00:43min:sVs CA: 32:24±00:20min:s, $p < 0.001$). This strengthened perceptions of the role of non-hematological variables in determining the success of long-distance running performance(Wishnizer et al., 2013).

There is currently limited haematological data from elite Kenyan and Ethiopian athletes (Wilber & Pitsiladis, 2012). The first study that involved high altitude native athletes was conducted by Saltin, Larsen, et al. (1995). Along with other physiological variables, this study assessed the Hgb concentration of both Kenyan and Scandinavian athletes at high altitude and sea level. Haemoglobin concentration in junior and senior Kenyan athletes ranged from 15.4 to $15.9 g.dL^{-1}$ at altitude (~2000m) and decreased to an average of $14.9 g.dL^{-1}$ seven days after they descended to sea level. Similarly to the Kenyan athletes, a slight change in Hgb concentration was observed in Scandinavian athletes when they were at high altitude ($14.9 g.dL^{-1}$) and after they descended to sea level ($14.6 g.dL^{-1}$). In another study, the altitude and sea level Hgb and Hct values for high altitude native Kenyan long-distance athletes, originally from the Kenyan Rift Valley, (between 2000m and 2500m a.s.l.) were compared (Pitsiladis et al., 2007). This study found that Hgb concentrations decreased from $164 \pm 9 g.L^{-1}$ at high altitude to $152 \pm 7 g.L^{-1}$ after seven days at sea level ($p \leq 0.05$). There was a similar decline in Hct values measured from 49±3% at high altitude to 45±2%, $p < 0.05$ at sea level.

One of the very few altitude training studies involving Kenyan athletes (n = 10) native to high altitude reported a decline in the mean Hgb concentration from $16.1 \pm 0.7 g.dL^{-1}$ (at baseline, 2090m a.s.l. Eldorate) to 15.4±1.0 $g.dL^{-1}$ two days after they arrived in Germany (340m a.s.l.); and 15.3±0.9$g.dL^{-1}$ after 40 days of training at 340m a.s.l. (Prommer et al., 2010). The study identified no difference in the haemoglobin concentrations between the Kenyan and German athletes (15.3±0.9$g.dL^{-1}$vs 15.5±1.2$g.dL^{-1}$, $p > 0.05$) after 40 days of endurance training at the specified altitude (340m). For the Kenyan athletes, the baseline measurement was taken within 12 hours of moving from Eldoret (2090m a.s.l.), the place where they had trained, to Nairobi (1600m a.s.l), where they were preparing to fly to Europe for 40 days of additional training and international competition (Prommer et al., 2010). The same study also identified a similar decline in Hct value from 48.6±2.4% at baseline at high altitude to 46.5±2.9% two days after the Kenyan athletes arrived in Germany (340m a.s.l.) and 46.1±2.1% after 40 days of endurance training at low altitude (340m a.s.l.). As far as the haematocrit values are concerned, no significant difference was reported between the Kenyan and German athletes (46.1±2.1% vs 45.4±3.1%, $p > 0.05$) after the Kenyan athletes had trained at 340m a.s.l. for 40 days. Although a decline in total haemoglobin mass was reported in the Kenyan athletes (~6% after 33 days living and training at 340m a.s.l.), this decline (total haemoglobin mass) did not affect the athletes' $\dot{V}O_2$ Max, as other similar studies reported (Lucia et al., 2006; Weston et al., 2000). Finally, the study (Prommer et al., 2010) concluded that haematological variables like total haemoglobin mass and blood volume were not the reasons for the superior running performance of Kenyan athletes, since all the measured haematological and physiological parameters were in the same range as those of the native low altitude athletes from Germany.

Another study compared Eritrean (who share the same genetic and cultural origins as Ethiopians) and Spanish long-distance athletes and reported no significant differences in RBC count (5.04±0.17 vs 4.95±0.16 x $10^6.\mu L^{-1}$, $p > 0.05$), Hgb concentration (15.4±0.3 $g.dL^{-1}$vs 15.1±0.4 $g.dL^{-1}$, $p > 0.05$) and Hct value (45.1±1.2% vs 45.2±1.1%, $p > 0.05$). The haematological findings in this study (Lucia et al., 2006) support other findings that reported no significant differences between east African high altitude native and sea level athletes (Prommer et al., 2010; Saltin, Larsen, et al., 1995). The Eritrean athletes (n = 7) who were involved in this study were native high altitude long-distance athletes who lived and trained at ~3000m a.s.l. in the capital Asmara before they travelled to sea level for international competition and laboratory tests at low altitude (~600m). Before the haematological and performance tests were conducted, they had spent two weeks at sea level and low altitude (~600m) in Europe. In this study, no baseline data (haematological) from the two groups were reported, so it was not possible to track a connection between the athletes' haematology and changes in performance. Although no significant differences between the two study groups were reported in the selected haematological indices (RBC, Hgb, and Hct), the time spent at sea level and low altitude, as well as the change in altitude by the Eritrean athletes from high altitude to sea level might indicate the possible haematological changes among the athletes in the same way as the past studies (Prommer et al., 2010; Pitsiladis et al., 2007).

2.6.3 Non-haematological variables and endurance performance of east African athletes native to high altitude

Over the last five decades, athletes from different sports have incorporated altitude training as part of their yearly training plan. One of the primary reasons behind this practice is the potential haematological advantage that can be gained (Wachsmuth et al., 2013; Garvican et al., 2012; Robertson, 2009). However, Prommer et al. (2010) confirmed that haematology-based oxygen transport of the blood cannot explain the superior endurance performance of Kenyan runners, since most measured parameters are in the same range as those of elite, German runners native to low altitudes.

Researchers identified the significant role of non-haematological variables in enhancing endurance performance following altitude training (Lundby, 2016; Wishnizer et al., 2013; Prommer et al., 2010; Gore et al., 2007; Weston et al., 2000). As Gore et al. (2007) argued that other non-haematological variables like angiogenesis, glucose transport, glycolysis, and pH regulation are partly responsible for improving endurance performance following hypoxic exposure. In support of this, superior running economy and lower lactate levels during exercise testing were shown to differentiate Kenyan from Scandinavian athletes (Pitsiladis et al., 2007; Saltin, Larsen, et al., 1995).

To date, there is no data regarding the skeletal-muscle-fibre characteristics and enzymatic activity of elite Ethiopian distance runners (Wilber & Pitsiladis, 2012), whilst one study examined these characteristics in Kenyan athletes compared with Scandinavian athletes (Saltin, Kim, et al., 1995). No statistically significant differences were reported in terms of skeletal muscle fibre type and size, capillary density, or activity of the oxidative enzyme citrate synthase, and muscle-fibre composition between elite Kenyan and Scandinavian runners (Saltin, Kim, et al., 1995). However, other studies confirmed the dominant roles of anthropometric characteristics, running economy and early childhood lifestyle (training) as the possible explanation behind the superior running performance of east African long-distance athletes (Wishnizer et al., 2013; Wilber & Pitsiladis, 2012; Lucia et al., 2008; Lucia et al., 2006).

2.7 Natural altitude training models and endurance performance changes

In contrast with laboratory based, simulated altitude training studies, there are few published natural altitude training studies (Wehrlin & Hallén, 2006; Wehrlin et al., 2006; Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997). The majority of these studies targeted sea level/low altitude native athletes and reported the physiological and performance effects of different altitude training models in different ways, including $\dot{V}O_2$ Max, lactate threshold, time to exhaustion, maximal aerobic speed, race performance and time trials (Wehrlin & Hallén, 2006; Niess et al., 2003; Stray-Gundersen et al., 2001).

A few altitude studies have been conducted on endurance athletes using natural altitude environments to assess the effects of different altitude models on physiological and performance outcomes (Wehrlin & Hallén, 2006; Niess et al., 2003; Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997). To the best of the authors' knowledge, none of these studies targeted athletes of African origin native to high altitude, or examined the effects of an extended period of training using different altitude training models on the performance outcomes of these athletes at high altitude.

There are some classical studies that examined the effects of extended weeks of natural altitude training on the endurance performance of athlete resident at sea level. One of the exemplary studies was an experimental study by Levine and Stray-Gundersen (1997). In this study, 39 athletes were initially matched, based on their fitness/performance levels and randomly assigned into three groups LL-TL (control), LH-TH (experimental), and LH-TL (experimental). After four weeks of the study, in comparison with the pre-altitude values, significant changes were indicated during post-altitude (three days after the end of the experimental period) sea level tests in the LH-TL and LH-TH groups in Hgb concentration (5%), red blood cell volume (9%), and $\dot{V}O_2$ Max (4%). In terms of the performance test, however, only athletes in the LH-TL experimental group improved their 5000m performance by an average of 13.4 seconds (1%).

In 2001, the physiological and performance effects of LH-THTL was examined (Stray-Gundersen et al., 2001). This study was based on the initial findings of Levine and Stray-Gundersen (1997) and was conducted on high level, low altitude native long-distance runners. The findings of the study indicated that after four weeks of LH-THTL training, there were significant improvements in Hgb concentration ($1.0 \pm 1.1 g.dL^{-1}$), red blood cell count (103±74%), and $\dot{V}O_2$ Max (2.3 ± 2.6 $ml.kg^{-1}.min^{-1}$). A 1.1% improvement in performance over the 3000m (pre: 8:45.2±0:39 to post: 8:39.6±0:39 min:s, $p \leq 0.05$) was observed following the four weeks altitude training by all athletes, with similar improvements in male (pre: 8:18.4±0:14.0 and post: 8:12.6±0:10.8 min:s, $p < 0.10$) and female (pre: 9:32.4±0:11.1 and post: 9:26.9±0:11.3 min:s, $p \leq 0.05$) athletes (Stray-Gundersen et al., 2001).

Despite the fact that these two studies (Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997) identified both positive physiological changes and performance improvements in sea level-living athletes, no similar study has been published in high altitude native athletes. The available altitude-based studies that involved athletes native to high altitude were comparative studies with those of sea level athletes (Wishnizer et al., 2013; Lucia et al., 2006; Weston et al., 2000; Saltin, Kim, et al., 1995; Saltin, Larsen, et al., 1995) and the studies mainly focused on identifying differences in selected haematological and non-haematological variables, rather than conducting intervention-based experimental studies.

In Ethiopia, thousands of young long-distance athletes are living and training at high altitudes, ranging between 2500m and 3000m. Due to a lack of the proper utilisation of different altitude training methods by both athletes and coaches, the athletes are generally forced to train at all training intensities (light, moderate, and high) at these high altitudes. In the principal investigator's long years of experience in coaching athletics and working as the technical committee of the national athletics federation, he has seen a significant number of young middle- and long-distance athletes being forced quit their athletic careers before reaching to their genetic potential because of the misuse of altitude training. Although the country's altitude varies from low to high within very short distances, currently endurance athletes and coaches in the country are not benefiting from these cheap, easily available, and geographically accessible altitude variations to minimise high altitude-related training challenges, and to improve the endurance performances of the athletes beyond the current level of their achievements.

Since the 1968 Summer Olympics were awarded to the city of Mexico, numerous altitude-based studies have been conducted and different altitude training models have been introduced to enhance the endurance performance of athletes in various sports at sea level. Throughout the years, significant numbers of athletes, coaches and sport scientists have been involved in these studies, although the majority of the studies were focusing on enhancing the athletic performance of athletes native to sea level and low altitudes. Unlike at sea level and low altitude areas, endurance training and competitions are challenging at relatively higher altitudes (Hamlin et al., 2015; Wehrlin & Hallén, 2006; Kayser, 2005; Niess et al., 2003). Based on anecdotal and research evidence, endurance athletes who live and train at high altitude areas like Ethiopia and Kenya are more exposed to challenging and strenuous training at high altitude than at sea level (Wilber, 2007). Therefore, it is rational to search for optimal, less risky, alternative altitude training approaches for high altitude long distance athletes. To date, to the best of the authors' knowledge, no study results have been reported that assessed the physiological (haematological, autonomic, neuromuscular), training load-responses and performance effects of any one of the most common natural altitude training models among high altitude native, east African origin, long distance athletes.

This study, therefore, set out to identify an optimal altitude training model that enhances the long-distance running performance of young Ethiopian athletes. In the process of meeting this objective, the study has come up with original findings that might fill the research gaps that have been observed for decades regarding the effects of natural altitude training models (LH-TH and LH-HTL) on some selected physiological and performance variables of high altitude native Ethiopian (east African) athletes. It is also believed that the major findings of this study might be used by other athletes and coaches in related and/or different endurance sports that share similar natural altitude conditions. The efforts that have been made to study and provide alternative altitude training models for young long-distance athletes native to high altitude might help them to reach their genetic potential with the proper training approaches (stress-recovery balance), thereby minimising the attrition rate of young athletes, enabling them to compete for longer.

In general, to the best of the authors' knowledge, this study is the first of its type to assess some selected physiological and performance variables of African athletes who were born, live and train at high altitude; and to compare these findings with reputable study results of endurance athletes native to sea level and low altitudes.

.CHAPTER THREE: THE DEMOGRAPHIC CHARACTERISTICS STUDY (MANUSCRIPT)

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This manuscript presents the results of the demographic characteristics of three groups of Ethiopian long-distance athletes. The study compares demographic characteristics between the retired, current elite and junior long-distance athletes of Ethiopia.

Target journal: Journal of Sport Science

Title: The demographic characteristics of junior Ethiopian long-distance athletes, past and present.

Abstract

Background: To date there is no single factor that has been identified as solely responsible for the ever-growing middle- and long-distance running successes of athletes from the high altitude nations of Kenya and Ethiopia. The aim of the study was to identify differences in demographic characteristics between the retired, current elite and junior Ethiopian long-distance runners. **Methods:** A total of 83 endurance runners were involved in this study. The athletes were classified into three separate groups based on their current performance status and age as retired elite (n = 32), current elite (n = 31) and academy junior athletes (n = 20). The average ages of the athletes in the three groups were 38±7.6, 25±4.5, and 18±1.2 years for retired elite, current elite and junior group athletes, respectively. **Results:** Although the demographic characteristics study identified significant difference between the three groups in the age at which formal training started ($p < 0.001$), no significant difference was identified between the groups ($p > 0.05$) regarding the altitudes where the athletes were born and raised. Moreover, the study reported no significant difference in the daily distance covered to and from school between the three groups during their primary education ($p > 0.05$) but not during their secondary education ($p < 0.05$).. There was also no significant difference ($p = 0.05$) between the three groups in the mode of transportation used to cover the daily distance to and from school. In addition to the above findings, this study also found no statistically significant difference in the types of major out-of-school activities between the three groups of athletes during their childhoods ($p > 0.05$). **Conclusion:** The findings of this study confirmed that the 20 junior athletes who were involved in the altitude study shared common demographic characteristics with the retired and current elite Ethiopian long-distance athletes.

Keywords: retired, current elite, junior athletes, home to school, regional distribution, mode of transportation, out-of-school activities

3.1 Introduction

The success of east African middle- and long-distance athletes is still an exceptional phenomenon in the world of athletics. Since the 1968 Mexico City Olympics, until the recent 2016 Rio Olympics, as well as in the recent IAAF World and Cross Country Championships, athletes from east African countries mainly, Ethiopia and Kenya, have been at the top of the medal tables in middle- and long-distance events (IAAF, 2017a; 2015).

Despite numerous explanations being proposed for the dominance of east African running (Wilber & Pitsiladis, 2012; Pitsiladis et al., 2007; Pitsiladis et al., 2004), to date there is no single factor that has been identified as solely responsible for the ever-growing middle- and long-distance running successes of athletes from these high altitude nations (Pitsiladis et al., 2004). Among the many explanations, genetic predisposition (Vancini et al., 2014; Scott et al., 2005; Scott et al., 2004); haematological characteristics (Wishnizer et al., 2013; Lucia et al., 2006); anthropometry and morphology; and superior biochemistry; nutritional and environmental conditions; psycho-social factors (Baker & Horton, 2003); childhood way of life; and living and training at high altitude were commonly quoted explanations (Pitsiladis et al., 2004). The daily home-to-school distance covered by east African long-distance athletes during childhood has been one of the explanations suggested for their endurance success (Onywera, Scott, Boit, & Pitsiladis, 2006; Baker & Horton, 2003; Saltin, Larsen, et al., 1995). Studies suggest that a combination of physical activity during childhood and intense training as teenagers contribute for the higher $\dot{V}O_2$ Max in Kenyan athletes (Saltin, Larsen, et al., 1995). Unlike the above studies, a study by Enomoto and Ae (2005) compared the biomechanical (running techniques) aspects of Kenyan and Japanese long-distance athletes.

According to this pioneering study (Saltin, Larsen, et al., 1995), the athletes involved used to walk 8 - 12km per day for five days a week, starting from the age of seven or eight. In addition to the daily distance covered to and from school, the study also identified that the athletes started regular training at the age of 15 years or when they started high school. According to the long term athlete development (LTAD) model this age is proposed to be the stage when athletes almost finish the training for training and start training for competition (Ford et al., 2011). The LTAD model is clearly designed to meet growth-related physiological and performance changes in which the athlete's training demands are met (Ford et al., 2011). Although this study reported distance covered to and from school and other childhood physical activities as one of the contributors to good endurance performance, the samples from which the data were collected was small and the home-to-school distance was not measured but was collected using questionnaires.

The first study (Scott et al., 2003) investigated the daily distance covered to and from school and the mode of transportation in Ethiopian long-distance athletes and concluded that the marathon athletes differ significantly from other track and field athletes: control and track and field ($p = 0.8$), control and 5-10km athletes ($p = 0.8$), track and field and 5-10km ($p = 0.7$). However, there were significant differences between the control and marathon ($p < 0.001$), track and field and marathon ($p < 0.01$), and marathon and 5-10km ($p = 0.015$) groups in the daily distance covered to and from school in childhood (Scott et al., 2003). In this study it was also reported that, as compared to athletes in the 5-10km (40%), track and field (32%), and control groups (36%), 73% of athletes in the marathon team covered more than 5km to and from school each day (Scott et al., 2003).

A study by Onywera et al. (2006), which researched the distance travelled to and from school, reported differences between the control and national ($p = 0.01$), control and international ($p = 0.002$), and national and international athletes ($p = 0.020$). According to this study, 75% the control, 49% of the international and 58% of the national level athletes travelled less than 5km to and from school every day. However, only 9% of the control, 11% of the national and 23% of the international level athletes used to travel more than 10km to and from school every school day.

A study by Onywera (2011) compared differences between the control, national and international endurance athletes in their mode of transportation and their movements and identified that 22%, 73%, and 83% of the study participates (athletes), respectively, used to run to school each day and covered greater distances, respectively, although the distances were not mentioned (Onywera, 2011). One of the limitations of this study was that, like the other studies, it did received information about the distances covered to and from school using questionnaires.

In terms of mode of transportation, differences had also been observed between athletes in the marathon team and control ($p < 0.001$), track and field ($p < 0.001$), and 5-10km ($p < 0.01$) athletes. No significant difference was identified between the track and field and 5-10km ($p = 0.18$) athletes. Moreover, when the modes of transportation of the athletes in the four groups was examined, the majority of the marathon athletes (68%), 31% of the 5-10km, 16% of the track and field and 24% of the control group used running as their mode of transportation to and from school in childhood.

Geographical - Distribution

Unlike the physiological and genetic studies, the few studies that appraised the role of environmental, training and childhood lifestyles of Kenyan and Ethiopian endurance athletes were not based on first-hand information, or sufficient sample size, and were poor in study design (Larsen & Sheel, 2015). Based on reports in the existing research concerning athletes from east African countries, particularly Kenya and Ethiopia, very few independent studies were conducted beyond the physiological and genetic studies. Most of the psychological, social, environmental and lifestyle studies were included in the few physiological and genetic studies.

Some studies focused on the geographical distribution of the successful east African middle- and long- distance athletes, following their achievements in international competition (Onywera, 2011; Onywera et al., 2006; Scott et al., 2003). A study conducted on Ethiopian long-distance athletes (Scott et al., 2003) indicated that the athletes in the marathon team were significantly different from other track and field athletes, but not from the athletes in the 5km and 10km events, in their place of birth. Specially, as compared to the control group, the majority (73%) of the athletes in the marathon team were from two regions: Arsi and Shoa. Most of the Kenyan and Ethiopian successful middle- and long-distance athletes were from specific areas and ethnic groups (Onywera, 2011)

Other studies reported that environmental factors are influential in the superior running performances of east African middle- and long-distance runners (Wilber & Pitsiladis, 2012; Pitsiladis et al., 2007). One of the major findings of a study by Saltin, Larsen, et al. (1995) highlighted the role of ethnic and geographical distribution (cultural and environmental factors) in producing elite athletes in Kenya (Saltin, Larsen, et al., 1995). A decade after this study, research in Kenya and Ethiopia again confirmed distinct regions and ethnic groups as the sources of successful long-distance athletes, both in Kenya and Ethiopia. These studies commonly identified cultural and environmental conditions, like altitude and training at altitude, and daily long distances travelled to and from school during childhood. These findings have partially been proposed as some of the reasons for the extraordinary endurance performance of Ethiopian and Kenyan athletes (Onywera et al., 2006; Scott et al., 2003).

Studies frequently reported that east African middle- and long-distance athletes are not evenly distributed throughout Ethiopia (Scott et al., 2003) and Kenya (Onywera et al., 2006). It was indicated that Arsi and Nandi were the two most well-known high altitude areas where the majority of the world-class middle-and long-distance athletes were concentrated in Ethiopia and Kenya, respectively. In addition to long distances covered to and from school and mode of transportation, it was reported that, among the elite endurance runners of Ethiopia and Kenya, the majority of these athletes spoke languages of Cushitic and Bantu origin, respectively (Pitsiladis et al., 2007). These findings suggested that genetic variation would explain this concentration and could be a reason for the success of Ethiopian and Kenyan athletes.

In general, the demographic characteristics of the athletes in the two prominent east African countries, in comparison to the control groups, were characterised by geographical clustering (high altitude areas of Arsi and Nandi), active childhood lifestyles, and distinct ethnic and language origins. Although these studies were the first to study the demographic characteristics of Ethiopian and Kenyan middle- and long- distance athletes, to the best of our knowledge no other studies were reported in the past 13 and 15 years on Ethiopian and Kenyan athletes respectively. Therefore, identifying the differences in the environmental factors (mainly demographic characteristics) between the Ethiopian retired, current elite and academy junior long distance athletes was the major objective of this study. To meet this objective, mainly the age at which formal training started, the altitude where the athletes born and raised at childhood, the distance travelled to and from school, the regional distribution of the athletes, the modes of transportation used at childhood as well as the out-of-school activities of the athletes at childhood were assessed and compared.

3.2 Methodology

Participants

A total of 83 endurance runners were involved in this study. The athletes were classified into three separate groups based on their current performance status and age as retired elite athletes who had been members of the national team and had finished their athletic career (n = 32); current elite, athletes who were in the national team during the study period (n = 31); and academy junior athletes, junior athletes who had trained in the national academy for a continuous of four years (n = 20). The average ages of the athletes in the three groups were 38±7.6, 25±4.5, and 18±1.2 years for retired elite, current elite and junior group athletes, respectively. All the retired athletes had been members of the national team since the early years of the Ethiopian athletics success (from 1992) until 2008. The current elite athletes were members of the national team actively competing at international level, including the 2012 London Olympics, the 2013 and 2015 World Championships, the 2016 Rio Olympics and the 2017 World and Cross-Country Championships. The academy junior athletes were long-distance athletes who were living and training at the national athletics training centre at the time of the study. All the athletes were professional long distance athletes. Except for the academy junior athletes, almost all of the selected retired and current elite athletes were frequent participants, with regular success, in events longer than or equal to 5km. The academy junior athletes were mainly prepared for competitions at national level and some of them were also members of the national long-distance team.

All of the athletes provided written informed consent before their participation in the study, which was approved by the College of Natural and Computational Sciences Research

Ethics Committee. Of the total participants, 53.1% (n = 17), 45.2 % (n = 14), and 20 % (n = 4) of the athletes in the retired, current elite and junior athletes, respectively, were female athletes. Moreover, in their past (retired) as well as current (current elite and academy junior) athletic careers, 62.5% of the retired, 19.4% of the current elite and none of the junior athletes had/have regularly participated and been successful in between four and six recognised middle- and long-distance events in international competitions.

Data Collection

Demographic data were collected both physically and through questionnaires. Data were collected from the retired athletes through interviewer-administered questionnaires and forms. Self-administered questionnaires were also used to collect data from the athletes. The self-administered questionnaire was translated into the two dominantly spoken languages – Amharic and Afan Oromo (Appendix VIII and IX). The home-to-school distances, as well as the places where retired and current elite athletes were born and raised, were measured using a Global Positioning System (Garmin forerunner 910XT).

Study Design

Questionnaire. Items like date of birth (current age); age at which formal training (running) started; altitude at birth; altitude during childhood; distance travelled to and from school during primary (grades 1-6 and/or 1-8) and secondary (grades 9-12) education; place of birth (Zone); the region where the athletes were represented; mode of transportation to and from school; and major out-of-school activities were included in a questionnaire. All the current elite (n=31) and junior (n=20) athletes filled in the questionnaire themselves. Only 46.8% of the retired elites (n=15) filled in the questionnaire and the rest 53.2% (n=17) of the retired elite athletes responded to the questionnaire via telephone.

Home-to-school distance. The home-to-school distance was used to examine the differences in daily distance covered to and from school between the three groups during their primary and secondary education. The home to school distance of 71.8% (n = 23) and

58.1% (n = 18) of retired and current elite athletes, respectively, was measured physically using a watch with Global Positioning System (Garmin forerunner, 910X).

Mode of transportation. The athletes were asked to choose the mode of transportation that they most frequently used to cover the daily distance to and from school. Although access to different modes of transportation varied from year to year following infrastructure expansion, in this study the athletes were asked to choose from the most widely and practically used modes of transportation in the countryside. In this regard walking, walking and sometimes jogging, frequently jogging, frequently running, and other modes of transportation (animal assisted and/or motorised) were given as choices for the athletes.

Out-of-school activities. The question related to daily out-of-school activity and was designed to assess the daily lifestyle of the athletes during childhood, along with the daily distance travelled to and from school.

3.3 Statistical Analysis

One-way analysis of variance with Bonferroni post-hoc testing was performed to compare current age; age at which formal running training started; altitude at birth and during childhood; home-to-school distance (elementary education); and home-to-school distance (secondary education) across the three groups (retired elite athletes, current elite athletes, junior athletes). Pearson Chi-Square testing was used to analyse non-parametric data like place of birth, regional distribution, modes of transportation, and out-of-school activities. Statistical significance was declared at $p < 0.05$. Analysis was performed using SPSS version 23.

3.4 Results

Age at which formal training started, altitude at birth and childhood

There was statistically significant difference between the three groups in the age at which formal training started ($p < 0.001$). In the age at which formal training started among the three groups, the pair-wise analysis revealed that there were significant differences between the retired and junior ($p < 0.001$), and currently elite and junior ($p < 0.001$), and retired and current elite (*p* < 0.001) athletes. The pair-wise analysis result also indicated that there were no age differences between the retired and currently elite athletes in the time formal training was started. As it is indicated in the descriptive data (Table 3.1), the age at which formal training started was almost the same for the retired (16.4±1.8) and currently elite (16.0±1) athletes although the junior (14.4±0.9) groups started by two years earlier than the two groups.

As far as the altitude where the athletes born and raised during childhood are concerned, no significant difference was identified between the groups ($p > 0.05$). Based on the data in Table 3.1, the mean altitude where athletes born and raised during childhood for the three groups is above 2500m a.s.l.

Table 3-1: Current age, age at which formal training started, altitude at birth and childhood, home-to-school distance

Characteristics	Groups	N	Mean	SD	95% CI for Mean	
					Lower Bound	Upper Bound
Current age in years	Retired Elite	32	38.3	7.6	35.6	41.1
	Current Elite	31	25.4	4.5	23.8	27.0
	Junior	20	18.4	1.2	17.8	18.9
	Total	83	28.7	9.8	26.6	30.8
Age at which formal running training started in years	Retired Elite	32	16.4	1.8	15.7	17.0
	Current Elite	31	16.0	1.0	15.6	16.4
	Junior	20	14.4	0.9	14.0	14.8
	Total	83	15.8	1.6	15.4	16.1
Altitude at birth and childhood in meters	Retired Elite	32	2542	235	2458	2627
	Current Elite	31	2606	210	2530	2683
	Junior	20	2630	213	2530	2730
	Total	83	2587	221	2539	2636
Home to school distance in km (elementary education)	Retired Elite	32	7.0	4.5	5.3	8.6
	Current Elite	31	5.3	3.3	4.1	6.5
	Junior	20	5.9	4.6	3.7	8.1
	Total	83	6.1	4.1	5.2	7.0
Home to school distance in km (secondary education)	Retired Elite	13	4.3	3.6	2.1	6.5
	Current Elite	8	10.7	7.9	4.0	17.3
	Junior	6	3.2	1.5	1.6	4.7
	Total	27	5.9	5.8	3.7	8.2

Home-to-school distance

The one-way analysis of variance (ANOVA) result revealed that there was no statistically significant difference in the daily distance travelled to and from school (round trip) between the retired, current, and junior athletes ($p > 0.05$) during the early school ages (primary education). There was a significant difference in the daily distance travelled to and from school during the athletes' secondary education between the three groups ($p < 0.05$). Based on the pair-wise comparison there were also significant differences between retired and current elite ($p < 0.05$), as well as current elite and junior ($p \leq 0.05$), athletes in the daily distance travelled from home to school during their secondary education. The mean daily distances for retired, current elite and junior athletes were 4.3 ±3.6km, 10.7±7.9km, and 3.2±1.5km, respectively.

Table 3-2: Daily distances travelled to and from school during primary education

Distance Covered	Retired Elite		Current Elite		Academy Junior	
	Count	Percentage	Count	Percentage	Count	Percentage
< 5km	17	53.1	18	58.1	11	55.0
>5 to < 10km	10	31.3	11	35.5	6	30.0
> 10 to < 15km	3	9.4	2	6.5	2	10.0
>15km	2	6.3	0	0.0	1	5.0
Total	32	100	31	100	20	100.0

The majority of the athletes in each group, i.e., retired, current and academy juniors daily travelled less than or equal to 5km per day to and from school (round trip). Moreover, above 80% of these athletes in each group daily covered less than 10km to travel to and from school (round trip) during their primary education (Table 3.2).

Table 3-3: Places where athletes were born and raised

Place of birth (Zones)	Groups												Total	
	Retired Elite				Current Elite				Junior					
	Number	% within group	% within code birth place	% of total	Number	% within group	% within code birth place	% of total	Number	% within group	% within code birth place	% of total	Number	% within group
Arsi	19	59.4	51.4	22.9	9	29.0	24.3	10.8	9	45.0	24.3	10.8	37	44.6
West Shoa*	2	6.3	28.6	2.4	3	9.7	42.9	3.6	2	10.0	28.6	2.4	7	8.4
Gojam	1	3.1	14.3	1.2	2	6.5	28.6	2.4	4	20.0	57.1	4.8	7	8.4
Tigray	2	6.3	25.0	2.4	5	16.1	62.5	6.0	1	5.0	12.5	1.2	8	9.6
Benishangul	0	0.0	0.0	0.0	1	3.2	33.3	1.2	2	10.0	66.7	2.4	3	3.6
North Shoa*	3	9.4	75.0	3.6	1	3.2	25.0	1.2	0	0.0	0.0	0.0	4	4.8
Addis Ababa*	3	9.4	60.0	3.6	2	6.5	40.0	2.4	0	0.0	0.0	0.0	5	6.0
South Shoa	1	3.1	25.0	1.2	3	9.7	75.0	3.6	0	0.0	0.0	0.0	4	4.8
Wollo Tenta	0	0.0	0.0	0.0	3	9.7	100.0	3.6	0	0.0	0.0	0.0	3	3.6
Others	1	3.1	20.0	1.2	2	6.5	40.0	2.4	2	10.0	40.0	2.4	5	6.0
Total	32	100	38.6	38.6	31	100	37.3	37.3	20	100	24.1	24.1	83	100

*In former years they were under Shoa Province (18.8%)

The Pearson Chi-Square (χ^2) tests revealed that there were no significant differences in the distribution of the locations between where the retired, current elite and academy junior athletes were born and raised ($p = 0.088$). However, the data in the descriptive statistics (Table 3.3) shows the majority of the athletes in the retire, current, and junior groups were born in Arsi Zone. In comparison to the retired elite athletes, a more even distribution in place of birth was observed among the current elite athletes. When the birth places of the athletes from the three groups are considered as a whole, the largest group were still born and raised in Arsi zone (44.6%).

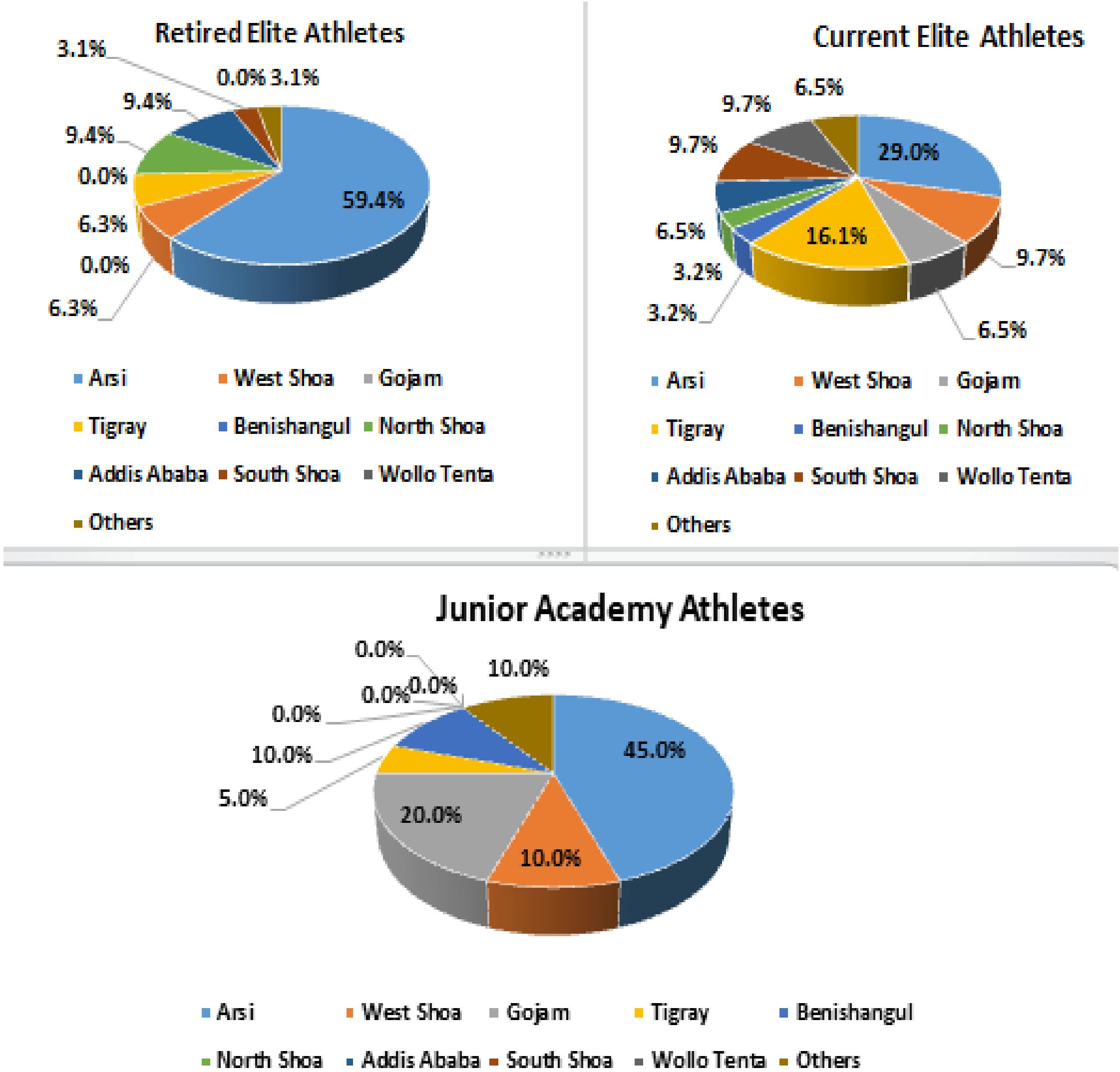

Figure 3.1 Places where athletes were born and raised

The study also revealed that there were significant regional distribution differences between the three groups (p = 0.002). As can be seen in the table (Table 3.4), the athletes in the retired and junior groups were predominantly from central Ethiopia. However, in the current elite group the distribution was fairly evenly shared between the central and north and north-west regions of Ethiopia. In comparing the three groups, it can be seen that the current elite group have relatively more athletes from south and south-west Ethiopia (12.5%).

Table 3-4: Regional distribution of athletes

Regional/Geographical Distribution		Group			Total
		Retired Elite	Current Elite	Junior	
Central Ethiopia	Number	26	15	11	52
	Percentage	81.3	48.4	55	63
North and North-West Ethiopia	Number	3	12	6	21
	Percentage	9.4	38.7	30	25
Western Ethiopia	Number	0	0	3	3
	Percentage	0	0	15	4
South and South-West Ethiopia	Number	3	4	0	7
	Percentage	9.4	12.5	0	8
Total	Number	32	31	20	83
	Percentage	100	100	100	100

There were no significant differences (p = 0.05) in the mode of transportation between the three groups in their travel to and from school during their childhoods. For example, higher percentage of the retired, current elite and junior athletes walked to school every day (Figure 3.2). In contrast to the junior and current elite athletes, a higher proportion of the retired athletes (43.8%) used both walking and jogging as their mode of transportation.

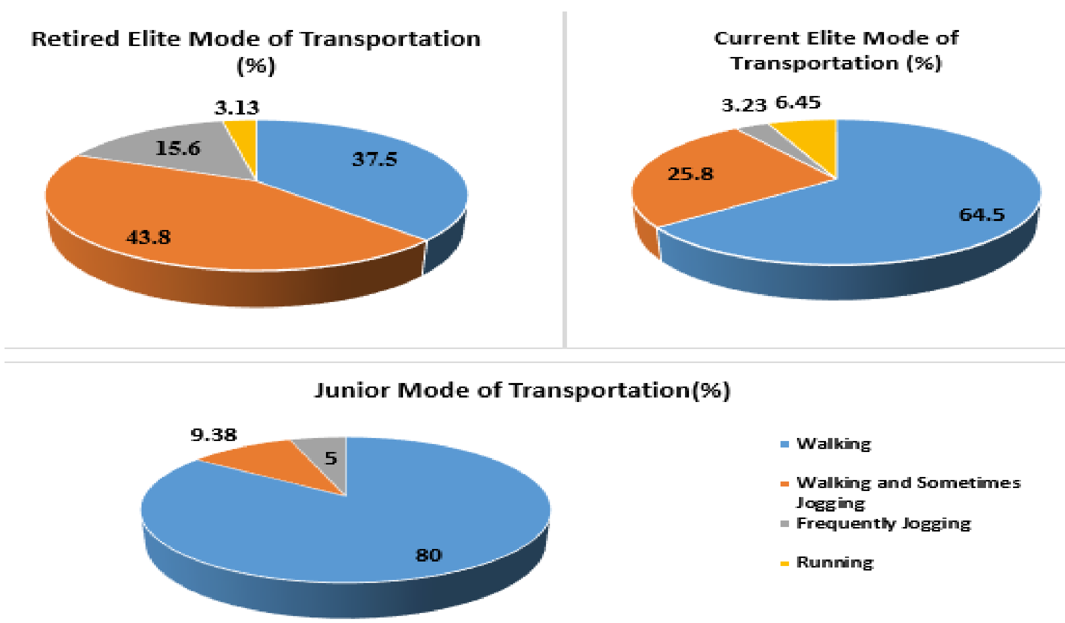

Figure 3.2 Modes of transportation of athletes (Primary Education)

This study identified that there was no statistically significant difference in the types of major out-of-school activities between the three groups of athletes during their childhoods ($p > 0.05$). Although no significant differences had been observed in the major out-of-school activities between the groups, clear differences were identified within the group's out-of-school activities. As is indicated in Table 3.5, housework, housework and fetching water, farming, as well as farming and cattle herding, were the major out-of-school activities that the athletes were involved in during their childhoods in all the three groups.

Table 3-5: Out-of-school activities

Dominant out-of-school activities		Group		
		Retired Elite	Current Elite	Junior
Housework	Number	12	9	5
	Percentage	37.5	29.0	25
Housework and fetching water	Number	6	5	1
	Percentage	18.8	16.1	5
Housework and cattle herding	Number	1	3	0
	Percentage	3.13	9.68	0
Farming	Number	8	4	3
	Percentage	25	12.9	15
Cattle herding	Number	0	3	6
	Percentage	0	9.68	30
Farming and cattle herding	Number	4	6	4
	Percentage	12.5	20	20
Housework and other activities	Number	0	1	0
	Percentage	0	3.23	0
Farming and other activities	Number	1	0	1
	Percentage	3.13	0	5
Total	Number	32	31	20
	Percentage	100	100	100

3.5 Discussion

The objective of this study was to assess the differences in demographic characteristics between the Ethiopian retired, current and junior academy long-distance athletes. In the past, very few studies were conducted and reported regarding the demographic characteristic of the east African athletes native to high altitude in general, and Ethiopian athletes in particular. It is just over a decade since this study was conducted(Scott et al., 2003). According to current anecdotal reports, in the past decade significant infrastructure changes in the area of road and school construction, transport facilities, in the number of athletics clubs, as well as in the quality and quantity of athletics coaches had been observed. In this time, Ethiopian long distance success has gradually shifted from the previously important geographical areas to other parts of the country. In this study attempts are made to physically measure the home-to-school distances of the retired elite athletes, and to gather the demographic characteristics of the whole study subjects using questionnaires.

The study compared the age at which formal endurance training was started and has identified significant difference between the three groups. Athletes in the retired (16.4±1.8 years) and current elite (16.0±1 years) groups started joined endurance training later than the juniors (14.4±0.89 years). According the IAAF competition rules (IAAF, 2017b), this age is considered the optimal age at which athletes start international competition in the junior category. According to this rule, any athlete 16 or 17 years old on 31 December in the year of the competition is eligible to compete in the under-18 category. Based on the existing data, it is possible to conclude that these athletes in the retired and current elite groups have not passed through the theoretical stages of athletic development (Ford et al., 2011), and lack training and competition experience, compared to athletes in countries which follow the long-term athlete development programmes (Ford et al., 2011). In comparison with the retired and current elite Ethiopian long distance athletes, the junior athletes started formal training at an earlier age. As Rowland cited in Ford et al. (2011), the development of aerobic ability and its impact on performance is influenced by growth-related changes to an individual's physiological characteristics like cardiovascular and muscular systems, and cellular and metabolic capability, as well as anthropometric characteristics like body composition.

There were no significant differences in the altitude where the athletes in the three groups were born and raised. The study revealed that almost all of the athletes in the three study groups were born and raised in high altitude areas of the country (mean altitude >2500m a.s.l). Like a previous study (Wilber & Pitsiladis, 2012), this study also confirmed that the high altitude areas of the country are still the sources of successful middle- and long-distance athletes. However, while Wilber and Pitsiladis (2012) reported on altitudes of 2000 to 2500m, the majority of the middle- and long-distance athletes in the current study were born and raised at higher altitude areas of the country (>2500m a.s.l). This finding may also strengthen the previous findings (Wilber & Pitsiladis, 2012), that living and training at high altitude is one of the possible explanations for the superior performance of Ethiopian long-distance athletes in the world athletics arena.

Based on the findings of this study, significant differences were not identified between the three groups in the daily distance travelled to and from school during their primary education. However, when the mean distance of each group is examined, the distance covered by the retired elite group was longer (7±4.5km) than the other two groups (current elite: 5.3±3.3km; juniors: 5.9±4.6km). When this difference is calculated over weeks, months or years, its effect on the athletes' physiology may be significant. It is assumed that the athletes start primary education at the age of 7 or 8 years and they would be expected to spend eight years in primary education.

The contribution made by the daily distance travelled to and from school to the superior performance of endurance athletes native to high altitude areas is one of the few non-physiological or non-genetic-related variables that have been studied for some time (Onywera et al., 2006; Scott et al., 2003). When the findings of the current study are compared with similar, previous studies by Scott et al. (2003) and Onywera et al. (2006), the majority of the athletes in the current study (53.1 % of retired, 58.1% of current, and 55.0 % of academy juniors) used to cover up to 5km a day; while the majority of Ethiopian long-distance athletes (73% of the marathon and 40% of the 5 and 10km athletes) (Scott et al., 2003) covered more than 5km daily. By comparison, 49% of the international, and 58% of the national, endurance athletes in Kenya used to cover less than 5km each day (Onywera et al., 2006). The current study also identified that 15.7% of the retired, 6.5% of the current elite, and 15.0 % of junior academy athletes used to cover more than 10km to and from school each day; where 11% of the national and 23% of the international long-distance athletes in Kenya covered more than 10km per day during their primary education (Onywera et al., 2006). As far as the home-to-school distance during secondary education is concerned, the current study has identified significant differences between the retired, current and junior academy athletes, although no results were reported in the previous studies to compare with the findings from the current study. In Ethiopia, the age at which students start secondary education is 15 or 16, which is the age at which the athletes in this study started formal training.

Based on anecdotal evidence, most Ethiopian students are pedestrians, particularly in the countryside. Although the majority of Ethiopian students walk, it is not uncommon to see students jogging or running. This is supported by responses that athletes in each of the three study groups gave when asked to choose their usual mode of transportation, when travelling to and from school during their primary education, from the four alternatives of walking, walking and sometimes jogging, frequently jogging and running. Based on their responses, no significant correlation was observed in modes of transportation between the three groups ($p = 0.05$). In the previous, similar studies no details about the different modes of transportation were given. However, in the current study, walking emerged as the predominant mode of transportation in all the three groups. In contrast to the current study, the previous two studies (Onywera et al., 2006; Scott et al., 2003) reported running as the dominant mode of transportation.

The findings of previous demographical studies (Onywera et al., 2006; Scott et al., 2003) clearly indicated that most of the elite endurance runners from Ethiopia and Kenya were concentrated in two specific high altitude areas called Arsi/Shoa and Nandi, respectively. In line with the findings of these two previous studies, the majority of athletes in the retired group of the current study were from Arsi (59.4%) and Shoa (25.1%). However, the places where the current elite athletes were born and raised are, geographically, more evenly distributed. As an example, the number of athletes from Arsi dropped from 59.4% to 29.0% and those areas from where fewer athletes in the retired group came (6.3% from Tigray; 3.1% from Gojam; 3.1% from South Shoa and 0% from Wollo), increased to 16.1%, 6.5%, 9.7%, and 9.7% respectively. The birthplace distribution of the junior academy athletes showed a similar pattern to that of the retired athletes. The findings of the current study may suggest that endurance performance, at least in the Ethiopian context, is evenly distributed. This study may also raise questions about the findings of the former studies which concluded that middle- and long-distance running performance was not evenly distributed in the two east African nations.

In terms of the regional distribution, the majority of the Ethiopian middle- and long-distance athletes in the three study groups were from the central part of the country (63%) followed by the north and north-west (25%). When the distribution is examined across the study groups, athletes from the central part of the country were overly represented, especially in the retired (81.3%) and junior academy (55%) groups. However, the central (48.4%) and north and north-west (38.7%) parts of the country were more evenly represented in the athletes in the current elite group. This study also identified that housework, housework and fetching water, farming, as well as farming and cattle herding, were the major out-of-school activities that the athletes were involved in during their childhoods in all three groups. In this regard, previous studies did not investigate the major out-of-school activities experienced either by the senior Kenyan or Ethiopian elite long-distance athletes. However, the dominant out-of-school activities that this study identified were characterized by low intensity intermittent activities.

Limitations

Unlike previous research, this study compared the demographic characteristics of middle- and long-distance athletes of three age categories. Although attempts were also made to assess wider demographic characteristics of Ethiopian middle- and long-distance athletes, it was not able to use uniform primary data collection methods across all the three study groups to measure the exact altitude, daily distance travelled to and from school, modes of transportation, out-off school activities.

3.6 Conclusion

The retired and currently elite long distance athletes were older when they started formal training, and possibly missed out recommended stages in athlete development program. Almost all the athletes in the three study groups were born at high altitude compared with participants of other studies. Moreover, the current Ethiopian long-distance athletes were born and raised in places which were evenly spread across the country; whereas the retired and junior academy athletes were from a few concentrated locations. Although no significant differences were observed in the daily distance travelled to and from school between the three groups, the distances reported by the current elite and junior academy athletes were shorter than the distances reported by the retired athletes, as well as those reported previously by Ethiopian and Kenyan athletes. Unlike the findings of the previous studies, walking was the most dominant mode of transportation during childhood by athletes in all three study groups. This study also found no difference in the types of major out-of-school activities between the three groups of athletes during their childhoods. In general, the findings of this study confirmed that the 20 junior athletes who were involved in the altitude study shared common demographic characteristics with the retired and current elite Ethiopian long-distance athletes.

Future Researches

The current study assessed the differences in demographic characteristics between three groups of athletes. The study confirmed no significant differences in most of the demographic characteristics. However, differences were identified specifically for age at which formal training between retired and current elite Ethiopian athletes compared with junior athletes and the recommended long term athlete' development program being accepted and implemented by the International Association of Athletics Federation and other organizations. Thus, taking the past and existing middle and long distance successes of the Ethiopian endurance athletes and the principles of the long term athlete development program into consideration, a recommends is to conduct longitudinal research associated with the development of an Ethiopian specific long term athlete development program.

CHAPTER FOUR: MACRONUTRIENT INTAKE AND ENERGY BALANCE (MANUSCRIPT)

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This manuscript presents the results for energy balance and macronutrient intake assessed over three days in junior Ethiopian long-distance athletes living and training at a high altitude training camp.

Target journal: Journal of the International Society of Sports Nutrition

Title: Macronutrient intake and energy balance in young Ethiopian long-distance athletes during an altitude training camp.

Abstract

Background: Very few studies have assessed the macronutrient intake, energy balance and/or hydration status of east African long-distance athletes. The primary objective of this study was to assess the macronutrient intake and energy balance of young Ethiopian long-distance athletes living in a training camp at a high altitude. **Methods:** The macronutrient intake and energy balance of 20 junior Ethiopian long-distance athletes who were living and training in (and around) the camp was assessed using the three-day direct dietary assessment method. Daily training activities and time spent in off-training activities were recorded and the daily total energy expenditure was calculated using Schofield equation (BMR) and PAR/PAL method. **Results:** The body mass (BM) and body mass index (BMI) measurements before and after the three days' dietary assessment remained stable (BM: 54.37±6.36 kg vs 54.44 ±6.44 kg, $p = 0.461$ and BMI: 18.7±1.51 vs 18.8±1.53kg.m^{-2} $p = 0.417$). There was a significant difference between the mean total energy intake (14593±895KJ.day^{-1}) and mean total energy expenditure (13423± 1134KJ.day^{-1}, $p < 0.001$). In relation to the energy derived from the foods, it appears that carbohydrates were the main energy source during the three days. The overall proportions of the energy derived from the foods were: carbohydrate (65.7±11.7 %), protein (18.7±6.9 %) and fat (15.4±4.9 %). **Conclusions:** Young Ethiopian long-distance athletes met the recommended daily macronutrient intake for carbohydrates and protein, but not for fat, for endurance athletes. They were found to be in a state of positive energy balance one week before their first major competition of the year.

Keywords: macronutrient intake, energy expenditure, energy balance, physical activity level, altitude natives

4.1 Introduction

Since the 1968 Mexico City Olympics, athletes from east African countries have dominated world middle- and long-distance running events (IAAF, 2017a; 2015). A number of reasons have been suggested to explain this dominance (Wilber & Pitsiladis, 2012; Onywera, 2009; Baker & Horton, 2003; Hamilton, 2000). Genetic predisposition (Mooses & Hackney, 2016; Vancini et al., 2014; Scott et al., 2004); physiological variables such as maximal aerobic capacity and running economy (Lucia et al., 2006); neuromuscular/biochemical factors (Wilber & Pitsiladis, 2012; Saltin, Kim, et al., 1995); psychological factors (Baker & Horton, 2003); training and environmental factors (Wilber & Pitsiladis, 2012; Fudge, 2009); nutritional practices and active lifestyles of the athletes have been the most frequently mentioned explanations (Pitsiladis et al., 2007). None of the above studies were able to isolate one particular reason for the success of east African runners, and it seems that a combination of factors is the most reasonable explanation (Wilber & Pitsiladis, 2012).

To date, there has been a greater research emphasis on the identification of genetic predisposition and/or physiological advantages of east African athletes. There has been limited focus on the role of psycho-social and environmental influences on their performance. Despite numerous endurance athlete nutritional assessment studies in the literature, there is limited information regarding the east African endurance athletes (Muia, Wright, Onywera, & Kuria, 2016; Beis et al., 2011; Fudge, 2009), To the best of our knowledge, no more than a handful of studies have examined the nutritional practices of high altitude- indigenous, east African endurance runners. Of these studies, the majority (Muia et al., 2016; Fudge, 2009; Onywera, Kiplamai, Tuitoek, Boit, & Pitsiladis, 2004; Christensen, Van Hall, & Hambraeus, 2002) were conducted on Kenyan athletes, with only one being conducted on elite Ethiopian endurance athletes (Beis et al., 2011). The majority of nutritional studies have examined the effect on performance (Jeukendrup, 2011; Burke & Maughan, 2009; Stellingwerff, Boit, & Res, 2007), whilst very few studies on the Kenyan and Ethiopian athletes have assessed their macronutrient intake, energy balance and/or hydration status (Beis et al., 2011; Fudge, 2009; Onywera et al., 2004). The findings of these few studies also lack consistency, particularly in terms of the energy balance.

A study by Christensen et al. (2002) focused on the nutritional practices of athletes from the Kalenjin tribe. In this study, there was a very small, positive energy balance with a daily total energy expenditure of 13186±247KJ.day^{-1} and a mean total energy intake of 13210±283 KJ.day^{-1}. Onywera et al. (2004) published the very first dietary assessment study on elite world champion (n=10) high altitude east African, endurance athletes. These athletes were found to be in a negative daily energy balance (Energy Expenditure (EE): 15083±119, Energy Intake (EI): 12497±293KJ.day^{-1}; $p = 0.001$) a week before their major cross-country championship. Another study that utilised a weighed dietary intake method for a continuous seven day's training in male Kenyan distance runners (n=9) was conducted by Fudge (2009). Comparable to the findings by Onywera et al. (2004), this study reported a significant negative energy balance in which the energy expenditure was greater than energy intake (EE: 14611±1043, EI:13241±1330 KJ.day^{-1}, $p = 0.046$).

A study (Beis et al., 2011) conducted on Ethiopian endurance athletes reported different results compared to those few studies that involved Kenyan athletes (Fudge, 2009; Onywera et al., 2004). This study was the first study conducted on Ethiopian athletes who lived and trained at high altitude. The dietary intake and the daily energy expenditure of these athletes were assessed for seven consecutive days during an intensive training week before their international competition. One of the major findings of this study revealed that there was no significant difference between the energy expenditure and energy intake (EE: 13670±862, EI:13375±1378 KJ.day^{-1}; $p = 0.69$) at the time of assessment. The dietary intake of 10 highly-trained Ethiopian long-distance runners was assessed during a 7-day period of intense training prior to competition using the standard weighed intake and physical activity ratio methods. Despite the fact that this study is the forerunner in dietary assessments in the Ethiopian context, to our knowledge, there are no studies that have been emerged to support the major findings in the last seven years.

Macronutrient intake and endurance athletes

Current endurance training practices are characterized by 'periodised' training plans (Manzi, Iellamo, Impellizzeri, D'ottavio, & Castagna, 2009). Modern training approaches are now dedicated to periodised nutritional plans that should consider the training demands of the athletes based on the unique characteristics of the training phase/period (Heydenreich et al., 2017). Since the training load varies from phase-to-phase, the energy expended following the load variations also varies significantly (Heydenreich et al., 2017). Because of this, the daily total energy intake and the food and macronutrient composition should also be taken into consideration to better maintain an ideal body weight and body composition (Heydenreich et al., 2017; Loucks, Kiens, & Wright, 2011).

A number of researchers have relied on the daily recommended macronutrient intake (carbohydrate, fat and protein) for different sports, including endurance events (Carlsohn, 2016; Potgieter, 2013; Phillips, 2012; Jeukendrup, 2011, Burke, Millet, & Tarnopolsky, 2007). Despite the fact that the information is widely available, they lack the recommended daily macronutrient intake based on training load variation across the training phases. Currently, it is recognized that daily nutrition guidelines are of general value, but are not based on training periodization (Carlsohn, 2016). In this regard, attempts have been made to review the existing macronutrient intake of endurance athletes in comparison to the daily recommendations.

Following the study by Mukeshi & Thairu (1993), four consecutive studies reported the absolute and relative daily macronutrient intakes of east African endurance runners. The study that involved athletes from the Kenyan Kalenjin (Christensen et al., 2002) reported that from the daily total calorie intake, 71%, 15%, and 13% were derived from carbohydrates (CHO), fat and protein, respectively. This study also reported a daily CHO and protein consumption of 8.7 and 1.6g. $kg.^{-1}$ per body mass per day, respectively. Similarly, a study by Onywera et al. (2004) reported that in the daily energy intake, the calories derived from CHO, fat and protein were 76.5%, 13.4% and 10.1%, respectively. This study also reported the relative daily CHO and protein intake as 10.4 and 1.3g. $kg.^{-1}$ per body mass per day respectively. In comparison to the daily recommended intake for endurance runners, the measured values were in the acceptable range (Carlsohn, 2016). In relation to the daily macronutrient intake composition of the athletes, the data in the abovementioned studies (Onywera et al., 2004; Christensen et al., 2002) indicated that the energy source in the daily intake was predominantly from CHO.

Two studies also reported the absolute and relative daily macronutrient intake of east Africa athletes native to high altitude. These studies were conducted in Kenya (Fudge, 2009) and Ethiopia (Beis et al., 2011). In the first study, the energy sources from macronutrients consisted of 67.3±7.8%, 17.4±3.9%, and 15.3±4.0% from CHO, fat and protein, respectively. The relative daily macronutrient intake of 9.8, 1.1 and 2.2 g. $kg.^{-1}$ per body mass per day was reported for CHO, fat and protein respectively. The macronutrient composition, as well as the daily absolute and relative CHO, fat and protein intake, of the Ethiopian study subjects was also reported in the second study (Beis et al., 2011). According to the reports, the diet of the Ethiopian athletes, like those in the above studies, was high in CHO (64.3±2.6%) and the daily calories derived from fat and protein were 23.3± 2.6 and 12.4±0.6% respectively. In their daily macronutrient consumption, the athletes were taking on average 545±49g of CHO, 83±14g of fat and 99±13g of protein.

It is well accepted that the dietary practices of junior, as well as senior, Ethiopian athletes have not yet been comprehensively studied. Despite the fact that the first dietary intake assessment study which was conducted in 2011 is the forerunner in dietary assessments in the Ethiopian context, no other similar studies have emerged to support the major findings in the past seven years. If the performances of middle- and long-distance Ethiopian athletes are to be enhanced, it is very important to assess the nutritional practices of the athletes based on the different training periods of the year. Therefore, the primary objective of this study was to assess the macronutrient intake and energy balance of young Ethiopian long-distance athletes living in a training camp at a high altitude.

4.2 Methodology

Study participants

The research protocol was approved by the University of KwaZulu-Natal (UKZN) and Addis Ababa University College of Natural Sciences (AAU – CNS) research ethics committees. All athletes provided their written informed consent prior to commencing the study and the research protocol was conducted in accordance with the Helsinki Declaration. Twenty (male = 16 and female = 4) Ethiopian junior, long- distance athletes (mean age 18.35 ±1.2 years; mean training time 4.6 ±1.5 years) participated in the study. The majority of the athletes (n=16) were 5 km runners while four competed in both 5 km and 10 km races. The athletes who participated in the study were attending an eight-week training camp and were living and training in and around Tirunesh Dibaba National Athletics Training Centre (TDNATC) located at an altitude of 2500m (7°57′N latitude and 39°7′E longitude). At the time of the dietary assessment the athletes were preparing for the 34th 'Jan Meda' International Cross-Country Championship (2017) that doubled up as the Ethiopian National Cross-Country Championship.

Study design

This study used the three-day direct dietary record method. As studies indicate, this method is often regarded as the 'gold standard' method (Biro, Hulshof, Ovesen, & Cruz, 2002; Tremblay, Sévigny, Leblanc, & Bouchard, 1983), among the different objective and subjective dietary assessment methods (Shim, Oh, & Kim, 2014). One of the major advantages of the direct dietary assessment method is that it doesn't depend on memorizing the food consumed and high precision of portion size about the food and drink ingested on a daily basis. The method involved the individual athlete and the principal investigator/coach weighing each item of food and drink prior to consumption and detailed description of the food and its weight was recorded separately in booklets designed for each athlete. The weight of food that was consumed was calculated by subtracting the uneaten matter and foods and drinks that were left after each meal. The three-day dietary intake was assessed during the last week of the eight-week training camp when the overall training load of the week was higher than in the previous seven weeks. During the assessment week, the dietary intake and the energy expenditure on three consecutive days, that included light, moderate and high loads, were assessed. Nude body mass measurements were taken before, during and after the three assessment days. Body mass was measured to the nearest 0.1 kg using an electronic digital scale (Beurer, Ulm, Germany). All body weight measurements were made after the athletes' first morning void and before any food or drinks had been consumed for the day.

Study Protocols

Dietary intake assessments

The daily food intake of all the athletes was assessed in the training camp. The menus were same for all participants and the meals were served together in the TDNATC cafeteria. Before the start of the three days' formal dietary intake assessment, the athletes underwent familiarisation sessions regarding the process that included the weighing of all the food before eating and after finishing the meal, and subtracting the weight of all the leftovers as well as the non-edible parts of their meals. All food measurements in this study were carried out when the three meals were served: breakfast (8:00 – 9:00am), lunch (12:00 am – 1:00pm), and dinner (6:00 – 7:00pm). All the measurements were taken and recorded by the principal investigator, together with the head coach of the athletes, using a digital weighing scale readable to 1 gram (Salter Housewares LTD, England). To ensure the measured dietary intake/habit was representative typical intake, all athletes were requested not to change their habitual diet (both in quantity and variety). In addition to the measurements taken in the athletes' cafeteria, two additional digital weighing scales were placed in the male and female sleeping rooms to record the extra food and fluid intakes consumed anytime outside of the TDNATC.

The dietary analysis of each individual athlete, including the total energy intake, and the energy contribution and gram values for carbohydrate, fat and protein from the consumed foods was performed using the nutritional software package Nutritics (v3.7, University Edition). The analysis of locally prepared Ethiopian foods was performed using the

Ethiopian food composition table which is published by the Ethiopian Institute of Health and Nutrition Studies (1998).

Training and daily energy expenditure measurements

Training type, intensity and duration, as well as external load, including distance, time covered and speed of the training were recorded in a daily training diary over the three consecutive days. Every week the athletes trained for six sessions per week, in which two of the training sessions were high intensity training and the other four were light and moderate. Of the three days of the dietary assessment, the first day was devoted to light training and the remaining two days were moderate and high intensity training sessions, respectively. The external load was measured using a digital watch with Global Positioning System(Garmin Forerunner 210 with distance and speed measure, USA). Total energy expenditure of each study participant was calculated from basal metabolic rate (BMR) using the Schofield equation (Schofield, 1985)and the physical activity ratio (PAR), and physical activity level (Ainsworth et al., 2000; James & Schofield, 1990). In addition to the daily training sessions, the time spent in other activities throughout the day (24 hours) was measured and recorded by the athletes. The overall energy expenditure of the day was calculated and summed up based on the PAR (Ainsworth et al., 2000; James & Schofield, 1990). PAR was calculated using the MET-based assigned values for specific activities.

4.3 Statistical Analysis

The normality of the distribution was determined using a Shapiro Wilk Test. Data are expressed as the mean ± SD. Paired t-tests were used to compare total energy intake versus total energy expenditure over the three days, as well as between the energy intake and expenditure for each of the days independently. One-way analysis of variance (ANOVA) was used to determine where there were any differences in the specific macronutrient (energy, grams of macronutrient intake/kg, and percentage of daily diet) intake as well as the total energy expenditure across the three days. Bonferroni post-hoc tests were performed where appropriate. Statistical significance was set at $p \leq 0.05$. All statistical analysis was performed using SPSS Statistics version 23 (Armonk, NY: IBM Corp).

4.4 Results

The body mass (BM) and body mass index (BMI) measurements before and after the three days' dietary assessment remained stable (BM: 54.37±6.36kg vs 54.44 ±6.44kg, $p = 0.461$ and BMI: 18.7±1.51 vs 18.8±1.53kg.m^{-2} $p = 0.417$). Along with the anthropometric measurements, the mean basal metabolic rate (BMR) was estimated at 6288±535KJ.day^{-1} for all the athletes, and 6502±328.4 and 5439± 268KJ.day^{-1} for male and female athletes, respectively (Table 4.1).

Table 4-1: Basal metabolic rate, anthropometric and personal characteristics

Anthropometric variables and metabolic rate		Mean ±SD	Minimum - Maximum
Height (metres)		1.7±0.1	1.6 - 1.8
Age (years)		18.4±1.2	17.0 - 20.0
Training Period (years)		4.6±1.5	2.0 - 6.0
BMR (KJ.d^{-1})Total		6288±535.6	5138 – 7163
BMR (KJ.d^{-1})	Male	6502±328.4	5899 – 7163
	Female	5439±267.8	5137.9 - 5782.3

The result (three days' mean) indicated that there was a significant difference between the mean total energy intake (14593±895KJ.day^{-1}) and mean total energy expenditure (13423± 1134KJ.day^{-1}, $p < 0.001$). Moreover, the daily total EI and EE over all three days for all subjects were also compared in the same way as the total EI and EE. In comparison to the daily energy expenditure, on day one there was a mismatch between EI (15682 ± 1599KJ.day^{-1}) and EE (12823 ± 1397KJ.day^{-1}, $p = 0.000$), and a positive energy balance was calculated. On day two there was no substantial difference between daily EI (14368 ± 1516KJ.day^{-1}) and EE (13688± 1618KJ.day^{-1}, $p = 0.146$). Similarly, there was also no significant difference between the EI (13728±412KJ.day^{-1}) and EE (13757± 1390KJ.day^{-1}, $p = 0.919$) on day three. Although there was no statistically significant difference between the daily EI and EE on days two and three, the one-way ANOVA result showed a difference in EI across the three days ($p < 0.001$), where the major EI difference was observed between day one and the other two days (day one vs day two, $p = 0.007$ and day one vs day three, $p < 0.001$). As far as the daily energy expenditure is concerned, there was no statistically significant difference between the three days.

Table 4-2: Daily energy derived from macronutrients in kilojoules, grams and percentage

Days		Mean(SD)			Sig.
		Day 1	Day 2	Day 3	
Carbohydrate	Kilojoules (KJ) *	8664(956)	11746(1221)	8331(368)	0.000
	g. $Kg^{-1}.day^{-1}$**	13.2(2.0)	13.0(1.19)	9.34(1.18)	0.000
	Percentage$^{\#}$	55.3(2.71)	81.9(1.22)	60.7(1.00)	0.000
Protein	Kilojoules (KJ)	3808(385)	1384(128)	3089(35.3)	0.000
	g. $Kg^{-1}.day^{-1}$	4.17(0.63)	1.44(0.14)	4.47(0.58)	0.000
	Percentage	24.3(1.82)	9.12(0.10)	22.5(0.49)	0.000
Fat	Kilojoules (KJ)	3198(481)	1300(212)	2295(30.7)	0.000
	g. $Kg^{-1}.day^{-1}$	1.57(0.23)	0.65(0.11)	1.92(0.26)	0.000
	Percentage	20.3(1.57)	9.0(1.17)	16.8(0.52)	0.000

*$P \leq 0.05$, * Sig. for Kilojoules, **Sig. for g. $Kg^{-1}.day^{-1}$, $^{\#}$ Sig. for Percentage*

In relation to the energy derived from the foods, it appears that CHO were the major energy source consumed during the three days. The overall proportion of the energy derived from the foods revealed that CHO provided 65.7% (±11.7 %); protein 18.7% (±6.9 %) and fat 15.4% (±4.9 %). When the overall proportions of energy (KJ) derived from the three macronutrients were analysed on a daily basis, there were statistically significant differences in CHO ($p < 0.001$), protein ($p < 0.001$) and fat ($p < 0.001$) consumption across the three days, (See Table 4.2). Moreover, substantial differences were identified in the day-to-day relative macronutrient intake (g. $Kg^{-1}.day^{-1}$) for CHO ($p < 0.001$), protein ($p < 0.001$), and fat ($p < 0.001$) consumption during the three dietary assessment days (see Table 4.2). The data in this Table (4.2) also revealed that there were significant differences in the proportion (percentage) of the daily energy derived from the three macronutrients - CHO ($p < 0.001$), protein ($p < 0.001$) and fat ($p < 0.001$).

The three-day dietary assessment revealed that the athletes' diet primarily comprised of plant sources (76.1%) such as cereals, legumes and vegetables (Table 4.3). Additionally, all the food consumed at the time of the assessment (three-days), 98% of CHO, 31.4% of protein and 60.1% of fat were derived from plant sources. The remaining CHO, protein and fat were derived from animal sources. The major source of energy was cereals (58.6% of all the food). Of the listed food sources, the locally prepared and fibre rich 'enjera', bread, macaroni, rice and spaghetti were the staple food of the athletes and the five major energy sources (Table 4.3).

Table 4-3: Percentage of energy derived from categorised food sources

Food Sources	Food Sources	CHO (KJ)	Protein (KJ)	Fat (KJ)	Total (KJ)	Energy Contribution (%)
Plant Sources	Bread	7691	1118	282	9091	18.6
	Added sugar	1199	0	0	1199	2.4
	Spaghetti	1891	380	408	2679	5.5
	Macaroni	3064	482	359	3905	8.0
	Tomato Sauce	137	38	370	545	1.1
	*Enjera	6879	643	2113	9634	19.7
	**Besso	627	87	26	741	1.5
	Minestrone	514	140	775	1429	2.9
	†Kik Wet	989	274	840	2103	4.3
	#Shiro Wet	191	85	68	344	0.7
	Rice	2899	266	181	3346	6.8
	Potato	388	20	5	413	0.8
	Carrot	67	4	5	76	0.2
	Cabbage	85	20	4	108	0.2
	Banana	388	16	26	430	0.9
	Strawberry Jam	1218	0	0	1218	2.5
Animal Sources	Tuna	0	3019	82	3101	6.3
	Egg	124	679	569	1372	2.8
	Curry Lamb	240	2172	97	2510	5.1
	Beef	211	1930	2587	4728	9.7
Total		6884	28803	11375	8795	48973
Total calories from plants		6747	28229	3574	5460	37262
Total calories from animals		137	575	7801	3335	11711
% of calories from plant sources		98	31.4	60.1	76.1	
% of calories from animal sources		2	68.6	39.9	23.9	
Total		100	100	100	100	

** a sourdough-risen flat bread with a unique, slightly spongy texture (Grando & Macpherson, 2005)*
***a food Prepared from roasted barley powder and water*
† sauce mainly prepared from split pea, shallot and liquid sunflower oil
 # sauce prepared from roasted pea powder, shallot and oil

The food items in the weekly menus of the athletes were reviewed. Based on the three-day dietary assessment and the review of the athletes' weekly menu, it was recognized that the food/menu composition in general lacked dairy products and fruit (except bananas). The weekly menus indicated that (See Appendix XI) animal sources like fried eggs (the only animal-source food during breakfast) were served twice a week for breakfast. Meat (lamb and beef) was served four times a week for lunch and dinner (twice for lunch and twice for dinner). Except for the three planned daily menus (breakfast, lunch and dinner), no other food was served by the academy.

The daily energy expenditure was calculated, based on the basal metabolic rate and the daily average physical activity level. The result of the one-way analysis of variance (ANOVA) revealed that there was no significant difference between the three days' physical activity level of the athletes, (p = 0.054). The three days' energy expenditure was calculated and a one-way ANOVA test was conducted. The descriptive statistics for the mean and standard deviation for daily energy expenditure are presented in Table 4.4. Based on the one-way ANOVA test, it was concluded that there were no statistically significant differences between the three days for energy expenditure EE, (p = 0.091).

Table 4-4: Daily physical activity level and total energy expenditure

	Days	Mean	SD	95% CI		Sig.
				Lower	Upper	
Daily Physical Activity Level*	Day One	2.04	0.094	1.99	2.08	0.054
	Day Two	2.19	0.349	2.03	2.35	
	Day Three	2.19	0.156	2.12	2.26	
Total Daily Energy Expenditure (KJ)	Day One	12820	1398	1260	13361	0.091
	Day Two	13686	1617	12817	14319	
	Day Three	13757	1390	12991	14281	

**The ratio of daily total energy expenditure to basal metabolic rate*

Long, steady endurance training was the dominant training in sessions over the week, followed by short and long interval training sessions. In comparison to the pre-dietary assessment weeks, the dietary assessment week was characterized by higher intensity sessions, although during the three training days, only one high intensity training day was included during the study week. Along with the energy expended for daily training sessions, the energy expenditure of the athletes during time not spent at training was measured using the PAR method. Almost all the weekly training sessions were conducted before breakfast between 6:00 – 8:00 am. During the rest of the day the athletes spent their time sleeping, watching television, on personal care and involved in indoor activities. In comparison to the other daily activities, the athletes, on average, used to spend the longest time sleeping (12.2±0.9 hours) per day. The ANOVA identified a significant difference ($p < 0.001$) in total sleep time between the three consecutive dietary assessment days when the athletes engaged in light, moderate and heavy intensity exercise workouts. In comparison to the light and moderate training days, the last day of the study was a heavy training day (Table 4.4).

4.5 Discussion

In the past, different dietary assessment studies using different methods were carried out on Ethiopian and Kenyan middle- and long-distance athletes. The most commonly used dietary assessment methods were the seven-day weigh and record (Fudge, 2009; Onywera et al., 2004; Christensen et al., 2002) and 24-hour recall methods (Christensen et al., 2002). Other studies applied a three-day weigh-and-record dietary assessment method (Johnson, 2002), as did this study.

Unlike the few previous dietary assessment studies, this study considered the energy balance and macronutrient intake of young Ethiopian endurance athletes living in the training camp. The calories in the energy intake (EI) were estimated using the three-day dietary intake, and the energy expenditure was assessed based on the basal metabolic (BMR) and the physical activity ratio/physical activity level (PAR/PAL) approaches. This study reported a significant positive energy balance (EI: 14590KJ.day^{-1}> EE: 13422KJ.day^{-1}) among the athletes. This finding was contrary to findings in the previous dietary assessment studies which reported negative energy balances (Onywera et al., 2004; Mukeshi & Thairu, 1993) and no significant difference between EI and EE (Beis et al., 2011; Christensen et al., 2002). Even though the current study indicated a positive energy balance, a remarkable energy gain was reported on one of the three days (day one). On this day, the energy difference/gain reached 683 KJ, although the difference was small (+682 KJ) and even negative (- 33.5kJ) on the next two days. One of the proposed explanations for these energy differences may be the variation in energy expenditure due to the different intensities of the training sessions on those days. On the first day of the study the athletes were involved in light-intensity training (10.2km.h^{-1}). However, on day three the athletes' training was intense (17.2 km.h^{-1}). It is noted that there is a direct relationship between energy expenditure and intensity and duration of exercise (Bompa & Haff, 2009; Ainsworth et al., 2000). This study is in line with this principle, since the total energy expenditure on day three was higher than day one and day two, even though there were no substantial differences reported in energy expenditure between the days.

One of the possible explanations for this positive energy balance might be that the study was conducted during the preparation phase of the athletes' training. A relatively recent systematic review (Heydenreich et al., 2017) reported that, in comparison to the competition phase of training, total energy expenditure was lower during the preparation phase ($p < 0.001$). The three-day dietary assessment study on young Ethiopian endurance athletes was conducted at the end of the second month of the yearly training plan, which falls into the preparation phase of the yearly training plan; even though the athletes were preparing for the national cross-country championship. This championship is not a major race for the study participants and they were not primarily focused on preparing for this competition. Their major competition is the national youth championship, usually conducted in the month of June. The other explanation for a positive calorie balance in humans is the level of physical exertion in day-to-day activity (Rodriguez, DiMarco, & Langley, 2009; Ainsworth et al., 2000). This might be one of the reasons for the positive energy balance in the current study participants. Although most of the previous studies were conducted in privately owned training camps (including the Ethiopian study), the current study was carried out in a camp which was managed and sponsored by the government. Most often athletes in different athletics clubs around the country do not have the opportunity to live in, and get meal service from, the same camp. It is more common for the athletes to live off-camp and prepare their own food. They also provide their own transportation when they come to and return from training. However, most of the athletes who were involved in this study were not students. They lived in the camp throughout the year and received full accommodation (with all meals), as well as transportation and medical services from the camp. These conditions might help them minimize their energy expenditure since they don't involve in energy demanding activities like cooking food, walk to and from training areas. These conditions might help them to maximize their recovery time or save energy and could cause athletes to minimize their daily energy expenditure and so have a positive energy balance.

This study identified that the daily CHO intake (65.9%) met the recommended amount (Rodriguez et al., 2009), although the fat (15.4%) and protein (18.7%) proportions were, respectively, above and below the daily dietary recommendations for athletes (Rodriguez et al., 2009). In the current study, the percentage of calories derived from CHO was lower than in two previous studies (Christensen et al., 2002; Mukeshi & Thairu, 1993) conducted on Kenya endurance athletes and almost equal to the percentages found in recent studies conducted in Kenya (Fudge, 2009) and Ethiopia (Beis et al., 2011). The three-day mean daily CHO consumption (g. kg^{-1} of BM. Day^{-1}) of the young academy athletes was 11.8 g. kg^{-1} of BM. day^{-1}. According to the America College of Sport Medicine daily dietary recommendations for endurance athletes (Burke & Maughan, 2009; Rodriguez et al., 2009), this amount is in the recommended range. In this regard, the findings of this study were in line with the previous studies and the recently recommended values for daily CHO intake (Rodriguez et al., 2009). However, the young academy athletes' mean daily CHO intake (11.8 g. kg^{-1} of BM. Day^{-1}) was higher than those measured in previous studies: 8.1 (Mukeshi & Thairu, 1993), 8.7 (Christensen et al., 2002), 10.4 (Onywera et al., 2004), 9.8 (Fudge, 2009) and 9.7 g . Kg^{-1} of BM. day^{-1} (Beis et al., 2011).

In contrast to similar dietary assessments studies conducted previously (Beis et al., 2011; Fudge, 2009; Onywera et al., 2004; Christensen et al., 2002), and daily dietary recommendations for athletes (Rodriguez et al., 2009), in the current study significantly higher protein consumption was identified (3.36 g . kg^{-1} of BM. day^{-1}). In most studies, the recommended daily protein intake ranges between 1.2 – 1.7 g. kg^{-1} of BM. day^{-1} (Carlsohn, 2016; Burke & Maughan, 2009; Rodriguez et al., 2009). One of the possible explanations for the increase in daily dietary protein intake might be the frequent availability of protein on the menu during the three days of the assessment.

In this study, a clear imbalance in the daily dietary macronutrient intake of the athletes was observed. As can be seen from Table 4.2, in two of the three dietary assessment days, the daily fat intake (%) was lower than the protein intake. When the three-day mean fat and protein proportions (15.4% vs 18.7%) of the young Ethiopian endurance athletes were compared with previous studies, they were not in agreement: 15% vs 13% (Christensen et al., 2002); 13.4% vs 10.1% (Onywera et al., 2004); 17.4% vs 15.3% (Fudge, 2009) and 23.3% vs 12.4% (Beis et al., 2011). Studies revealed that body fat makes its own contribution to enhancing the endurance performance of athletes (Rodriguez et al., 2009). Regarding the nutrition and athletic performance the American Dietetic Association, Dieticians of Canada, and the American College of Sports Medicine (Thomas, Erdman, & Burke, 2016) released a joint position statement that stated 20% to 35% of the athletes' daily dietary intake should be from fat or fat sources. In this statement it was highlighted that a daily fat consumption which is less than or equal to 20% doesn't benefit performance in sport (Rodriguez et al., 2009). However, from the other angle, the daily proportion of the macronutrient intake (CHO, protein and fat) particularly the high protein and lower fat intake of the Ethiopian junior long-distance athletes during the three day dietary assessment might be seen as advantageous. The reason why the macronutrient intake of the athletes was accepted was due the relatively higher intensity of training at the time of the assessment as compared with the previous seven weeks of the study. During the yearly training phases, when long distance-athletes engage in high intensity training, consuming high CHO and protein sources can benefit distance runners, ensuring a relevant energy source that suits the nature of the training, increasing muscle adaptation and recovery (Burke & Maughan, 2009). In contrast to the higher CHO and protein consumption, a lower fat consumption dietary strategy is recommended for endurance runners to achieve lighter and leaner physique (race weight) which enhances performance in long-distance endurance running (Burke et al., 2007).

Upon examination of the source of the food it was noted that plants provided the major daily energy sources for the athletes. Similarly, most of the calories from CHO (98%) and fats (60.1 %) were derived from plant sources; but the reverse was true for protein (68.6 %). However, when the overall food sources during the dietary assessment days were examined, plant sources were seen to dominate in providing calories for the athletes. This finding supports the same finding in a study conducted by (Beis et al., 2011).

Limitations

The three-day macronutrient intake and energy balance of the athletes were studied during the last week of the athletes' preparation for the first yearly official competition. Although the study assessed the macronutrient and energy balance of the junior athletes it could not addressed the fluid and micronutrient intake of the study participants.

4.6 Conclusion

Similarly to previous studies on Kenyan and Ethiopian endurance athletes, the young Ethiopian athletes met the recommended daily macronutrient intake for carbohydrates and protein for endurance athletes. However, the study also identified that the athletes' dietary fat consumption was below the recommended amount for endurance athletes. Moreover, based on the three-day dietary assessment results, the young Ethiopian endurance athletes were found to be in a state of positive energy balance one week before their first major competition of the year (albeit during the preparation phase of their yearly training plan).

Future Research

Taking the significant role of fluid and micronutrient intake in enhancing the middle- and long-distance performance into consideration, the current study recommends more detailed studies examining the nutrition demands of junior athletes who live and train at high altitude.

CHAPTER FIVE: HAEMATOLOGY (MANUSCRIPT)

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This manuscript presents the results relating to the first hypothesis of the altitude study. To the best of our knowledge this study is the first of its type to investigate the effects of the live high-train high and live high-train high train low altitude training models on some selected haematological indices among Ethiopian long-distance athletes native to high altitude, following eight weeks of endurance training. In addition to identifying the haematological differences between the two groups, it is the first study to examine changes in selected haematological indices in junior Ethiopian long-distance athletes.

Target journal: PLOS ONE: Physiology

Title: Differences in haematological variables among junior Ethiopian long-distance athletes following eight weeks of live high-train high and live high-train high train low endurance training at altitude in Ethiopia.

Abstract

Background: The major objective of this study was to identify haematological parameter (haemoglobin and haematocrit) differences between junior Ethiopian long-distance athletes who trained in the live high – train high (LH-TH) and live high – train high train low (LH-THTL) altitude training models. **Methods**: This study applied a balanced randomised experimental design. A total of 20 (male = 16 and female = 4) well trained junior long distance athletes were assigned to the LH-TH (n=10) and LH-THTL (n=10) groups. The mean age of the athletes was 18.7±1.08 (male) and 17.3±0.5 (female). Resting venous blood was drawn at three time points (baseline, week four and week eight) for complete blood count tests (red blood cell, haemoglobin concentration and haematocrit percentage) on rest days. **Results:**No statistically significant difference in RBC count was observed between the LH-TH and LH-THTL study groups following eight weeks of endurance training (Δ0.05; CL ±0.029; p = 0.741; ES = 0.12). A decline in the mean RBC count was observed from baseline to week eight in the LH-THTL (BL: 5.1±0.47 x 10^6/µL vs week 8: 4.9±0.34 x 10^6/µL); but this was unchanged in the LH-TH group (BL: 5.4± 0.29 x 10^6/µL vs week 8: 5.3±0.31 x 10^6/µL). Although no significant change was identified between the groups (Δ0.03; CL±0.65; p = 0.926; ES = 0.02), after eight weeks of endurance training the haemoglobin concentration had declined substantially from baseline to week eight in both groups (Experimental: Δ-0.48; CL±0.46; p = 0.040; ES = -0.35 and control: Δ-0.51; CL± 0.46; p = 0.030; ES = -0.37). **Conclusion:** The findings of this study revealed no significant differences in RBC, haemoglobin concentration, and haematocrit values between the two study groups following eight weeks of endurance training. The phase of the training period, variations in training loads as well as mechanical factors such as ground-and foot contact may have contributed towards the decline in haematological indices.

Keywords: red blood cell, haemoglobin concentration, haematocrit, high altitude native, live high-train high, live high-train high train low

5.1 Introduction

The most common haematological indices that have altered either by changes in altitude, load of endurance training and phase of training are plasma volume, red blood count, haematocrit values, and haemoglobin concentration (Mairbäurl, 2013; Banfi et al., 2011).Changes in haematological variables due to long-term endurance training were reported in different studies. For example, a decrease in RBC counts and volume during the onset of race season as compared to the preparation phase (Prommer et al., 2010; Rietjens et al., 2002); a decrease in haematocrit in elite cyclists from light training sessions to intense training sessions/the competition phase (Mørkeberg et al., 2009); and a decrease in haemoglobin concentrations from the preparation phase to the peak competition phase (Mørkeberg et al., 2009) are among the few findings.

As studies revealed haematocrit and haemoglobin are the two haematological variables that decreased during intense training weeks (Banfi et al., 2011). Even though these variations appeared differentially in different sports, on average it was indicated that haemoglobin changed from 3-8% during the competition season. A longitudinal study (Mørkeberg et al., 2009) conducted on professional cyclists revealed significant seasonal-based haematological changes following endurance training. In this study the average Hct and Hgb decreased during competition (Hgb = 14.1g.dL^{-1} and Hct = 40.9%), as compared to during preparation periods (Hgb = 15.0g.dL^{-1} and Hct = 43.5%). However, the lower Hct and Hgb returned to their baseline values after the end of the competition season. In comparison to the preparation period, low Hct and Hgb (43.2 % and 15.0 g.dL^{-1}) values observed during the competition period (40.9 % and 14.1 g.dL-1).

In addition to the seasonal and training load variations, mechanical rupture at the time RBCs pass through capillaries during muscle contraction; compression of red blood cells at the time of foot sole contact during running; RBC destruction due to frequent foot-strike haemolysis; and continual exposure to high-oxygen flux are among the different reasons for a decline in RBC count in endurance runners (Telford et al., 2003).

In relation to the performance level of individuals (athlete vs non-athlete) conflicting findings on changes to haematocrit value were reported. For example, a study (Sawka et al., 2000) identified lower haematocrit in athletes than non-athletes. On the contrary some studies found haematocrit values above the normal range in athletes (Mairbäurl, 2013) and among individuals native to high altitude (Vergouwen et al., 1999). Although inconsistent findings have been reported as far as the haematocrit values between athletes and non-athletes, most of the athlete-based studies revealed seasonal variations in athletes' hematocrit (Anđelković et al., 2015; Banfi et al., 2011). A recently reviewed article (Mairbäurl, 2013) noted that haematocrit values increase during exercise because of a reduction in plasma volume triggered by fluid balance/fluid loss to maintain homeostasis. This condition (the reduction in haematocrit) is higher in endurance events than other sports like swimming.

On the other perspectives there were some studies that reported haematological data (indices) following changes in altitude or altitude based trainings. There are also studies that examined time-based variations in blood cell and plasma volume among endurance athletes native to high altitude (Prommer et al., 2010; Schmidt et al., 2002). A study by Prommer et al. (2010) indicated that blood cell volume decreased and plasma volume increased in high altitude athletes after six weeks of endurance training at low altitude. This situation (elevated blood and plasma volume) can cause a decrease in haematocrit for a certain period, as reported by other studies (Mairbäurl, 2013; Prommer et al., 2010). One of the possible explanations for the post-exercise increase in plasma volume in highly trained athletes was aldosterone-dependent renal sodium ion reabsorption and water retention stimulated by elevated antidiuretics hormones to compensate for the water loss during each training sessions (Mairbäurl, 2013).

The effects of the length of time and altitude at which endurance training occurred were observed among east African athletes native to high altitude (Prommer et al., 2010; Zubieta-Calleja, Paulev, Zubieta-Calleja, & Zubieta-Castillo, 2007). In a study (Prommer et al., 2010) that compared east African runners and native sea level (German) long-distance athletes, a drop in both haemoglobin concentration and haematocrit values were reported from baseline to day 40 after a drop in elevation from 1660m a.s.l (12 hours after the athletes left Eldoret, 2090m a.s.l) in Kenya and after 40 days of endurance training at low altitude (340m a.s.l.) in Germany. In this study, the changes over time in haemoglobin concentration were from 16.1±0.7 $g.dL^{-1}$ (at baseline) to 15.3±0.9 $g.dL^{-1}$ (day 40).

The haematocrit values of the Kenyan athletes also dropped from 48.6±2.4% (at baseline and high altitude) to 46.1±2.1% (after 40 days at low altitude) resembling the haemoglobin concentration. Other studies (Anđelković et al., 2015) that involved elite-level athletes identified a significant reduction in haemoglobin concentration (15.7±3.9 to 15.2±2.1 $g.dL^{-1}$) and haematocrit percentage (48.2±1 to 46.2±0.5) after 90 days of training, as compared to baseline readings. In another comparative study (Schmidt et al., 2002) that involved native elite lowlanders and native highlanders, endurance athletes had no statistically significant differences in their haemoglobin concentration (15.8±0.07 vs 15.8±0.07 $g.dL^{-1}$, $p > 0.05$) and haematocrit (47.7±1.9 vs 47.8± 1.5%, $p > 0.05$) after the preparation phase of endurance training. In addition to seasonal variations in haemoglobin concentration and haematocrit values, studies also reported changes in these haematological indices due to altitude. (Moore et al., 2007). Moore et al. (2007) reported a significant decline in haemoglobin concentration in the high altitude native athletes of Kenya, from baseline at high altitude (167±7$g.L^{-1}$) to seven days after the athletes descended to sea level (152±7$g.L^{-1}$, $p < 0.05$) before their major competitions. Like the haemoglobin concentration, a decline in haematocrit was also observed from high altitude (50±2%) at baseline to sea level (45±2%, $p < 0.05$) after seven days, prior to their competing at sea level. Although attempts were made to review relevant studies on the effects of endurance training on some selected haematological indices among endurance athlete's native to high altitude, this study confirmed critical research gaps in the area. Thus, the objective of this study was to identify the haematological response differences between two study groups (LH-TH vs LH-THTL) following eight weeks of endurance training. To meet this objective, red blood cell (RBC) count, haemoglobin concentration (Hgb) and haematocrit (Hct) tests were conducted.

5.2 Methodology

Study Participants

The sample used for this study was 20 well trained long-distance athletes (16 male and 4 female) who lived and trained in the national athletics training centre. The mean age and training period of the athletes were 18.4±1.2 years and 4.6±1.5 years, respectively. The athletes who participated in the study were living and training in the national athletics training centre (TDNATC) which is located at an altitude of 2500m a.s.l. (7°57′N latitude and 39°7′E longitude). These athletes joined the training centre from all over the country after they competed in their endurance trained age groups. The experiment was approved by Biomedical Research Ethics Committee (BFC193/15) of University of KwaZulu-Natal and Research Ethics Committee of College of Natural and Computational Sciences, Addis Ababa University. The procedures and risks involved were fully explained to the athletes before the study began and written informed consent was obtained.

Study Design

This study applied a balanced randomised experimental design. Before the eight weeks of the experiment began, all the athletes were trained together for four continuous weeks. During the four pre-study weeks, attempts were made to train all athletes at the same training venues; to provide the same frequency, volume and intensity of training; to apply similar content and methods of training; to consume the same food and receive similar recovery strategies. At the end of the four pre-study weeks, the athletes were matched based on their performance and equally assigned into control and experimental groups using a simple random sampling method. There was no difference in gender balance between the groups and the four female athletes were equally assigned into the two study groups.

The study used the modified LH-THTL altitude training model in which all the athletes lived together at 2500m a.s.l and trained for four days together at this altitude. The two study groups separated for two high intensity training sessions, with the experimental and control groups training at 1470m and 2500m, respectively. The blood samples were collected 24 hours before the 5km time trial.

Study Protocol

Resting venous blood samples for complete blood count analysis (5 mL for EDTA blood) was drawn three times (BL, week four and week eight). The samples were drawn from a cubital vein under standard conditions (rest days, between 08:30 and 09:30, before breakfast, and after a ten-minute rest period in a sitting position) in the haematology laboratory of the College of Health Sciences of Arsi University, Ethiopia. Before the test all athletes were told not to participate in any physical activity. To ensure the reliability of the test results, identical blood analyser machines were used (CELL-DYN 3700 Abbott, Illinois, USA).

5.3 Data Analysis

Data are expressed as the mean ± SD as appropriate, following a test for the normality of distribution.Independent sample t- test was used to compare the mean age, training age, body mass, and body mass index variables between the two groups. Regression analysis was then used to identify any significant changes within each subject's set of data, between subjects and over time. Cohen's '*d*' effect sizes (ES) and 95% confidence intervals (CI) were also calculated for all measurements. Magnitudes of the standardised effects were interpreted using thresholds of '*d*' <0.2, 0.2-0.6, 0.6-1.2, 1.2-2.0, 2.0-4.0. These values correspond to trivial, small, moderate, large and very large ES, respectively. Statistical significance was set at $p \leq 0.05$. Statistical analyses were performed using the IBM SPSS Statistics for Windows, Version 23.0. (Armonk, NY: IBM Corp).

5.4 Results

Personal Characteristics

A total of 22 long-distance athletes began the study. Of these, two female athletes (one from each study group) withdrew at an early stage of the study because of injury and family problems. Thus, the results of the 20 participants (10 in each group) were used for the final analysis.

In each group, eight male and two female athletes successfully completed the overall study which lasted for eight continuous weeks. The age of these participants ranged from 17 to 20 years for all the study participants (18.4 ±1.18 years); with the mean age of the experimental group 18.4±1.18 years, and the control group 18.3±1.25 years. The mean body mass (BM) for the total, experimental and control groups was 54.4±6.4kg, 53.6±5.01kg, and 55.3±7.73kg, respectively. The descriptive data for the other anthropometric and personal characteristics of the study participants at baseline are presented in Table 5.1.

Table 5-1: Personal characteristics of the study participants

Characteristics	Descriptive Statistics	Control (n=10)	Experimental (n=10)	Total (n=20)
Age (years)	Mean	18.3	18.4	18.4
	SD	1.25	1.18	1.18
	Min - Max	17 – 20	17 - 20	17-20
Body mass (kg)	Mean	55.3	53.6	54.4
	SD	7.73	5.01	6.4
	Min-Max	40-62.7	46 - 60.7	40.0 - 62.7
Height (m)	Mean	1.7	1.7	1.7
	SD	0.06	0.056	0.056
	Min-Max	1.60 - 1.80	1.6 - 1.78	1.6 - 1.78
Body Mass Index ($kg.m^{-2}$)	Mean	18.9	18.6	18.8
	SD	1.7	1.36	1.53
	Min-Max	14.9 - 20.7	15.6 - 20.3	14.9 - 20.7
Period in training (years)	Mean	4.8	4.4	4.6
	SD	1.4	1.47	1.47
	Min-Max	3.0 - 6.0	2.0-6.0	14.9-20.7
5km personal best (sec.ms)	Mean	918.9	914.3	916.6
	SD	69.4	51.5	59.5
	Min-Max	864.2 - 1062.11	865.05 - 1011.20	864.2 - 1062.1

At baseline there were no statistically significant differences between the two study groups in their age (p = 0.856), period in training (p = 0.556), body mass (p = 0.706), and body mass index (p = 0.724). The descriptive data for the personal characteristics of the study participants (athletes) are presented in Table 5.1.

The time that the athletes spent in endurance training ranged from two to six years for all the athletes and the athletes in the experimental group, and three to six years for the control group. The mean training period for all the athletes, athletes in the experimental group and in the control group was 4.6±1.47, 4.4±1.47, and 4.8±1.4 years, respectively. No significant difference between the two groups in the time the athletes had been in training ($p = 0.556$) was observed. The athletes who were involved in this study had been mainly involved in 3km to 5km track events and 4km, 6km and 8km cross-country races. There were four athletes (two athletes in each group) who had been involved in 10km track events.

Haematological Indices

The descriptive data for the haematological variables (red blood cell count, haemoglobin concentration and haematocrit percentage) of the study participants (athletes) at three time points are presented in Table 5.2. At baseline, week four and week eight, the athletes in the control and experimental groups were tested and had mean red blood cell counts (RBC) of 5.09±0.47 and 5.41±0.29 x 10^6/µL (Experimental), 5.04±0.32 x 10^6/µL and 5.07±0.42 x 10^6/µL (Experimental), 4.92±0.34 x 10^6/µL and 5.28±0.31 x 10^6/µL (Experimental), respectively. The mean haemoglobin concentrations at the same three times were 15.7±1.53 and 16.2±1.22 g.dL^{-1} (Experimental), 15.9±1.33 and 16±1.27 g.dL^{-1} (Experimental), as well as 15.1±1.19 g.dL^{-1} and 15.7±1.24 g.dL^{-1}, (Experimental) respectively. The mean haematocrit values for athletes in both experimental and control groups at baseline, week four and week eight were 45.1±4.2% and 46.5±2.83% (Experimental); 43.3±3.5% and 44±3.13% (Experimental); and 44.1±3.28% and 45.6±3.15 % (Experimental), respectively.

Table 5-2: Red blood cell count, haemoglobin concentration and haematocrit descriptive values

Variables	Time points	Study groups	Mean	SD	95% CI for mean	
					Lower	Upper
Red blood cell count (x 10^6/μL)	Baseline	Control	5.09	0.47	4.76	5.43
		Experimental	5.41	0.29	5.21	5.62
		Total	5.25	0.41	5.06	5.44
	Week4	Control	5.04	0.32	4.82	5.27
		Experimental	5.07	0.42	4.77	5.37
		Total	5.06	0.36	4.89	5.23
	Week 8	Control	4.92	0.34	4.67	5.16
		Experimental	5.28	0.31	5.06	5.50
		Total	5.10	0.37	4.93	5.27
Haemoglobin concentration ($g.dL^{-1}$)	Baseline	Control	15.7	1.53	14.6	16.7
		Experimental	16.2	1.22	15.3	17.1
		Total	15.9	1.38	15.3	16.6
	Week 4	Control	15.9	1.33	15.0	16.9
		Experimental	16.0	1.28	15.1	16.9
		Total	16.0	1.27	15.4	16.6
	Week 8	Control	15.1	1.19	14.3	16.0
		Experimental	15.7	1.24	14.9	16.6
		Total	15.4	1.22	14.9	16.0
Haematocrit (%)	Baseline	Control	45.1	4.20	42.1	48.1
		Experimental	46.5	2.83	44.4	48.5
		Total	45.8	3.55	44.1	47.4
	Week 4	Control	43.33	3.50	40.8	45.8
		Experimental	44.0	3.13	41.7	46.2
		Total	43.6	3.25	42.1	45.2
	Week 8	Control	44.1	3.28	41.7	46.4
		Experimental	45.6	3.15	43.4	47.9
		Total	44.8	3.23	43.3	46.4

No statistically significant difference in RBC count was observed between the two study groups following eight weeks of endurance training (Figure 5.1A). Similarly, the RBC count showed no significant change from baseline to week eight, both in the experimental and control groups (Table 5.3). Although the changes between the two groups and across the eight weeks in each group were insignificant, a small ES was observed in both athletes in the control group (ES = -0.46) and experimental group (ES:-0.33). As can be seen in Table 5.2, a decline in the mean RBC count was observed from baseline to week eight in the experimental group; but a very small in the control group.

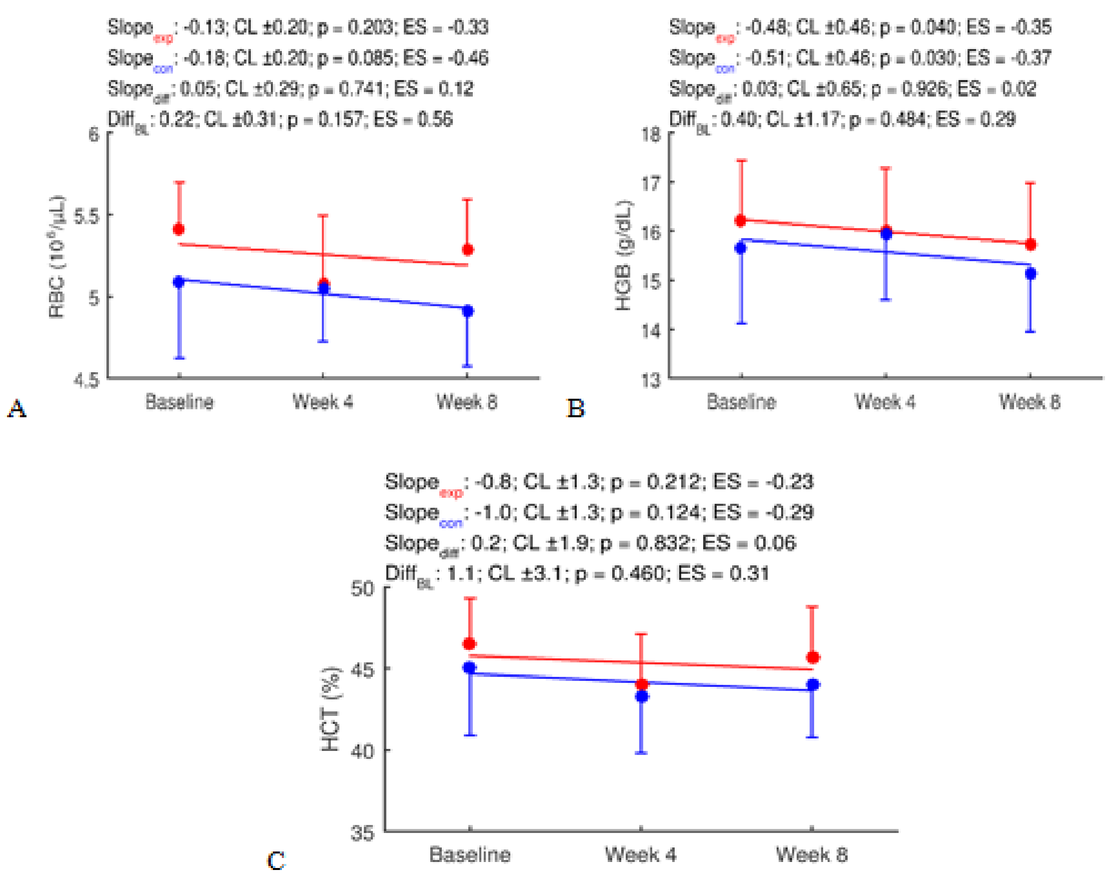

Figure 5.1 Regression analysis results for haematological indices - red blood cell (A), haemoglobin concentration (B), and haematocrit (C)

Table 5-3: Regression analysis results for haematological variables within and between study groups

Variables	Groups	Slope	95% CL	Sig.	Effect Size	Rating
Red blood cell (x 10^6/µL)	Control	-0.18	±0.20	0.085	-0.46	Small
	Experimental	-0.13	±0.20	0.203	-0.33	Small
	Difference	0.05	±0.29	0.741	0.12	Trivial
Haemoglobin C concentration ($g.dL^{-1}$)	Control	-0.51	±0.46	0.030*	-0.37	Small
	Experimental	-0.48	±0.46	0.040*	-0.35	Small
	Difference	0.03	±0.65	0.926	0.02	Trivial
Haematocrit (%)	Control	-1	±1.3	0.124	-0.29	Small
	Experimental	-0.8	±1.3	0.212	-0.23	Small
	Difference	0.2	±1.9	0.832	0.06	Trivial

*$p \leq 0.05$

In comparison to the initial (baseline) measurements, significant changes in haemoglobin concentration were observed after eight weeks of endurance training, both in the experimental and control groups (Table 5.3, Figure 5.1B). Although the haemoglobin concentration substantially declined in both groups, no significant difference was identified between the groups (Δ0.03; CL±0.65; p = 0.926; ES = 0.02) after eight weeks of endurance training. As can be seen in Table 5.3, in comparison to the baseline value, a decline in haemoglobin concentration was observed both in the experimental and control groups at week eight (Table 5.2). In this study, as compared with the control group consistent relative and absolute decline in Hgb concentration was observed in the experimental group (Table 5.4)

Table 5-4: Percentage changes in haemoglobin concentration

Weeks	Control		Experimental		Total	
	Absolute	Relative (%)	Absolute	Relative (%)	Absolute	Relative (%)
BL – W4	0.2	1.27	- 0.2	- 1.23	0.1	0.628
W4 - W8	-0.8	- 5.03	-0.3	- 1.88	-0.6	-3.75
BL – W8	- 0.6	-3.82	- 0.5	- 3.08	0.5	- 3.14

This study also identified no substantial difference in haematocrit concentration between the two study groups following eight weeks of endurance training (Δ0.2; CL±1.9; p =

0.832; ES = 0.06). The results of the three separate tests revealed no significant changes in haematocrit values in both the experimental and control groups from baseline to week eight, although the effect sizes were small and negative in both groups (Table 5.3).

5.5 Discussion

This study is the first to report the effects of two different altitude training models (LH-TH and LH-THTL) on the three selected haematological indices among junior Ethiopian long-distance athletes native to high altitude. The objective of this part of the study was to identify differences in some selected haematological variables (red blood cell, haemoglobin, and haematocrit) between athletes in the two study groups (LH-TH and LH-THTL training models) following eight consecutive weeks of endurance training. At the beginning of this study, no significant differences in haematological indices between the two study groups were hypothesized. The test results of the three haematological indices, i.e., red blood cell count, haemoglobin concentration and haematocrit revealed no significant differences between the two study groups. However, significant changes in haemoglobin concentration were observed from baseline to week eight in both the experimental and control groups. Despite the substantial changes that were observed in haemoglobin concentration in both groups from baseline to week eight, no significant changes were identified in the other haematological indices (RBC and Hct) in the experimental and control groups.

Although the statistical analyses found no significant difference between the two groups, or across time in each group, declines in RBC count from baseline to week eight were observed in both the experimental and control groups. As can be seen in Figure 5.1A, the RBC count of the athletes in both groups plotted as a negative slope due to a decline in the RBC count from baseline to week eight. The changes in the RBC for each of the study groups, and between the groups, were rated as small and trivial, respectively. Although the RBC counts of the athletes in both groups declined, the athletes in each study group improved their endurance performance (5km) from baseline to week eight by 1.99% and 0.715% respectively (see Table 9.6, Chapter 9).

Like the RBC count, there was no significant difference between the two study groups in haemoglobin concentration, despite significant changes over time that were identified in the haemoglobin concentration in both the experimental and control groups. Although these changes with time were significant in both groups, the changes in haemoglobin concentration in both groups were small and the slopes plotted as negative. In comparison with the baseline value, the haemoglobin concentration declined significantly and consistently in athletes in the experimental group; but the decline was irregular in the control group (Table 5.4). Based on the baseline, week four and week eight test results, no significant differences were identified between the two study groups in haematocrit values following eight weeks of endurance training. Similarly, no significant changes were observed in both the experimental and control groups after eight weeks of endurance training. Despite no significant differences and changes between and within the two study groups, the study revealed a decline in haematocrit values from baseline to week eight. This study also identified negative but small changes in both groups.

RBC count, haemoglobin concentration and haematocrit are the most common haematological indices that can be altered by phase and load of training (Mairbäurl, 2013; Banfi et al., 2011). In the current study, declines in the RBC count from baseline to week eight were observed in both study groups, although the athletes in both groups improved their 5km performances. Compared to baseline readings, the athletes' RBC count had declined by the end of the study. The current study started during the first month of preparation training and ended just one week before the first national competition of the year. Based on this time frame, the first four weeks of the study fell into the preparation phase and the training was relatively light and moderate. However, the last two weeks of the study fell into the pre-competition weeks when athletes were preparing for their first competition. As a result, the training load of the last two weeks was deliberately increased by the coach. If one considers the phase of training and the intensity of the training during which the RBC counts declined, then the current study reported similar results to those of previous studies (Mairbäurl, 2013; Banfi et al., 2011; Rietjens et al., 2002). Even though no study results reported on the changes in RBC count among athletes native to high altitude following prolonged periods of endurance training, variations in RBC count following endurance training were reported, especially among athletes native to low altitude (Banfi et al., 2011; Rietjens et al., 2002). An article by Banfi et al. (2011), for example, reported that the RBC count dropped from the preparation phase to competition. Another study found that the RBC count was higher during the early season (beginning) of the training period and declined as competition approached (Rietjens et al., 2002). In addition to seasonal variations, mechanical rupture at the time RBCs pass through capillaries during muscle contractions; compression of red blood cells at the time of foot-ground contact while running; RBC destruction due to frequent foot-strike haemolysis; and continuous exposure to high-oxygen flux are among the different reasons for a decline in RBC count in endurance runners (Telford et al., 2003).

The mean haemoglobin concentration (15.4 $g.dL^{-1}$) of the athletes at the end of the current study (week eight) was closer to that of other elite long-distance Eritrean athletes 15.4$g.dL^{-1}$(Lucia et al., 2006) and Kenyan athletes (16.1$g.dL^{-1}$) native to high altitude. The mean haemoglobin concentration of these native high altitude athletes, including athletes in the current study, was not that different from long-distance athletes of German, 15.5$g.dL^{-1}$(Prommer et al., 2010); Scandinavian, 15.8 $g.dL^{-1}$(Saltin, Larsen, et al., 1995); and Spanish 15.1$g.dL^{-1}$(Lucia et al., 2006) origin; all native to low altitude. In relation to the haemoglobin concentration in the general Ethiopian population (all native to high altitude), a study by Beall et al. (2002) reported similar haemoglobin concentrations (15.9±0.1 $g.dL^{-1}$ with a range from 12.7 to 18.9$g.dL^{-1}$ for males and 15.0±0.1 with a range from 12.0 to 18.2$g.dL^{-1}$ for females) within the normal range of fully acclimatised sea level residents; but lower than other individuals native to high altitudes from the Andes and Tibet. In relation to the variability in haemoglobin concentration among people native to high altitude, Beall et al. (1998) also reported differences between Tibetan natives of the Himalayas and Bolivian natives of the Andes. The results of this study revealed that the Bolivian residents had higher haemoglobin concentrations than the Tibetans (native to the Himalayas (3800 – 4065m a.s.l)), whose haemoglobin concentrations were similar to residents at sea level. Taking this variability into consideration, Beall at al. (2002)

concluded that there is more than one way in which humans adapt to high altitude. The similarity in the values of the haemoglobin concentrations of Ethiopians and sea level residents may invite further research.

As studies have reported, substantial declines in haemoglobin concentration in well-trained endurance athletes is a normal phenomenon (Mairbäurl, 2013; Banfi et al., 2011). The findings of the current study which identified a decline (negative slope) in haemoglobin concentration over time are supported by other studies (Anđelković et al., 2015; Prommer et al., 2010; Mørkeberg et al., 2009). Different studies reported greater seasonal variations in haemoglobin concentration (Mairbäurl, 2013; Banfi et al., 2011). Like the RBC, haemoglobin concentration is higher in the early stage of endurance training (the preparation phase in the yearly training programme) and decline during the competition phase. As studies (Banfi et al., 2011) reported, the decline in haemoglobin concentration ranges between 3 and 8% from the preparation phase to the competition season; or as the intensity of training increases and the volume of training decreases. The decline in haemoglobin concentration (baseline to week eight) in the current study was within this range (3 – 8%) both in the experimental (3.82%) and control (3.08%) groups. In another altitude based study (Wachsmuth et al., 2013) that involved athletes native to sea level, different findings were reported. After 53 days of altitude training, when the male athletes' haemoglobin concentration increased, no significant change in haemoglobin concentration was reported in the female athletes from pre- to post-altitude training. A study (Prommer et al., 2010) that involved native high altitude (Kenyan) athletes also reported a decline in mean haemoglobin concentration when the Kenyan endurance athletes were tested at high altitude (2090m a.s.l.) and then trained for 40 continuous days at low altitude (340m a.s.l.). During this time, the haemoglobin concentration dropped from 16.1±0.7g.dL^{-1} (baseline and altitude) to 15.3± 0.9 g.dL^{-1} (day 40 and low altitude). Although a decline in haemoglobin concentration was identified, no explanation for the decline was provided by the study. The direction of changes in haemoglobin concentration from baseline to week eight in the current the study by Prommer et al. (2010) in which the haemoglobin concentration changed from 16.1±0.7 at baseline to 15.3±0.9 g.dL^{-1} after 40 days of endurance training at low altitude (340m a.s.l.), although the relative percentage changes varied in the experimental (- 3.08%), control (-3.82%) and Kenyan athletes (-4.96%) groups.

Like the RBC and haemoglobin concentrations, it is common to see seasonal variations in haematocrit values among endurance athletes (Lombardi et al., 2013; Banfi et al., 2011). According to studies (Banfi et al., 2011; Prommer et al., 2010; Mørkeberg et al., 2009), a reduction in haematocrit values was reported from light intensity training (preparation) to high intensity training (competition). In this regard the findings of the current study are in line with the results of the above studies. In addition to seasonal variations in haematocrit, changes in haematocrit were also reported before and after training (Mairbäurl, 2013). Taking this finding into consideration, the current study attempted to conduct all three haematological tests 24 hours after the end of training, and before athletes engaged in any physical activities.

Although, in the current study, no significant changes in haematocrit values were observed in either the experimental or control groups, time-based variations in haematocrit readings were identified. A study by Moore et al. (2007) also investigated variations in haematocrit due to altitude differences among Kenyan long-distance athletes native to high altitude. In this study, like the haemoglobin concentration, a decline in haematocrit was also observed in athletes moving from high altitude (50±2%) at baseline to sea level (45±2 %, $p < 0.05$), measured after seven days prior to their competing at sea level. In this study, the decline in both haemoglobin concentrations and haematocrit levels can be from altitude changes and seasonal training variations. Even though the significant changes in haemoglobin concentration and haematocrit values between baseline and seven days after athletes' descent to sea level might be attributed to the change in altitude, the passage of time can be another reason.

The findings on haematocrit levels in the current study agree with research (Prommer et al., 2010) conducted on few Kenyan athletes native to high altitude who share similar physiological and environmental characteristics with Ethiopian endurance athletes resident at high altitude. The study by Prommer et al. (2010) reported a reduction in haematocrit levels among high altitude athletes from baseline (48.6±2.4%) to (46.1 ± 2.1%) after 40 days of endurance training at low altitude.

Surprisingly, no difference in the selected haematological indices was identified between the two study groups following the two altitude training models. The effect of different altitude training models on the haematological variables of athletes native to sea level and low altitudes is well-established in the existing literature. The reported changes in the haematological indices of athletes native to sea level and low altitudes were associated with changing altitude for an extended period of time to improve physiological well-being and enhance performance. The haematological changes that had been reported in these athletes were mostly associated with elevation changes. Unlike this group of athletes (sea level natives), athletes in the current study (both experimental and control groups) were living at the same altitude throughout the study (eight weeks). Only the athletes in the experimental group were trained separately at low altitude (1470m) twice a week. As is indicated in different studies, one of the purposes of the LH-TL or the LH-THTL altitude training models is to benefit athletes physiologically while living at high altitude and to gain training advantage (speed of running) at low altitude. One of the possible explanations for no differences between the two study groups and no positive haematological changes in either study group might be because the athletes remained living at the same altitude.

Studies have also reported that changes in haematological variables can occur when athletes are exposed to hypoxic conditions. When athletes are exposed to hypoxic conditions, erythropoietin, and thereby, RBC production increases. The declines that were observed in haematological indices from baseline to week eight might not be attributed to the altitude where the athletes were living, but rather to the endurance training that lasted for eight consecutive weeks. The overall assessments of the current study also showed declines in the three haematological indices following use of the two selected altitude training models; although the declines were accompanied by endurance performance changes. The findings, especially the decline in haematological indices, were supported by other similar studies as phase in the yearly training period, training load changes as well as mechanical injury and foot contact might contribute to changes in haematological indices in athletes following endurance training.

Limitations

Although several different altitude training models are being used, due to logistic and financial limitations the current study only selected two altitude training models (LH-TH and LH-THTL). Small sample size and unequal gender representation were limitations of this study. It is also worth noting that total haemoglobin mass (tHb) measurements, which is less susceptible to dehydration and/or body's fluid balance changes when measuring athletes' haemoglobin level, could have been used instead of haemoglobin concentration (Lombardi et al., 2013; Mairbäurl, 2013; Otto et al., 2013; Schmidt & Prommer, 2005). Considering the variability in haematological results, the short duration (eight weeks) of the current study is another drawback. Although the haematological laboratory in which the tests were conducted was well supervised and up-to-standard, the place where the haematological samples were taken (Asella Referral Hospital) might be considered as another limitation of the study as it put athletes under stress.

5.6 Conclusions

The findings of this study revealed no differences in RBC, haemoglobin concentration, and haematocrit levels between the two study groups following eight weeks of endurance training. This study also identified a decline in the selected haematological variables, although athletes in both study groups improved their endurance performance. The summary of the results of this existing study revealed that the phases in the yearly training period, training loads of training as well as mechanical factors such as ground-and foot contact might contribute towards the decline in the selected haematological indices of the athletes in both study groups. In general, this study underlined the insignificant effect of eight weeks of LH-TH and LH-LHTL altitude training on selected haematological variables, but highlighted its positive training effect in enhancing the endurance performance of junior Ethiopian long-distance runners native to high altitude.

Future Research

In order to exhaustively investigate the effects of different altitude training models on haematological variables among endurance athletes native to high altitude, this study recommends repeating similar studies, but with modified study designs. To achieve better results, further studies should be conducted using large sample sizes with balanced gender proportions, while also paying attention to non-haematological variables, and using additional altitude training models like live moderate - train high as well as live low - train low (live and train at 1500m).

CHAPTER SIX: VAGAL-RELATED HEART RATE ASSESSMENT (MANUSCRIPT)

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This manuscript presents the results of research into the second hypothesis of the altitude study. To the best of our knowledge this study is the first of its type to investigate the effects of the live high - train high and live high - train high/train low altitude training models on vagal-related heart rate responses among Ethiopian long-distance runners native to high altitude following eight weeks of endurance training.

Target journal: Frontiers in Endocrinology

Title: Autonomic response differences of Ethiopian junior long-distance athletes following eight weeks of live high - train high and live high - train high train low (periodized) altitude training at altitude in Ethiopia.

Abstract

Background: Different studies have reported the long-term effects of endurance training on the sympathetic and parasympathetic nervous system activity using heart rate indices including heart rate variability(HRV) and heart rate recovery (HRR). The major objective of this study was to identify differences in vagal-related heart rate responses (HRV and HRR) between athletes in the live high-train high (LH-TH) and live high – train high train low (LH-THTL) groups following eight weeks of endurance training. **Method:** This study applied a balanced randomised experimental design. A total of 20 well-trained junior long distance athletes, were assigned into the LH-TH (n=10) and LH-THTL (n=10) groups. Resting HRV and one- and two-minute post-exercise HRR measurements were taken at three time points (baseline, week four and week eight). **Results:** The resting HRV (RMSSD) measurements revealed no meaningful differences between the LH-TH and LH-THTL groups (Δ-0.18; CL±0.43; $p = 0.407$; ES = -0.29), from baseline to week eight in the experimental (Δ0.05; CL±0.31; $p = 0.761$; ES = 0.08) and control (Δ0.22; CL±0.31; $p = 0.145$; ES = 0.37) groups; although the changes in both groups were positive. The size of the difference between the experimental and control groups was negative and small (Δ-0.29). The regression analysis also revealed no significant differences, both in the one-minute (Δ4.4; CL±10.8; $p = 0.413$; ES = 0.47) and two-minute post-exercise HRR (Δ3.1; CL±10.4; $p = 0.550$; ES = 0.31) between the experimental and control groups. **Conclusion:** Eight weeks of altitude- based endurance training did not cause any significant differences in the vagal-related heart rate activities between the two study groups of junior Ethiopian long-distance runners. However, positive improvements both in HRV and post-exercises HRR were identified in the LH-TH altitude training group and only positive HRV change in the LH-THTL group.

Keywords: vagal-related heart rate, autonomic nervous system, heart rate variability, heart rate recovery, live high - train high, live high - train high train low

6.1 Introduction

A study by George et al. (2012) reported the long-term effects of endurance training on the sympathetic and parasympathetic nervous system. Other related studies have reported the chronic effects of endurance training on the resting (Vesterinen, 2016), recovery (Bellenger et al., 2016; Cornforth et al., 2014; Daanen et al., 2012), maximal (Whyte et al., 2008) and heart rate variability (HRV) (Saboul et al., 2016; Schmitt et al., 2015; Reichert & Picanço, 2014; Makivić et al., 2013) indices. Of these heart rate indices, HRV is the most researched non-invasive tool to monitor training. Heart rate variability is defined as the variability in time between each consecutive heartbeat, and is determined by recording the R-R interval of a P-Q-R-S wave during a normal electrocardiograph (George et al., 2012).Although different methods of HRV measurement have been reported in the literature, the European Society of Cardiology and the North America Society of Pacing and Electro-Physiology recognise the time domain, frequency domain as well as the non-linear methods as the most common methods to analyse HRV (Camm et al., 1996). Of these methods, the time domain method of HRV analysis is as the simplest of all others (Plews, 2014).

In a recent review by Buchheit (2014), the advantages and disadvantages of different HRV measurements were discussed. This review clearly reported that RMSSD, which is measured from one to five-minute recordings in a supine position upon waking, is the most useful resting HRV indicator. However, other studies (Plews, Laursen, Stanley, Kilding, & Buchheit, 2013) have recommended the use of different HRV measuring methods to collect HRV data; but the use of only one method for analysis. In this regard, RMSSD is the method most recommended by researchers to analyse HRV data (Plews et al., 2013).

In relation to the effects of endurance training on HRV a recent review by Buchheit (2014) reported HRV and other HR indices responses could fluctuate during training interventions that can take place over several weeks. For example, the ANS activity of the heart varies considerably from time to time, based on the training load distribution of the intervention. A decrease in vagal-related HRV and slower HRR is associated with high training load, although moderate training loads are associated with increased vagal-related HRV indices (Buchheit, 2014). Unlike in general endurance athletes, the autonomic nervous system activity did not always follow the same pattern in elite endurance athletes during prolonged training (Buchheit, 2014). Studies (Plews et al., 2013; Stanojević et al., 2013; Plews et al., 2012) on HRV demonstrated that the hearts' autonomic regulation improves during the beginning of the training phase in which the majority of the training is extensive endurance training (the first phase of training), which decreases during the competition phase or before the competition period. This review (Buchheit, 2014) boldly suggested the importance of considering the phase in any given training and the training load of that particular week before interpreting the HRV and HRR data which has been collected. In endurance athletes, cardiac autonomic regulation possibly improves during the first part of the training phase (build-up or extensive endurance phase, possibly leading to functional over-extending), while it decreases over the weeks preceding competition (tapering) (Hug et al., 2014).

In addition to studies that have been carried out to examine the relationship between positive training adaptations and HRV, there are also some studies that reported a decrease in HRV in relation to negative training adaptations (Meeusen et al., 2013; Meeusen et al., 2006). Studies that focused on HRV responses in over-trained or over-reached athletes reported different findings. For example some studies (Bosquet et al., 2003; Hedelin, Wiklund, et al., 2000; Uusitalo et al., 2000) reported no change in HRV among non-functional and over-trained athletes. In other similar studies, both a decrease (Uusitalo et al., 2000) and an increase (Hedelin, Wiklund, et al., 2000) in HRV were reported in subjects who were over-reached (NFOR) and over-trained (OTS). Both positive and negative endurance training adaptations are associated with increased and decreased HRV (Buchheit et al., 2010; Mourot, Bouhaddi, Perrey, Rouillon, & Regnard, 2004;Yamamoto, Miyachi, Saitoh, Yoshioka, & Onodera, 2001). Although this explanation has been frequently reported in the literature, the majority of the published data HRV did not study elite or top-level endurance athletes (Mourot et al., 2004; Yamamoto et al., 2001). There are few HRV studies (Plews et al., 2013; Schmitt et al., 2013; Plews et al., 2012; Pichot et al., 2000) that involved elite endurance athletes; and their findings were inconclusive.

In a similar study that involved seven middle-distance athletes a shift in cardiac autonomic balance and HRV toward a predominance of the sympathetic over the parasympathetic drive following heavy trainings was reported (Pichot et al., 2000). This study measured nocturnal HR and HRV during three weeks of high and one week of light training and reported significant changes in HRV indices over the specified weeks (Pichot et al., 2000). During the study the nocturnal HR increased by 9% ($p < 0.05$) and decreased by 11% ($p < 0.05$) from week one to week three and from week three to week four, respectively. This study also measured time-related HRV indices (PNN50, SDNN, RMSSD, and SDNN index) and reported significant changes (decreases in HRV) from the intense training at week three to the recovery period in week four in SDNN (from 148.5±43.5 ms to 190.0±67.7ms) and the SDNN index (from 116.8±37.8 to 152.7±61.7ms), both $p < 0.05$ (Pichot et al., 2000). Although increases in other absolute HRV indices (PNN50, RMSSD) were reported, statistical tests revealed insignificant changes between weeks three and four. In summary, this study found a significant and progressive decrease in parasympathetic indices of up to – 41% (p<0.05) during the third week of heavy training, followed by a significant increase during the relatively easy rest week of up to + 46% ($p < 0$ .05).

There are some studies that reported a parallel increase in HRV and aerobic fitness in sedentary and recreational-level athletes (Buchheit, Simpson, Al Haddad, Bourdon, & Mendez-Villanueva, 2012; Mourot et al., 2004; Yamamoto et al., 2001). Similarly a study by Buchheit et al. (2010) reported a strong relationship between pre-training resting HRV (RMSSD) and the time taken to cover 10 km (r = - 0.77, $p < 0.01$); and post-training HRV (RMSSD) and 10 km performance (r = - 0.65, $p < 0.01$). On the other hand earlier studies reported increases in HRV, despite no change in aerobic performance (Portier, Louisy, Laude, Berthelot, & GuÉzennec, 2001); and decreases in HRV although there was improvement in aerobic fitness (Iellamo et al., 2002). A study by Buchheit et al. (2010), however, concluded that resting as well as post-training HRV measurements may predict endurance performance changes in athletes. In support of Buchheit et al. (2010), a study by Plews et al. (2013) reported that an increase in HRV values a few days before competition might be an indication of positive training adaptation.

Along with HRV, post-exercise HRR, which is the result of the joint activities of sympathetic withdrawal and parasympathetic reactivation have been reported in different heart-rate based studies to monitor the effects of endurance training. Passive post-exercise HRR, the rate at which heart rate decreases after training or physical exercise, has been widely used to determine endurance performance changes (Stanojević et al., 2013). Studies reported that optimal endurance training enhances the role of parasympathetic activation and sympathetic withdrawal (Stanojević et al., 2013) which ultimately results in a quicker heart rate recovery. Other studies (Buchheit et al., 2010; Lamberts et al., 2009) also supported the study by Stanojević et al. (2013) in that parallel in HRR and endurance performance changes. In line with the above studies, a study by Aubry et al. (2015) similarly reported a rapid decrease in heart rate within one minute after the end of maximal aerobic power exercise among well-trained tri-athletes at the period of functional over-reaching. However, a recent review by Bellenger et al. (2016) noted inconsistent results regarding the relationship between HRR and endurance performance. According to this review, there were studies that reported endurance training interventions with a moderate increase, both in post-exercise HRR and improved exercise performance (Cornforth et al., 2014; Buchheit et al., 2010; Lamberts et al., 2009), and a small increase in HRR and improvement in performance (Capostagno, Lambert, & Lamberts, 2014; Buchheit et al., 2012).

Contrary to this positive relationship, there were also studies that indicated an increase in post-exercise HRR, but a decrease in performance (Thomson, Bellenger, Howe, Karavirta, & Buckley, 2016; Dupuy et al., 2013). Taking these opposing findings in to consideration, the recent review by Bellenger et al. (2016) highlighted the need to not use HRR as the only marker to monitor changes in endurance performance (Bellenger et al., 2016). Based on the existing literature, and to the best of the authors' knowledge, no study has reported on the effects of endurance training on vagal-related heart rate indices among high altitude native Ethiopian endurance athletes. Therefore, the objective of this study was to identify vagal-related heart rate differences between two groups of endurance athletes (LH-TH Vs LH-

THTL) following eight weeks of endurance training. To meet this objective, resting HRV and one- and two-minute post-exercise HRR measurements were obtained.

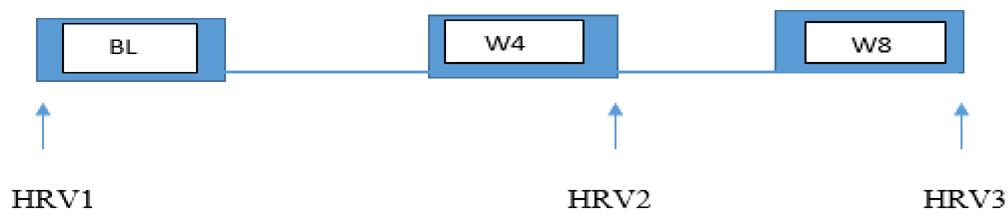
6.2 Methodology

Study Participants

The sample size for this study was 20 long distance athletes (male = 16 and female = 4) who lived and trained in the national athletics training centre (TDNATC). The mean age of the athletes and years in training were 18.4±1.2 years and 4.6±1.5 years, respectively (Table 6.1). Before the study begun all the athletes gave their written informed consent and the research protocol was conducted in accordance with the Helsinki declaration. The research protocol was approved by the UKZN and AAU-CNCS research ethics committee. The athletes who participated in the study were living and training in the national athletics training centre where it is located at an altitude of 2500m (7°57′N latitude and 39°7′E longitude). These athletes joined the training centre from all over the country after they had in their appropriate endurance trained age groups.

Study Design

This study applied a balanced randomised experimental design. The outline of the study design is presented in Figure 6.1. Before the eight experimental weeks began, all the athletes were trained together for four continuous weeks (pre-experimental weeks). During the four pre-experimental weeks, attempts were made to train all athletes at the same training venue; to provide the same frequency, volume and intensity of training; to apply similar content and training methods; and to provide uniform nutrition and similar recovery strategies. At the end of the four pre-study weeks, the athletes were matched based on their performance and equally assigned into control and experimental groups using a simple random sampling method. There was no difference in gender balance between groups: the four female athletes were equally assigned between the two study groups. Throughout the study, both the control and experimental groups lived together at an altitude of 2500m. All the athletes in both groups had light and moderate intensity endurance training together for four days per week at an altitude of 2500m. However, athletes in the control and experimental groups were separated for high intensity interval training twice a week at altitudes of 2500m and 1470m, respectively. Resting HRV measurements were taken at three times: baseline, week four, and week eight.



BL = baseline, W = week, HRV = heart rate variability

Figure 6.1 Study design for heart rate variability

Study Protocol

The HRV and HRR data were collected using a HR monitor (First-beat SPORTS Textile Heart Rate adjustable chest strap transmitter belt 600-800mm length and 45g weight, manufactured in Finland) with a measurement accuracy of 1ms. The HR monitor was wirelessly connected with a First-beat SPORTS Team Receiver (Receiver 30: with a radius of 200m range, First-beat SPORTS Technologies Jyväskylä, Finland) which is recommended for indoor and outdoor use.

The two vagal-related heart rate measurements were taken at two different times of the day. The three resting HRV measurements were taken early in the morning before the athletes left their rooms for daily endurance training. The one- and two-minute heart rate recovery measurements were taken one and two minutes after each 5km time trial.

Before each HRV measurement was taken, the participants were told to avoid any exercise, caffeine or a large meal before the test. In order to get the most accurate results, the resting HRV test protocol was standardised. The tests were conducted in a silent environment (sleeping rooms) where the athletes were able to relax properly and could breathe naturally. The athletes were instructed not to talk, move or use any electronic devices at the time of measurement. Before the measurements were taken, the personal profiles of the athletes, including belt identification numbers and other relevant data that were initially registered by the software, were checked, based on the individual code provided for each athlete.

The HRV measurements were taken at baseline, and in the fourth and eighth weeks, three days each week, early in the morning, 20-30 minutes after the participants woke up. All the measurements were taken at the same time of day (between 6:00 a.m and 7:00 a.m) for five continuous minutes, with the athletes lying down in their sleeping rooms at the sport academy. The measurements were accepted when the measurement error was less than 5%. If a higher measurement error registered, another measurement was taken on the spot. Of the three HR and HRV measurements, two of the measurements were taken 20 to 22 hours after a hard training session; and the resting measurement was taken 22 hours after a light training session. The collected heart rate and HRV data (IBI) data was analysed using First-beat SPORTS Version 4.7.3.1(Jyväskylä, Finland).

The HRR measurements were obtained immediately (one or two minutes) after each 5km time trial. Athletes were instructed to lie down as soon as they finished the 5km time trial. The apparatus that started reading the heart rates at the beginning of the 5km time trial did not stop until the one- and two-minute post-exercise heart rate recovery measurements of all the athletes had been completed. The heart beats that appeared on the screen at one- and two-minutes after the 5km time trail were recorded, exported and documented in Excel file format.

Training

Throughout the eight study weeks all the athletes in both groups (experimental and control) received similar training (mainly endurance/aerobic training with continuous, fartlek and interval variations). The study followed a single training session pattern in which the sessions were conducted every day in the morning before breakfast. Over the six training days in a week, the athletes were involved in two short and long interval trainings, two long, slow recovery runs and two fartlek trainings. During the entire study, no resistance or plyometric training sessions were conducted.

6.3 Statistical Analysis

Normal distribution of the variables was checked using the Shapiro-Wilk Test. In addition, visual inspection of the data distribution was performed. The test indicated that the HRV data were not normally distributed ($p < 0.01$) and therefore a natural logarithm (Ln) was applied. After Ln-transformation, heart HRV was normally distributed. Data are expressed as the mean ± SD. Independent sample t- test was used to compare the mean age, training age, BM, and BMI between the two groups. Regression analysis was used to identify any significant changes within each subject's set of data, and between subjects, as well as over time. Cohen's *d* effect sizes (ES) and 95% confidence intervals (CI) were also calculated for all measurements. Magnitudes of the standardised effects were interpreted using thresholds of $d < 0.2$, 0.2-0.6, 0.6-1.2, 1.2-2.0, 2.0-4.0. These values correspond to trivial, small, moderate, large and very large ES, respectively. Statistical significance was set at$p<$ 0.05. Statistical analyses were performed using the IBM SPSS Statistics for Windows, Version 23.0. (Armonk, NY: IBM Corp).

6.4 Results

Personal characteristics

The sample size for this study was 20 long distance athletes (male = 16 and female = 4) who lived and trained in the national athletics training centre (TDNATC). In each group, eight male and two female athletes successfully completed the overall study that lasted for eight weeks. The age of these participants ranged from 17 – 20 years; for all the study participants (18.4 ±1.18 years), and the experimental (18.4±1.18years) and control (18.3±1.25years) groups. The mean body mass (BM) for the total, experimental and control groups was 54.4±6.4kg, 53.6±5.01kg, and 55.3±7.73kg, respectively. The descriptive data for the other anthropometric and personal characteristics of the study participants at baseline are presented in Table 6.1.

Table 6-1: Personal characteristics of the study participants

Characteristics	Descriptive Statistics	Control (n=10)	Experimental (n=10)	Total (n=20)
Age (years)	Mean	18.3	18.4	18.4
	SD	1.25	1.18	1.18
	Min - Max	17 – 20	17 - 20	17-20
Body mass (kg)	Mean	55.3	53.6	54.4
	SD	7.73	5.01	6.4
	Min-Max	40-62.7	46 - 60.7	40.0 - 62.7
Height (m)	Mean	1.7	1.7	1.7
	SD	0.06	0.056	0.056
	Min-Max	1.60 - 1.80	1.6 - 1.78	1.6 - 1.78
Body Mass Index (kg.m^{-2})	Mean	18.9	18.6	18.8
	SD	1.7	1.36	1.53
	Min-Max	14.9 - 20.7	15.6 - 20.3	14.9 - 20.7
Period in training (years)	Mean	4.8	4.4	4.6
	SD	1.4	1.47	1.47
	Min-Max	3.0 - 6.0	2.0-6.0	14.9-20.7
5km personal best (sec.ms)	Mean	918.9	914.3	916.6
	SD	69.4	51.5	59.5
	Min-Max	864.2 - 1062.11	865.05 - 1011.20	864.2 - 1062.1

The cumulative amount of time in years that the athletes had spent in endurance training ranged from two to six years for all the athletes and athletes in the experimental group; and from three to six years for the control group. The means of the years spent in training by all the athletes, and athletes in the experimental and control groups were 4.6±1.47, 4.4±1.47, and 4.8±1.4 years, respectively. There were no significant differences between the two groups in their time spent in training (p = 0.556). The athletes who were involved in this study had been mainly involved in track events between 3km and 5km; and in 4km, 6km and 8km cross-country races. There were four athletes (two in each group) who had been involved in 10km track events.

Vagal-related heart rate measurements: heart rate variability

Resting HRV indices like the square root of the mean squared differences of successive R-R intervals (RMSSD), the standard deviation of all normal R-R intervals (SDNN), low frequency (LF), high frequency (HF), low frequency to high frequency ratio (LF/HF), and low frequency plus high frequency (LF + HF) were taken at baseline, week four and week eight, three times per week. Of all the above listed HRV indices studies (Al Haddad, Laursen, Chollet, Ahmaidi, & Buchheit, 2011) support the use of RMSSD because of its greater reliability compared with other HRV indices. Thus, the vagal-mediated square root of the mean squared differences of successive R-R intervals (RMSSD) analysis was selected and used to compare the heart rate variability-based training load responses between the two study groups.

The resting HRV (RMSSD) measurements revealed no meaningful differences between the LH-TH and LH-THTL groups following eight weeks of endurance training, and at baseline. Based on the resting HRV measurements taken at three time points (BL, week four, and week eight), no significant changes were identified, either in the experimental or control groups; although the changes in both groups were positive (Figure 6.2B, Table 6.2). As far as the change is concerned, it was positive but trivial (ES = 0.08) in the experimental group and positive and small (ES = 0.37) in the control group. The difference between the experimental and control groups (Table 6.2), however, was negative and small (ES = -0.29).

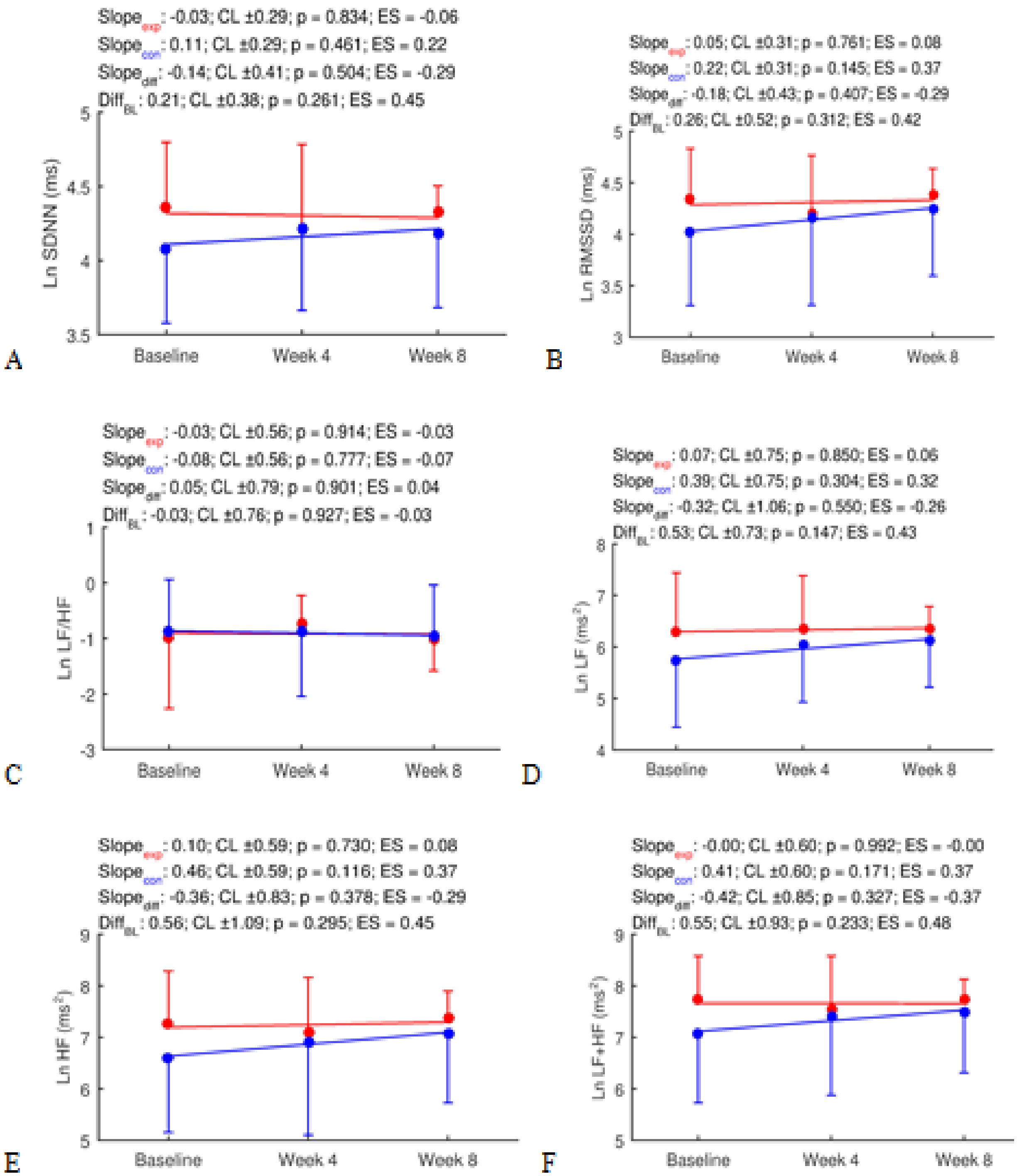


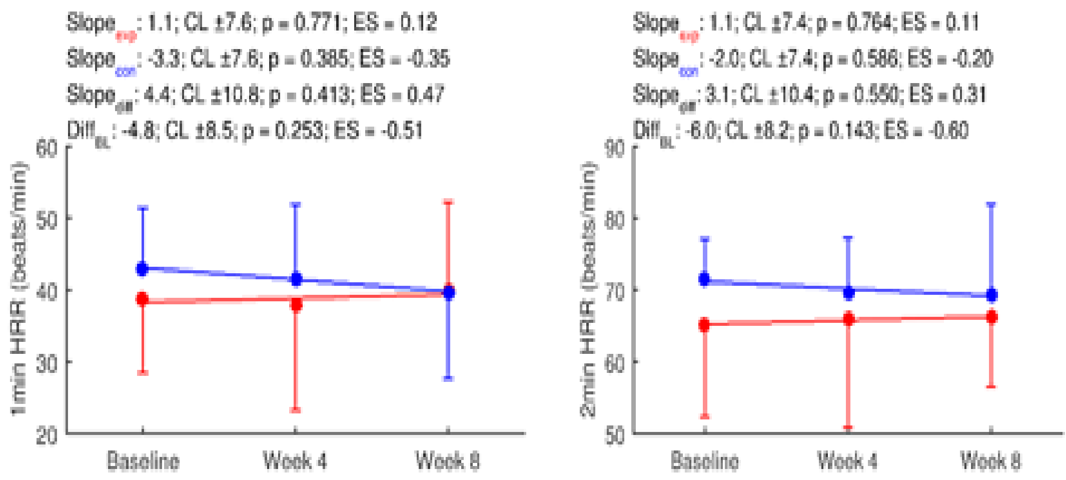
Figure 6.2 Regression analysis results for heart rate variability indices - LnSDNN (A), LnRMSSD (B), LnLF/LH (C), LnLF (D), LnHF (E), LnLF+HF (F)

Table 6-2: Heart rate variability indices

Heart rate variability indices	Groups	Slope	95% CL	Sig.	Effect	Rating
HRV Ln HF (ms^2)	Control	0.46	±0,59	0.116	0.37	Small
	Experimental	0.1	±0,59	0.730	0.08	Trivial
	Δ (Exp - Con)	-0.36	±0,83	0.378	-0.29	Small
HRV Ln LF (ms^2)	Control	0.39	±0,75	0.304	0.32	Small
	Experimental	0.07	±0,75	0.850	0.06	Trivial
	Δ (Exp - Con)	-0.32	±1,06	0.550	-0.26	Small
HRV Ln LF/HF	Control	-0.08	±0,56	0.777	-0.07	Trivial
	Experimental	-0.03	±0,56	0.914	-0.03	Trivial
	Δ (Exp - Con)	0.05	±0,79	0.901	0.04	Trivial
HRV Ln RMSSD (ms)	Control	0.22	±0,31	0.145	0.37	Small
	Experimental	0.05	±0,31	0.761	0.08	Trivial
	Δ (Exp - Con)	-0.18	±0,43	0.407	-0.29	Small
HRV Ln SDNN (ms)	Control	0.11	±0,29	0.461	0.22	Small
	Experimental	-0.03	±0,29	0.834	-0.06	Trivial
	Δ (Exp - Con)	-0.14	±0,41	0.504	-0.29	Small
HRV Ln LF+HF (ms^2)	Control	0.41	±0,60	0.171	0.37	Small
	Experimental	0	±0,60	0.992	0	Trivial
	Δ (Exp - Con)	-0.42	±0,85	0.327	-0.37	Small

Vagal related heart rate measure: heart rate recovery

Three one- and two-minute post-exercise HRR measurements were taken at baseline, week four and week eight immediately after the 5km time trials. The regression analysis revealed (Figure 6.3) that there was no difference between the experimental and control groups in the one-minute post-exercise HRR. Based on these measurements, no significant changes in absolute HRR after one minute were observed in either the experimental or control groups following eight weeks of endurance training using the two altitude training models (Figure 6.2, Table 6.4). Although the analysis reported no significant changes between the two groups, variations were observed both in magnitude and direction in the two groups. The one-minute HRR measurement revealed that the change in the experimental group was trivial and positive (Δ1.1; ES = 0.12); while the change in the control group was small and negative (Δ-3.3; ES = -0.35). The descriptive data for post-exercise HRR are presented in Table 6.3.



A B

Figure 6.3 Regression analysis results for Post-exercise absolute heart rate recovery - one-minute (A), two-minute (B)

Table 6-3: Descriptive statistics for post-exercise absolute heart rate recovery

Absolute heart rate recovery(HRR)	Test Weeks	Study groups	Mean	SD	95% CI for mean	
					Lower Bound	Upper Bound
One-minute heart rate recovery (beats.min^{-1})	BL	Control	43.0	8.35	37.0	49.0
		Experimental	38.4	10.9	31.4	46.2
		Total	40.8	9.67	36.5	45.3
	Week 4	Control	37.6	16.7	34.2	49.0
		Experimental	37.8	15.5	27.4	48.2
		Total	37.7	15.7	33.9	45.5
	Week 8	Control	39.7	12.0	31.1	48.3
		Experimental	40.0	13.0	31.1	48.7
		Total	39.8	12.2	34.3	45.3
Two-minute heart rate recovery (beats.min^{-1})	BL	Control	71.4	5.64	67.4	75.4
		Experimental	65.1	12.7	56.0	74.2
		Total	68.3	10.1	63.5	73.0
	Week 4	Control	62.8	23.3	64.3	75.1
		Experimental	59.4	25.8	55.2	76.8
		Total	61.1	24.0	62.3	73.4
	Week 8	Control	69.4	12.5	60.5	78.3
		Experimental	66.2	9.66	59.3	73.1
		Total	67.8	11.0	62.7	72.9

Table 6-4: Regression analysis results for one- and two-minute post-exercise absolute heart rate recovery

HRR Variables	Groups	Slope	95% CL	Sig.	Effect Size	Rating
Absolute HRR 1 min (beat.min^{-1})	Control	-3.3	±7,6	0.385	-0.35	small
	Experimental	1.1	±7,6	0.771	0.12	trivial
	Δ (Exp - Con)	4.4	±10,8	0.413	0.47	small
Absolute HRR 2min (beats.min^{-1})	Control	-2.0	±7,4	0.586	-0.2	small
	Experimental	1.1	±7,4	0.764	0.11	trivial
	Δ (Exp - Con)	3.1	±10,4	0.550	0.31	small

The analysis (Table 6.4) also revealed that there was no difference between the experimental and control groups in the magnitude of change for two-minute post-exercise HRR (Table 6.4). Like the one-minute HRR, no significant changes were observed in two-minute post-exercise absolute HRR in either the experimental or control groups following eight weeks of endurance training (Table 6.4). Although the analysis reported no significant changes between the two groups, variations were observed both in the magnitude and direction of changes in the two study groups (experimental and control). The effect sizes were rated as trivial and positive (ES = 0.11), and small and negative (ES: -0.20), for the experimental and control groups, respectively (Table 6.4).

6.5 Discussion

This study is the first of its type to report on the effects of two different altitude training models (LH-TH and LH-THTL) on the vagal-related heart rate indices among east African long-distance athletes native to high altitude; specifically, Ethiopian junior long-distance athletes. One of the objectives of this study was to identify differences in the vagal-related autonomic heart rate response between the LH-TH and LH-THTL study groups following eight weeks of endurance training. Two types of heart rate measurements were assessed to test vagal-related heart rate differences – HRV and post-exercise HRR. Although different HRV and HRR measurement methods were employed in this study, the RMSSD and one-and two-minute absolute HRR measurements were used to analyse HRV and HRR differences between and within the two study groups.

At the beginning of this study it was hypothesised that there would be no difference between the two study groups in their vagal-related heart rate indices (HRV and HRR). The findings of this study supported the null hypotheses since no substantial differences in the LnRMSSD-based HRV or in the one- and two-minute HRR indices were identified. The tests confirmed insignificant differences between the two study groups, both at baseline and at the end of the study. Differences in the magnitude of slope and effect size were observed between the two groups in the HRV measurements. In comparison to the experimental group (trivial), the effect size was small in the control group. The summary of the findings for the HRV measurements are presented in Table 6.2.

Like the HRV, the findings in the one- and two-minute post-exercise HRR tests also confirmed insignificant differences between the two groups. However, when the magnitude of the changes (slope and effect size) that were achieved across the eight weeks (baseline to week eight) is examined, differences were identified between the experimental and control groups in both hear rate indices (see Table 6.2 and Table 6.4). The findings of the current study in relation to the two vagal-related heart rate measurements (HRV and HRR) support each other. No significant differences were identified in either of these indices (LnRMSSD and one- and two-minute HRR measurements). Similarities were also observed in the slopes of HRV and HRR plotted results in the control group. Both the positive slope in HRV and the negative slope in HRR are considered as indications of positive training adaptation, or the dominance of the parasympathetic activation over the sympathetic (Bellenger et al., 2016). Moreover, the changes in both HRV and HRR indices in the experimental group yielded lower results (stable) as compared to the control group.

In the past, conflicting findings were reported on the effects of endurance training on the vagal-related heart rate measurements, especially in HRV (Buchheit, 2014; Hedelin, Wiklund, et al., 2000; Uusitalo et al., 2000). Some studies (Plews et al., 2013; Buchheit et al., 2010) reported an increase in HRV following extended endurance training, as a result of positive training adaptation. A study by Buchheit et al. (2012) also confirmed an increase in HRV and endurance performance in amateur athletes following extended endurance training. In contrast, other studies have indicated a decrease in HRV following endurance training. For example, a study by Iellamo et al. (2002) reported a decrease in HRV, while improvements in aerobic performance were noted. In another study (Pichot et al., 2000) that involved well-trained endurance athletes, a dominance of the sympathetic over the parasympathetic activation, or a reduction in HRV following endurance training, was proven. Although no significant changes were observed between the two study groups, the findings of the current study are in line with the findings of the above two studies (Plews et al., 2012; Buchheit et al., 2010) in both HRV and 5km performance. As can be seen in Table 6.2 (HRV) and Table 9.5 (5km time trials, Chapter Nine) athletes in both groups showed positive changes in their parasympathetic activity (HRV) and endurance performance (5km time trials) following eight weeks of endurance training using two different altitude training models.

Similarly to the HRV findings, no substantial differences were observed in one- and two-minute absolute HRR between the two study groups following eight weeks of endurance training. Surprisingly, in this study the results of both the one- and two-minute absolute HRR results coincided with the LnRMSSD results, as the HRV results increased (positive slope) and the HRR results decreased (negative slope) for the control group, but not for the experimental. The slopes as well as the effect sizes for both the one- and two-minute HRR measurements were higher and negative in the control group, but lower and positive in the experimental group. In this study positive improvements were observed in HRV and 5km endurance performance (See Chapter 9, Table 9.5) although the magnitude of changes from baseline to week eight in both groups were inversely proportional (higher HRV and slower time to cover the 5km in the control group as compared with lower HRV and faster time to cover 5km in the experimental group).

In contrary to the HRV results, only athletes in the control group improved their post-exercise heart rate recovery in line with the 5km endurance performance (See Chapter 9) following eight weeks of endurance training. In relation to HRR, previous studies have reported inconclusive findings (Bellenger et al., 2016). Some studies (Aubry et al., 2015; Stanojević et al., 2013; Buchheit et al., 2010; Lamberts et al., 2009) proved the strong and positive relationship between faster HRR and endurance performance, as well as the positive role of optimal endurance training in enhancing the parasympathetic activity and thereby hastening HRR. However, there were also studies that reported improved endurance performance without faster HRR. One such study (Thomson et al., 2016; Dupuy et al., 2013) raised the possibility of having faster HRR without improving endurance performance. As can be seen from the summary of the HRV (Table 6.2), HRR (Table 6.4) and 5 km time trial (Table 9.5) results, athletes in the control group achieved better results in vagal-related heart rate measurements (HRV and HRR), with smaller improvements in 5km times, than the experimental group. The current findings reflect the findings of (Dupuy et al., 2013). Unlike the above findings, athletes in the control group improved both vagal-related heart rate indices (HRV and HRR) and 5km performance. However, athletes in the experimental groups did not show improvements in HRR but achieved better results in 5km performance. Unexpectedly, in this study, the HRR was faster in the control group than in the experimental group, although athletes in the experimental group performed better in 5km time trials.

Different explanations can be put forward for the different results achieved in the vagal-related heart rate indices and 5km performances (Chapter Nine, Table 9.5,) between the control and experimental groups. As is shown in Figure 6.1B, no significant differences between the two groups, either at baseline or during weeks four and eight were observed. However, following eight weeks of endurance training, athletes in the control group showed larger changes in LnRMSSD and HRR indices than the experimental group. In this regard, the two high intensity interval training sessions that were conducted at high altitude (2500m) might have played a role in improving the vagal-related heart rate indices. As compared to the experimental group, athletes in the control group responded to the higher weekly training load, especially during the last two weeks of the study (Table 8.2 or Figure 8.1, Chapter Eight).The cumulative effect of heavy load training, which could be accompanied by repetitive oxygen flux, might positively affect the parasympathetic activity of the heart. Most studies agreed that, when improved endurance performance is accompanied by positive vagal-related heart rate indices, like an increase in HRV, faster HRR, and lower resting heart rate, it indicates positive training adaptation (Meeusen et al., 2013) although some other similar studies reported endurance performance changes without showing change in HRV and HRR .

Limitations

Small sample size and unequal gender representation (4 females and 16 males) are possibly the limitations of this vagal-related heart rate study. Moreover, this study was conducted mainly during the early stages of the yearly training season when the athletes were preparing for the first competition of the year and so did not include vagal-related heart rate measurements taken when the training reaches a maximum intensity and the athletes are preparing for the major competitions of the year. This might also be the other drawback of the current study.

6.6 Conclusion

Eight weeks of altitude-based endurance training did not result in any significant differences in the vagal-related heart rate activity (autonomic activities) between the two study groups of Ethiopian junior long-distance runners. However, positive improvements both in HRV and post-exercises HRR were identified in the LH-TH altitude training group and only positive HRV change in the LH-THTL group. The findings of this study indicated that both the LH-TH and LH-THTL altitude training models brought about positive changes in HRV indices which were accompanied by improved endurance performance(time to cover 5km) although the performance change from baseline to week eight was significant in the LH-THTL group as compared with the LH-TH altitude training model

Future Research

Altitude-based endurance training studies that target high altitude natives of east African origin are scarce. In order to thoroughly assess the effects of different altitude training models on the performance and health status of long-distance runners, more studies should be conducted based on the study design of the current research. Taking the limitations of this study into consideration, this study recommends other large scale studies that will incorporate large sample sizes with equal gender representation, be of extended duration, and using more altitude training models like the live moderate-train high, and live low - train low as well as live high-train low.

CHAPTER SEVEN: NEUROMUSCULAR PERFORMANCE AND FATIGUE (MANUSCRIPT)

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This manuscript presents the results of the study that tested the neuromuscular performance differences between the two study groups. To the best of our knowledge this study is the first one of its type to investigate the effects of the live high-train high and live high-train high train low altitude training models on neuromuscular indices among Ethiopian long-distance athletes native to high altitude following eight weeks of endurance training.

Target journal: Journal of Strength and Conditioning Research

Title: The effect of live high-train high vs live high-train high train low on neuromuscular performance and fatigue in Ethiopian junior long-distance runners following eight weeks of per iodized endurance training at altitude in Ethiopia.

Abstract

Background: The primary objective of this study was to identify the neuromuscular performance/fatigue response differences between athletes in the live high-train high (LH-TH) and live high-train high train low (LH-THTL) study groups following eight weeks of endurance training. **Methods:** This study applied a balanced randomised experimental design. A total of 20 well-trained junior long-distance athletes were equally assigned into the LH-TH and LH-THTL groups. Counter movement jump (CMJ) and squat jump (SJ) tests were used to assess the neuromuscular fitness ability of the athletes at five time points (baseline, week two, week four, week six and week eight) All the vertical jump tests (CMJ and SJ) were conducted after 10 hours of light training. **Results:** The counter movement jump (Δ0.5; CL±4.8; p = 0.829; ES = 0.06), squat jump (Δ1.8; CL±3.9; p = 0.353; ES = 0.26) and eccentric utilization ratio (Δ-0.05; CL±0.16; p = 0.511; ES = -0.39) test results revealed no significant difference between the two study groups following eight weeks of endurance training. However, athletes in both groups revealed significant changes in CMJ ($p < 0.001$) and SJ ($p < 0.001$) ability from baseline to week eight. This study also identified no significant changes from baseline to week eight in eccentric utilization ratio both in the experimental (Δ0.05; CL±0.11; p = 0.398; ES =0.36) and control (Δ0.10; CL±0.11; p = 0.079; ES = 0.75) groups. **Conclusion:** The results of the neuromuscular indices (CMJ, SJ and EUR) revealed that no statistically significant differences between athletes in the LH-TH and LH-THTL altitude training models. Although no significant differences were observed between the LH-TH and LH-THTL groups athletes in both groups significantly improved their counter movement and squat jump ability and identified insignificant but positive change in the eccentric utilization from baseline to week eight.

Keywords: neuromuscular, counter movement jump, squat jump, eccentric utilisation ratio, neuromuscular fatigue index, live high-train high, live high-train high train low

7.1 Introduction

Studies related to the assessment of performance in different sports reported the positive effects of well-balanced training on the neuromuscular/vertical jump ability both after short (Buchheit, 2014) and prolonged repetitive training sessions or competition (Coutts, Reaburn, Piva, & Murphy, 2007). In middle- and long-distance running events, along with time trials, maximal and sub-maximal running tests, different vertical jump tests like counter movement (CMJ) and squat jump (SJ) tests have been used to monitor the effect of a given training programme on the overall performance of athletes (Esteve-lanao, San Juan, Earnest, Foster, & Lucia, 2005).

In a study (Buchheit et al., 2010) that compared the heart rate-derived indices and some selected athletic performance tests, including CMJ, bigger improvements in CMJ in the endurance training responders (from 31.1±5.1cm to 33.1±4.5cm) were reported, than in non-responders (from 29.2±3.7cm to 28.8±3.1cm). In this study the CMJ was measured on subjects who were considered as responders (who changed their 10km time by more than 0.5%) and non-responders (who did not change their 10km time by more than 0.5%). A relatively recent study by Balsalobre-Fernández, Tejero-González, and del Campo-Vecino (2014)also reported a significant relationship between seasonal salivary cortisol and CMJ ($r = -0.777$, $p < 0.001$), CMJ and session-RPE ($r = -0.489$, $p = 0.049$), and session RPE and cortisol ($r = 0.551$). In a similar study, the relationship between the weekly cortisol, CMJ and session RPE tests were assessed. Based on the results, CMJ scores correlated significantly with both the session RPE ($r = -0.426$, $p = 0.012$) and cortisol ($r = 0.556$, $p < 0.001$) (Balsalobre-Fernández et al., 2014).

Studies also (Balsalobre-Fernández et al., 2014) identified different CMJ results in endurance athletes one week before their seasonal worst (SW) and seasonal best (SB). The athletes showed better CMJ performance before their seasonal best (32.5±4.5cm) than their seasonal worst (29.7±4 cm) results (Balsalobre-Fernández et al., 2014). Although they reported lower session RPE scores, and covered fewer kilometres (-11km) during the week before their personal best, their CMJ score was higher than it had been one week before their seasonal worst (Balsalobre-Fernández et al., 2014). This study confirmed the results of other studies that found a similar association between CMJ and other training load monitoring methods (Cormack et al., 2008).

The CM, SJ and eccentric utilisation ratio are being used to monitor the neuromuscular ability of athletes in different sports (Secomb et al., 2015). In recent years, the CMJ and SJ have been used together to assess the stretch-shortening cycle (SSC) of the muscles through the eccentric utilisation ratio (Secomb et al., 2015; McGuigan et al., 2006). The SSC is a natural type of muscle function in which a muscle is stretched immediately before contraction (Komi, 2000). These days the SSC is studied by researchers (Halson, 2014; Pitsiladis et al., 2007) to distinguish between the neuromuscular performance and the fatigue level of athletes following a training programme.

Neuromuscular ability studies are widely reported in the areas of anaerobic and team sports (Cormack et al., 2008; McGuigan et al., 2006); but not in endurance sports. There are very few studies that reported their findings using the SJ and EUR in assessing either the effectiveness of a certain endurance training programme, or in monitoring the neuromuscular fatigue level in athletes (Esteve-lanao et al., 2005).

A study by McGuigan et al. (2006) compared the EUR, using both jump height and peak power, to assess performance changes (stretching shortening cycle) among sports and during the course of yearly training plans (off season vs pre-season). The findings of this study revealed significant differences between the EUR which was calculated from height and peak power (McGuigan et al., 2006) in different team sports (Australian rules football, rugby, and field hockey) during the pre-season testing ($p < 0.05$). However, in comparison to the off-season measurements, a significant increase in EUR was reported in the pre-season in field hockey and rugby players ($p < 0.05$). In a similar study (McGuigan et al., 2006) significant differences were observed in EUR in men playing soccer, rugby and Australian rules football (0.83 to 0.92 effect size) than in softball; and a higher EUR was reported in women soccer players than in field hockey and softball players (0.86 to 1.0).

A study by Kubo, Kanehisa, Kawakami, and Fukunaga (2000) compared the EUR (CMJ/SJ) ratio between long-distance runners and the control group and reported significantly lower EUR in the trained subjects than the untrained ones. A possible explanation for the lower EUR was the effect of the endurance training on the structure or size of the fast-twitch muscle fibres (Kubo et al., 2000). In contrast to Kubo et al.'s (2000) study, a study by Harrison, Keane, and Coglan (2004), which aimed to compare the EUR between endurance and sprint athletes, revealed no significant differences between the tested athletes' EUR. In this, the jumping height-based EUR ratios for male athletes involved in soccer, Australian Rules football and rugby union was 1.14±0.15, 1.1±0.08, and 1.13±0.14, respectively. Moreover, a change in EUR was reported from off-season (1.13±0.14) to preseason (1.33±0.23) in Rugby union teams (McGuigan et al., 2006). In comparison to other training monitoring methods, very limited studies have been conducted to assess the training progress or the negative effects of a training programme using the neuromuscular or the stretch shortening cycle (SSC), although the method is easy to use, inexpensive and time saving.

In comparison to the power sports, very few studies have been conducted using neuromuscular tests to examine the effects of endurance training on neuromuscular ability. Even though the application of neuromuscular testing to detect the effects of training and over-training among athletes is easy and does not affect the regular training programme, its use by athletes or coaches is very limited. Existing studies that compared selected neuromuscular fitness tests, particularly CMJ and SJ results, confirmed their reliability after testing their relationship with other subjective and biochemical markers. Despite abundant research has been conducted using vertical jump tests to track the positive and negative effects of a training programme, the results of very few studies have been reported in the scientific literature to assess the neuromuscular changes following endurance training using vertical jump tests in middle- and long- distance events (Balsalobre-Fernández et al., 2014). To the best of the authors' knowledge, there is no altitude-based neuromuscular research, conducted either at altitude in general, or particularly, on endurance athletes native to high altitude. Other studies also confirmed the lack of supporting research using neuromuscular tests and their association with other training monitoring tools in high level endurance athletes (McGuigan, Egan, & Foster, 2004).

To the best of the authors' knowledge, there has been no altitude-based neuromuscular research, conducted either at altitude in general, or particularly, on high altitude native endurance athletes of Ethiopian origin. Thus, the objective of this study was to identify neuromuscular performance/fatigue differences between two groups of endurance athletes (LH-TH Vs LH-THTL) following eight weeks of endurance training. To meet this objective counter-movement jump (CMJ) and squat jump (SJ) performance were determined and the eccentric utilisation ratio (EUR) was calculated.

7.2 Methodology

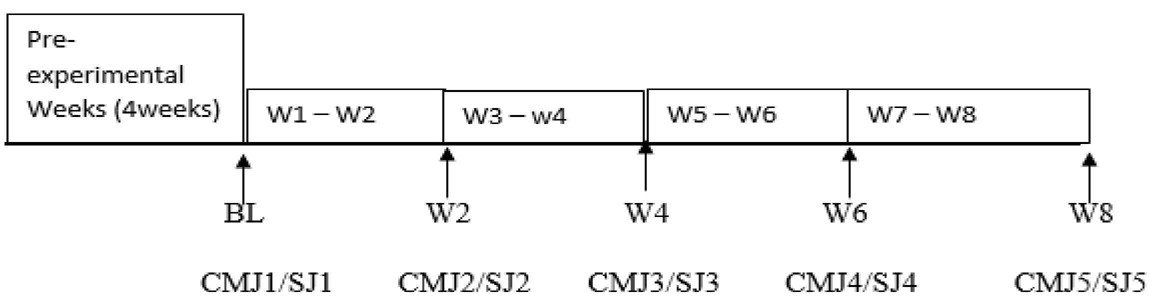
Study Participants

The sample used for this study was 20 well trained long-distance athletes who lived and trained in the national athletics training centre (TDNATC). The mean age, and years spent training, of the athletes were 18.4±1.2 years and 4.6±1.5 years, respectively. The research protocol was approved by the biomedical research ethics committee of UKZN and the AAU-CNS research ethics committee. Before the study began, all athletes signed written, informed consent forms and the research protocol was conducted in accordance with the Helsinki declaration. The athletes who participated in the study were living and training in the national athletics training centre which is located at an altitude of 2500m (7°57′N latitude and 39°7′E longitude). These athletes joined the training centre from all over the country after they had competed in their appropriate endurance trained age groups.

Study Design

This study applied a balanced randomised experimental design and involved two groups of study participants (control and experimental). Before the experiment began, all athletes had been trained together for four weeks continuously. During these weeks all 20 athletes who were assigned to the experimental and control groups together received a similar volume and intensity of training at the same altitude (2500m). At the end of the four pre-study weeks, the athletes were matched based on their performance and equally assigned into control and experimental groups using a simple random sampling method. Athletes who were assigned to the experimental group received four days of light and moderately intense training at high altitude and two days of intense training at low altitude. Athletes who were assigned to the control group trained for six days each week throughout the experiment at an altitude of 2500m. For six days a week, during the whole experiment, they received light and moderate training for four days together with the experimental group; but trained separately and intensively for the remaining two days.

The study also used the modified LH-THTL altitude training model in which all the athletes lived together at 2500m and trained for four days together at that altitude. The two study groups separated for two high intensity training sessions in which the experimental and control groups were trained at 1470m and 2500m, respectively. Five consecutive counter movement and squat jump tests were conducted at five time points – baseline, week two, four, six and eight. Based on the counter movement and squat jump measurements, the eccentric utilisation ratio was calculated (EUR = CMJ/SJ). Throughout the study (eight weeks) no resistance/plyometric training was provided.



BL – Baseline, W – Week, CMJ – Counter Movement Jump, SJ – Squat Jump

Figure 7.1 Study design for neuromuscular performance assessment

Testing Protocol

Five consecutive CM and SJ tests were conducted at baseline, week two, four, six, and eight on the same day of the week (Tuesday) and the same time of the day (between 5:00 and 6:00 p.m.), in a similar place (gymnasium) with the same spatial environment, and with the athletes wearing similar shoes and sport clothes. Both tests were conducted using standardised vertical jump mats (Gill Athletics, USA). The selected day of the test was a training day with a light training session and between the morning training session and the CMJ and SJ testing, the athletes were rested for 10 hours (no training session in the afternoon or immediately before the tests). Before the baseline test, the athletes were provided the opportunity to practice the CMJ and SJ in three training sessions. In these tests the athletes performed unweighted CMJ and SJ without the use of the arm swing. The SJ involved the subject flexing the knee to approximately 90^0, maintaining the position for three seconds, and then jumping on the command “go”. The CMJ was performed under the same conditions, but involved flexion of the knee followed immediately by extension of the legs. For each test three attempts were allowed and the average of the three was taken. The reliability of the test -retests was calculated using Cronbach’s Alpha Test (r = 0.94).

Training

Throughout the eight study weeks all the athletes in both groups (experimental and control) received similar training (mainly endurance/aerobic training with continuous, fartlek and interval variations). The study followed a single training session pattern in which the sessions were conducted every day in morning before breakfast. Of the six training days in a week, the athletes were involved in two short and long interval trainings, two long slow recovery runs and two fartlek trainings. During the entire study, no resistance or plyometric training sessions were conducted.

7.3 Statistical Analysis

Data are expressed as the mean ± SD as appropriate following a test for the normality of distribution. Independent sample t- test was used to compare the mean age, training age, body mass, and body mass index variables between the two groups. Regression analysis was then used to identify any significant changes within each subject’s set of data, between subjects and over time. Cohen’s *d* effect sizes (ES) and 95% confidence intervals (CI) were also calculated for all measurements. Magnitudes of the standardised effects were interpreted using thresholds of $d < 0.2$, 0.2-0.6, 0.6-1.2, 1.2-2.0, 2.0-4.0 and these values corresponded to trivial, small, moderate, large and very large ES, respectively. Statistical significance was set at $p < 0.05$. Statistical analyses were performed using the IBM SPSS Statistics for Windows, Version 23.0. (Armonk, NY: IBM Corp).

7.4 Results

Personal characteristics

The sample size for this study was 20 long distance athletes (male = 16 and female = 4) who lived and trained in the national athletics training centre (TDNATC). In each group, eight male and two female athletes successfully completed the overall study that lasted for eight weeks. The age of these participants ranged from 17 – 20 years; for all the study participants (18.4 ±1.18 years), and the experimental (18.4±1.18years) and control (18.3±1.25years) groups. The mean body mass (BM) for the total, experimental and control groups was 54.4±6.4kg, 53.6±5.01kg, and 55.3±7.73kg, respectively. The descriptive data for the other anthropometric and personal characteristics of the study participants at baseline are presented in Table 7.1.

Table 7-1: Personal characteristics of the study participants

Characteristics	Descriptive Statistics	Control (n=10)	Experimental (n=10)	Total (n=20)
Age (years)	Mean	18.3	18.4	18.4
	SD	1.25	1.18	1.18
	Min - Max	17 – 20	17 - 20	17-20
Body mass (kg)	Mean	55.3	53.6	54.4
	SD	7.73	5.01	6.4
	Min-Max	40-62.7	46 - 60.7	40.0 - 62.7
Height (m)	Mean	1.7	1.7	1.7
	SD	0.06	0.056	0.056
	Min-Max	1.60 - 1.80	1.6 - 1.78	1.6 - 1.78
Body Mass Index ($kg.m^{-2}$)	Mean	18.9	18.6	18.8
	SD	1.7	1.36	1.53
	Min-Max	14.9 - 20.7	15.6 - 20.3	14.9 - 20.7
Period in training (years)	Mean	4.8	4.4	4.6
	SD	1.4	1.47	1.47
	Min-Max	3.0 - 6.0	2.0-6.0	14.9-20.7
5km personal best (sec.ms)	Mean	918.9	914.3	916.6
	SD	69.4	51.5	59.5
	Min-Max	864.2 - 1062.11	865.05 - 1011.20	864.2 - 1062.1

At baseline there were no statistically significant differences between the two study groups in their body mass (p = 0.706) and body mass index (p = 0.724). There were also no statistically significant differences between the two study groups at baseline in body mass (p = 0.706), and body mass index (p = 0.724); or in their age (p = 0.856) or years in training (p = 0.556). There were no significant differences between the two groups in their time spent training (p = 0.556). The athletes who were involved in this study had been mainly involved in track events between 3km and 5km; and in 4km, 6km and 8km cross-country races. There were four athletes (two in each group) who had been involved in 10km track events.

The CMJ test results (Table 7.2) revealed no significant difference between the two study groups following eight weeks of endurance training (Δ0.5; CL±4.8; p = 0.829; ES = 0.06). However, significant changes in CMJ ability were identified in both the experimental and control groups from baseline to week eight (Table 7.2). The results of this test also revealed that changes in the CMJ ability (neuromuscular ability of the lower extremities) were positive and rated moderate in both the experimental (ES = 0.92) and control (ES = 0.86) groups; whereas they were trivial and positive between the groups (ES = 0.06). The means and standard deviations for the CMJ, SJ, and eccentric EUR scores for each study group are presented in Table 7.4.

Table 7-2: Summary of regression analysis results for neuromuscular indices

Variable	Study Groups	Slope	95% CL	Sig.	Effect Size	Rating
Counter movement jump(cm)	Control	7.8	±3,4	0,000*	0.86	Moderate
	Experimental	8.3	±3,4	0,000*	0.92	Moderate
	Δ(Exp – Con.)	0.5	±4,8	0.829	0.06	Trivial
Squat jump (cm)	Control	2.9	±2,8	0.039**	0.42	Small
	Experimental	4.8	±2,8	0.001**	0.69	Moderate
	Δ(Exp – Con.)	1.8	±3,9	0.353	0.26	Small
Eccentric utilisation ratio (Aubry et al.)	Control	0.1	±0,11	0.079	0.75	Moderate
	Experimental	0.05	±0,11	0.398	0.36	Small
	Δ(Exp – Con.)	-0.05	±0,16	0.511	-0.39	Small

*$p<0.001$ **$p<0.05$

Along with the CMJ, five consecutive SJ tests were conducted. Similarly to the CMJ, significant changes in SJ ability were observed, both in the experimental and control groups following eight weeks of endurance training (Figure 7.1B). Even though both the experimental and control groups were able change their SJ ability, no significant difference was identified between the two study groups following eight weeks of endurance training (Table 7.2). The study revealed a positive and moderate change in the experimental group (ES: 0.69), and a positive and small change in the control group (ES = 0.42) and between the two groups (ES = 0.26).

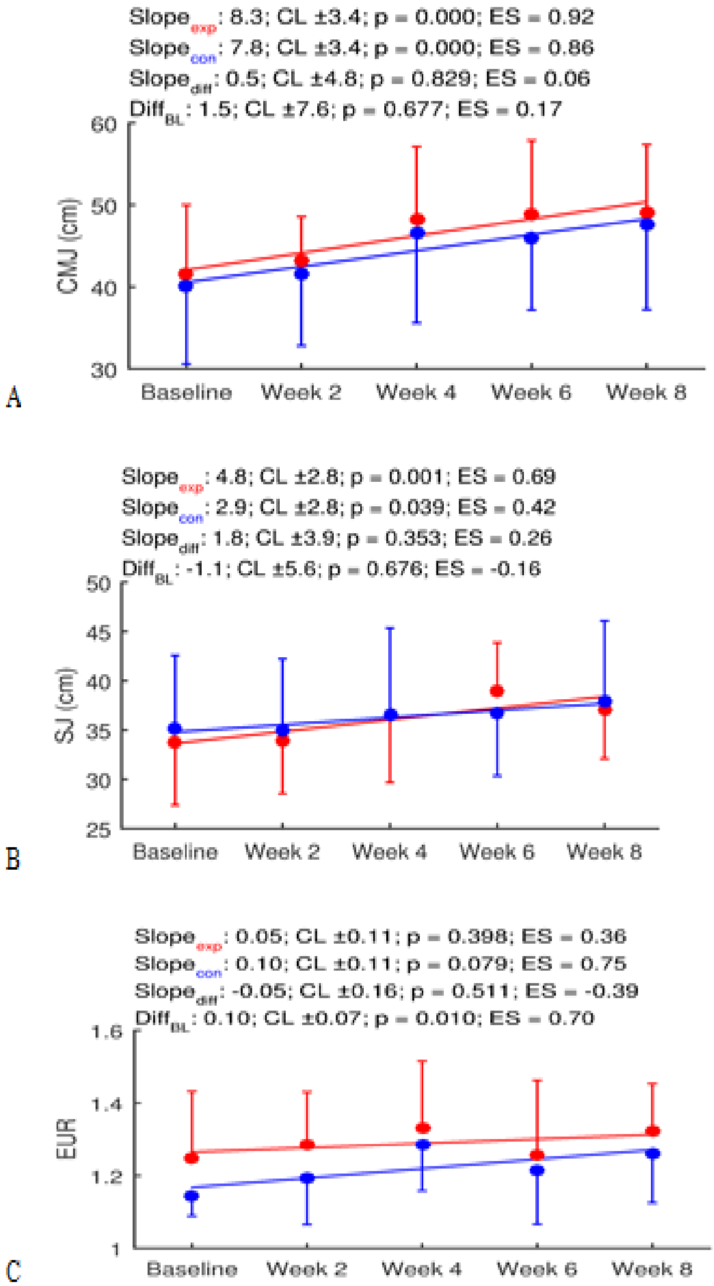


Figure 7.2 Regression analysis for neuromuscular indices - CMJ (A), SJ (B) and EUR(C)

This study also confirmed no significant difference (Figure 7.2C) between the two study groups in the EUR following eight weeks of endurance training. The regression analysis result for the EUR revealed that there were no significant changes in either the experimental (Δ0.05; CL±0.11; p = 0.398; ES =0.36) and control (Δ0.10; CL±0.11; p = 0.079; ES = 0.75) groups during the eight weeks of endurance training. In spite of the fact that all the changes in the EUR were not significant in either group, or between the two study groups, the effect sizes were positive and small in the experimental group (ES: 0.36); positive and moderate in the control group (ES: 0.75); and negative and small between the groups (ES: -0.39). The EUR scores for each study group at each time point or testing weeks are presented in the descriptive statistics table (Table 7.4).

Table 7-3: Baseline to week eight: relative changes in neuromuscular indices

Changes in Neuromuscular Indices	Descriptive Statistics	Study Groups		Sig.
		Control	Experimental	
ΔCMJ (%)	Mean	20.1	19.4	0.925
	SD	19.0	13.7	
	95%CI	-14.8-16.3	-14.9 - 16.4	
ΔSJ (%)	Mean	9.22	12.7	0.690
	SD	17.2	21.3	
	95%CI	-21.7-14.7	-21.8 - 14.7	
ΔEUR (%)	Mean	10.9	8.30	0.726
	SD	15.9	17.5	
	95%CI	-13.0-18.4	-13.1 - 18.4	

Table 7-4: Descriptive statistics for CMJ, SJ and EUR test results

Variable	CMJ (cm) BL			CMJ(cm) Week 2			CMJ(cm) Week 4			CMJ(cm) Week 6			CMJ(cm)Week 8		
Study groups	Con	Exp	Total	Con	Exp	Total	Con	Exp	Total	Con	Exp	Total	Con	Exp	Total
Mean	40.2	41.6	40.9	41.6	43.2	42.4	46.6	48.3	47.5	46.0	48.9	47.5	47.7	49.1	48.4
SD	9.64	8.40	8.83	8.77	5.39	7.13	11.0	8.77	9.72	8.78	8.95	8.76	10.4	8.24	9.18
Variable	**SJ (cm) BL**			**SJ (cm) Week 2**			**SJ(cm)Week 4**			**SJ(cm) Week 6**			**SJ(cm) Week 8**		
Study groups	Con	Exp	Total	Con	Exp	Total	Con	Exp	Total	Con	Exp	Total	Con	Exp	Total
Mean	35.1	33.7	34.4	35.0	33.9	34.5	36.6	36.5	36.6	36.7	39.0	37.9	37.9	37.1	37.5
SD	7.52	6.33	6.80	7.24	5.36	6.23	8.75	6.82	7.63	6.36	4.90	5.65	8.17	5.02	6.61
Variable	**EUR (ratio) BL**			**EUR (ratio) Week 2**			**EUR(ratio) Week 4**			**EUR(ratio) Week 6**			**EUR(ratio) Week 8**		
Study groups	Con	Exp	Total	Con	Exp	Total	Con	Exp	Total	Con	Exp	Total	Con	Exp	Total
Mean	1.14	1.25	1.19	1.20	1.29	1.24	1.28	1.33	1.31	1.21	1.26	1.24	1.26	1.32	1.29
SD	0.054	0.187	0.144	0.129	0.144	0.141	0.126	0.182	0.154	0.14	0.205	0.175	0.13	0.131	0.134

BL – baseline, CMJ – counter movement jump, SJ – squat jump, EUR – eccentric utilisation ratio, Con – control, Exp – experimental, SD – standard deviation, N - number

7.5 Discussion

As indicated in the result part of this study the findings supported the null hypotheses since the differences between the two study groups were not meaningful in all the three variables (CMJ, $p = 0.829$; SJ, $p = 0.353$; and EUR, $p = 0.511$). Although no significant differences between the two study groups were observed, athletes in each study group achieved positive and meaningful improvements in their CMJ and SJ ability over time (BL to week eight). These improvements found in the existing study are in line with other studies that reported neuromuscular improvements during the pre-season, as compared to off-season (McGuigan et al., 2006). Athletes in both the experimental and control groups improved their performance in the CMJ from baseline (Experimental: 41.6±8.4cm and Control: 40.2±9.64cm) to week eight (Experimental: 49.1±8.24 and Control: 47.7±10.4cm). The improvements that were achieved both by the experimental and control groups are in line with previous findings (Buchheit et al., 2010) which reported that endurance athletes (who improved their 10km performance by greater than 0.5%) performed better in neuromuscular ability (CMJ). Athletes in the experimental and control groups improved their CMJ by 19.40% and 20.11%, respectively (Table 7.3), from baseline to week eight; although there was no significant difference between the groups' mean scores ($p = 0.925$). However, greater improvement in the 5km time was achieved by the experimental (LH-THTL) group, compared to the control (LH-TH) group. There was no difference in the relative change (percentage) in SJ ability from baseline to week eight between the experimental (12.73%) and control (9.22%, $p = 0.690$) groups, although the change in the experimental group was greater than in the control group. Based on this findings, the neuromuscular tests results and the 5km performances achieved (see Chapter Nine, Table 9.5) by participants in the current study are in line with the previous findings by Buchheit et al. (2010).

The current study indicated that the athletes in both study groups were not stressed by the cumulative training load, to the detriment of their neuromuscular performance. A possible explanation for this is that the CMJ performance of the athletes had not deteriorated, indicating that the athletes were not under excessive physical stress (Freitas et al., 2015). Previous studies (Balsalobre-Fernández et al., 2014) reported a high inverse relationship between neuromuscular ability (CMJ) and cortisol level (r = -

0.777, $p < 0.001$). Cortisol is one of the physical stress hormone that increase when the athlete is in a state of overload and raised cortisol levels after prolonged cumulative fatigue are seen as a sign of non-functional over-reaching and over-training (Saw et al., 2015). In addition to the high inverse relationship between cortisol level and CMJ, studies (Balsalobre-Fernández et al., 2014) have indicated higher neuromuscular ability (CMJ) a week before an athlete's personal best time. The results of the current study also support this finding, with both the CMJ ability and 5km performance of the athletes in both study groups improving from baseline.

EUR is one of the most important indicators of power performance in athletes (McGuigan et al., 2006). In this study, the EUR is used along with the CMJ and SJ performance measurements as a tool to assess the neuromuscular performance and fatigue level of long distance athletes following eight weeks of an endurance training programme (Halson, 2014). Although no significant differences were identified in the EUR between the two study groups ($p = 0.511$), or within each study group (experimental, $p = 0.398$; and control, $p = 0.079$), the effect sizes for the experimental and control groups were rated as small (ES: 0.36) and moderate (ES: 0.75), respectively. In relation to the changes in EUR, positive slopes were identified in both study groups, marking neuromuscular improvements from baseline to week eight in the study. A small difference in the decline in EUR was identified between the two groups, which is reflected in the negative slope (-0.05) and ES (-0.39). Based on the EUR results of this study, athletes in the control group showed better performance in the stretch-shortening cycle than the control group. Although the athletes in the control group achieved better EUR than the experimental group, athletes in both groups showed positive changes from baseline to week eight (see Table 7.4). One of the possible explanations for higher EURs in the control group might be their lower SJ ability as compared to the experimental group. It is assumed that lower SJ ability can increase the EUR. As can be seen in Table 7.4, of the five consecutive SJ tests, athletes in the control group performed better than the experimental group in four. The lower EUR among the experimental group may be due to the negative endurance training effect on the size of fast twitch muscle fibre as endurance training enhances the slow rather than the fast twitch fibre (McGuigan et al., 2006). These enhanced EURs of the athletes, in combination with improved 5km performances, indicated season-based performance changes without the athletes being exposed to non-functional over-reaching and/or over-training.

These EUR improvements over time, in both the experimental and control groups, were in line with previous findings in other power sports (McGuigan et al., 2006). To date there have been few studies (Harrison et al., 2004; Kubo et al., 2000) that have assessed neuromuscular performance changes following endurance training, especially in the stretch-shortening cycle efficiency of endurance athletes, using the EUR. To the best of our knowledge, no single study was conducted on neuromuscular changes in high altitude-based athletes. Currently research outputs that compared the SSC responses of endurance runners or long-distance athletes using EUR are limited. So, due to this reason it was found very difficult to compare, discuss and come to a conclusion about the results of the current EUR changes achieved by the athletes in both experimental and control groups.

In this study, all three neuromuscular performance indicators reported insignificant differences between the groups, although in two of the neuromuscular indices substantial changes were identified from baseline to week eight, both in the experimental and control groups. These findings were also in line with the vagal-related heart rate results (HRV and HRR, Chapter Six) and the 5km time trial results (Chapter Nine): in all these measurements the athletes improved their baseline results positively. One of the reasons for positive neuromuscular performance changes among the athletes might be the athletes' continual involvement in long-hill interval training sessions which were designed and implemented once a week throughout the study. Some earlier studies had indicated that long-term endurance training affects the neuromuscular ability of athletes due to its effect on the structure or size of the fast twitch muscle fibres (Kubo et al., 2000). In line with these findings, previous studies (Gore et al., 2007; Moore et al., 2007; Saltin, Kim, et al., 1995) reported on the role of non-haematological muscle enzymatic activity in the success of athletes native to high altitude who have been using the conventional live high-train high altitude training model throughout their careers.

Limitations

Although positive neuromuscular performance changes were achieved following eight weeks of endurance training, the independent effects of interval training (short and long) and the long slow continuous training sessions were not investigated separately. Moreover, like the other variables, the neuromuscular assessments were conducted at an early stage in the yearly training schedule, in a training phase in which there is less possibility of cumulative fatigue. Thus, this might not be enough to identify the cumulative effects of the two altitude training models on the neuromuscular performance and/or fatigue levels of the athletes in both study groups. In addition to the above limitations, the neuromuscular assessments that had been conducted in this study were not supported by other specific hormonal/biochemical tests. It might, therefore, not be possible to reach acceptable conclusions on the effects of the two altitude training models on the neuromuscular adaptation of Ethiopian junior long-distance athletes.

7.6 Conclusion

The results of the neuromuscular performance tests (CMJ, SJ and EUR) revealed that no statistically significant differences between athletes in the LH-TH and LH-THTL altitude training models. Although no significant differences were observed between the LH-TH and LH-THTL groups athletes in both groups significantly improved their counter movement and squat jump ability and identified insignificant but positive change in the eccentric utilization from baseline to week eight. In this regard the Ethiopian junior long-distance athletes were equally benefited from the two altitude training models in enhancing their neuromuscular performances. However, the neuromuscular performance changes in the LH-THTL group were better accompanied with lower training load response and significant 5km endurance performance change as compared with the LH-TH group.

Future Research

In the future, in order to get more reliable and meaningful data, a more comprehensive neuromuscular study should be designed with a large sample size and more study groups, using altitude training models. Additional assessment tools need to be used, and the study needs to last longer to enable the inclusion of different phases of the yearly training plan (preparation, pre-competition, competition and transition).

CHAPTER EIGHT: TRAINING LOAD RESPONSE (MANUSCRIPT)

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This manuscript presents the results of research into the fourth hypothesis of the altitude study. To the best of our knowledge this study is the first of its type to investigate the effects of the live high-train high and live high-train high/train low altitude training models on training load responses among Ethiopian long-distance athletes native to high altitude following eight weeks of endurance training.

Target journal: International Journal of Sports Science & Coaching

Title: Differences in endurance training load response between the live high-train high and live high-train high train low groups after eight weeks of per iodized endurance training at altitude in Ethiopia.

Abstract

Background: The primary objective of this study was to investigate the difference in training load response between the live high-train high and live high-train high train low study groups. **Methods:** This study applied a balanced randomised experimental design. A total of 20 well-trained junior long-distance athletes were equally assigned to the live high-train high (n=10) and live high-train high train low (n=10) groups. The training load-response of the athletes was measured for a total of 47 training sessions for eight weeks continuously. The session rating of perceived exertion (Session-RPE) method was used as the primary tool to assess the internal training load responses. Training load response was measured based on the 10 - scale categorical ratio (CR) and the session load of every athlete was calculated by multiplying the RPE scale and the duration of the training session. Once the day’s training session load (RPE * Duration of the session) was derived, the weekly load was calculated by adding the session-RPEs for the whole week. **Results:** The results of the analysis identified significant differences between the groups and for all the weekly training load responses at all the training sessions, i.e., light, moderate and high-intensity training ($p = 0.019$) and high intensity training ($p = 0.000$). No substantial difference was identified between groups ($p = 0.133$) for the light and moderate intensity training sessions. Out of the 47 training sessions, light intensity sessions (< 4 RPE, less than the first ventilatory threshold) made up 87.2% of sessions in the Experimental group and 68.1% in the Control group, while 12.8% (Experimental group) and 31.9% (Control group) of the training sessions were completed at RPE > 4 < 7 RPE. **Conclusion:** This study identified differences in the weekly training load responses between the two study groups. In line with the previous findings on athletes native to sea level and low altitudes, Ethiopian junior long-distance athletes native to high altitude experienced different internal training loads based on perceived responses relating to the two different altitude training models.

Keywords: RPE, session-RPE, weekly load, high intensity training, live high-train high, live high-train high train low

8.1 Introduction

Monitoring training load is considered a necessity for understanding athletes' training load responses and changes in performance (McGuigan, 2017; Mujika, 2017; Halson, 2014; Meeusen et al., 2013). Through monitoring, athletes, coaches and sport science researchers can provide scientific explanations for the changes due to particular training programmes or interventions (Halson, 2014). Moreover, such continual and regular training load monitoring can assist athletes, coaches and researchers in understanding the reasons for changes. Unlike other sports, training for endurance sports like long-distance running and cycling is characterised by a higher volume of training at varying intensity. The training does not follow a similar pattern, dose and combination in the year-round training plan (Halson, 2014).

Studies (Halson, 2014; Seiler & Kjerland, 2006) focusing on training load distribution noted that training loads are adjusted at different times in the yearly or seasonal training plan to enhance the performance of long-distance athletes. These changes in training load are mainly a result of intentional changes to increase or decrease the fatigue level of the athlete. In the process, a training plan which is properly monitored and quantified on a regular basis, will mostly result in positive performance changes (Mujika, 2017).

Several studies were conducted (Sanders et al., 2017; Halson, 2014;Roos et al., 2013) using different training quantification methods to assess training effectiveness and performance changes. Most of these studies used internal (Roos et al., 2013) or external work load responses, or both (Halson, 2014), to see the effects of different training modalities and interventions. Heart rate indices (Hough, Corney, Kouris, & Gleeson, 2013; Stanojević et al., 2013; Brasil et al., 2011), and immunological, biochemical, and hormonal (Balsalobre-Fernández et al., 2014; Hough et al., 2013; Meeusen et al., 2013) changes are the most widely used indices to understand or evaluate internal load responses and training adaptation among athletes. In addition to the above mentioned internal training load monitoring methods, perception of exertion, which is measured with session-RPE, is also a widely used internal load monitoring tool in competitive sports (Sanders et al., 2017; Manzi et al., 2015; Halson, 2014). Most of these internal training quantification methods are also considered as physiological and objective methods in most endurance sports (Mujika, 2017).

The vast majority of studies argue that session-RPE, which is one of the methods that has been used by athletes, coaches and sport scientists, is highly reliable, valid and easy to implement (Roos et al., 2013). Its application involves the athlete rating, from one to ten, the global intensity of the training session and then multiplying the rated value by the duration of the session (Haddad et al., 2014). The calculated value is considered as the training load response to the session and is expressed in arbitrary units (AU). When this measurement is applied to all the training sessions of the week, it can show the overall weekly pattern of the training sessions. The sum of all the training loads (in arbitrary units) of the week's training sessions gives what is called weekly load. Like the session training load, the weekly load is also expressed in arbitrary units.

In the past, different studies have proved the effectiveness of session-RPE in monitoring internal training load responses in middle- and long-distance athletes. For example, studies (Borresen & Lambert, 2009; Lucia, Hoyos, Santalla, Earnest, & Chicharro, 2003) proved a strong association between session-RPE and heart rate zones (Wallace, Slattery, Impellizzeri, & Coutts, 2014); session-RPE and salivary cortisol levels (Balsalobre-Fernández et al., 2014); session-RPE and blood lactate production (Seiler & Kjerland, 2006; Reilly & White, 2005); and session-RPE and lactate /ventilator threshold (Haddad, Stylianides, Djaoui, Dellal, & Chamari, 2017; Lucia et al., 2003). There were also studies that confirmed session-RPE or session-RPE-driven weekly load score variations due to changes in training intensity (Cabral-Santos et al., 2017; Vesterinen, 2016; Wallace, Slattery, & Coutts, 2009)..

As a non-invasive training monitoring method, a study by Seiler and Kjerland (2006) reported classification of training loads in endurance events using a 10-scale RPE to estimate ventilatory threshold (VT) responses. The 10-scale RPE breakpoints corresponding to VT_1 (RPE 4) and VT_2 (RPE 7) intensity thresholds were determined by preliminary laboratory study, as well as with the assistance of cumulative maximum heart rate zone data, where VT_1 and VT_2 were estimated at 81±2 and 91±2% of maximum heart rate, respectively(Seiler & Kjerland, 2006; Lucia et al., 2003). Based on studies (Haddad et al., 2017; Seiler & Kjerland, 2006), RPE less than or equal to four, or less than the first ventilatory threshold (VT_1), is considered as light intensity training. An RPE greater than four and less than or equal to seven (between VT_1 and VT_2) is considered as moderate intensity or anaerobic threshold training; and RPE greater than seven (greater than the second ventilatory threshold, VT_2) is high intensity training.

Studies researching the RPE and ventilatory threshold-based training load distribution proved that elite endurance athletes train less at lactate threshold intensity (between VT_1 and VT_2) than less successful athletes (Seiler & Kjerland, 2006; Billat, Demarle, Slawinski, Paiva, & Koralsztein, 2001; Gaskill et al., 2001). In the existing literature, there are two types of training load distributions. These two training models, most widely used in endurance training, are threshold-training and polarised training (Seiler & Kjerland, 2006). Studies suggested that the threshold training model, a model that advocates training mainly at lactate threshold, was more successful at improving endurance performance in untrained athletes (Stöggl & Sperlich, 2014; Esteve-Lanao, Foster, Seiler, & Lucia, 2007; Seiler & Kjerland, 2006; Gaskill et al., 2001). The polarised training model is widely used by elite and successful athletes and it suggests that the majority of the training sessions (> 75%) should consist of training intensity below the lactate threshold; with the rest above the lactate threshold (Seiler & Kjerland, 2006; Billat et al., 2001). This study doesn't recommend threshold training to enhance the endurance performance of elite athletes (Seiler & Kjerland, 2006).

One of the studies by Brasil et al. (2011) measured the internal load response (perception of different training efforts) of 10 women endurance athletes (cyclists) using RPE and reported that the RPE method differentiated the load variations in the athletes. Three years later, a study by Balsalobre-Fernández et al. (2014) supported the former study's (Brasil et al., 2011) findings by comparing the relationship between session-RPE with CMJ and salivary cortisol. In this study (Balsalobre-Fernández et al. (2014), a significant relationship was reported between a seasonal stress hormone called salivary cortisol and CMJ (r = - 0.777, p < 0.001); CMJ and session-RPE (r = - 0.489, p =0.049); and session RPE and cortisol (r = 0.551). In a similar study, the relationship between the weekly cortisol, CMJ and session RPE were assessed. Based on the results, CMJ scores correlated significantly with both the session RPE (r = - 0.426, p = 0.012) and cortisol (r = 0.556, p < 0.001) (Balsalobre-Fernández et al., 2014).

In modern training quantification, the use of session-RPE is the most widely recommended internal training quantification method. Although the method is easy to implement, cost effective, reliable, and practical, to the best of our knowledge, no studies have reported the use of session-RPE on east African endurance athletes. Anecdotal evidence has revealed a gap in the application of training quantification and monitoring methods to trace performance changes or to prevent athletes from non-functional over-reaching or over-training.

To the best of the authors' knowledge, there is gap in altitude-based studies relating to the assessment of training load responses of endurance athletes native to high altitude (e.g. Ethiopia). Therefore, the objective of this study was to identify the subjective training load response differences between two groups of endurance athletes (LH-TH Vs LH-THTL) following eight weeks of endurance training. Session-RPE was obtained to determine the subjective responses of the two groups.

8.2 Methodology

Study Participants

The sample used for this study was 20 well trained long-distance athletes who lived and trained in the national athletics training centre. The mean age, and years spent training, of the athletes were 18.4±1.2 years and 4.6±1.5 years, respectively. The research protocol was approved by the biomedical research ethics committee of UKZN and the AAU-CNS research ethics committee. Before the study began, all athletes signed written, informed consent forms and the research protocol was conducted in accordance with the Helsinki declaration. The athletes who participated in the study were living and training in the national athletics training centre which is located at an altitude of 2500m (7°57′N latitude and 39°7′E longitude). These athletes joined the training centre from all over the country after they had competed in their appropriate endurance trained age groups.

Study Design

This study applied a balanced randomised experimental design and involved two groups of study participants (control and experimental). Before the experiment began, all athletes had been trained together for four weeks continuously. During these weeks all 20 athletes who were assigned to the experimental and control groups together received a similar volume and intensity of training at the same altitude (2500m). At the end of the four pre-study weeks, the athletes were matched based on their performance and equally assigned into control and experimental groups using a simple random sampling method. Athletes who were assigned to the experimental group received four days of light and moderately intense training at high altitude and two days of intense training at low altitude (1470m a.s.l.). Athletes who were assigned to the control group trained for six days each week throughout the experiment at an altitude of 2500m. For six days a week, during the whole experiment, they received light and moderate training for four days together with the experimental group; but trained separately and intensively for the remaining two days.

The study also used the modified LH-THTL altitude training model in which all the athletes lived together at 2500m and trained for four days together at that altitude. The two study groups separated for two high intensity training sessions in which the experimental and control groups were trained at 1470m and 2500m, respectively.

Study Protocol

Along with other training load quantification methods, the session rating of perceived exertion (session-RPE) method was employed to monitor the training load responses of the study participants during every training session throughout the study (eight weeks). Rating of the perceived exertion of each session (session-RPE), which was developed by Foster (1998), was used to measure the global intensity of the internal training load response of the subjects. Before the experiment had begun, the study participants were familiarised with the session RPE ratings for six continual training sessions. During the familiarisation session, standard instructions and anchoring procedures were explained and the participants practised how to use the method during both light and intense training sessions. Following the familiarisation period, copies of the 10-point scale with its description were provided for all study participants and posted inside their sleeping rooms to enable them to internalise the scales. In all 47 training sessions during the experiment, athletes were asked to subjectively indicate the efforts they had put into every training workout. Thirty minutes after the end of the training sessions, they were asked: “How was your workout?” They responded by choosing a response between 0 and 10 on the scale that most accurately described their subjective feelings about the overall load of that session’s workout (A rating of 0 is associated with no effort and a rating of 10 is considered to be the maximal physical effort during the workout.). Then the session load of every athlete was calculated by multiplying the RPE scale and the duration of the training session, including the warm-up. Once the session load (RPE * duration of the session) for the day's training session was calculated, the weekly load and the average daily load were calculated.

Training

Throughout the eight study weeks all the athletes in both groups (experimental and control) received similar training (mainly endurance/aerobic training with continuous, fartlek and interval variations). The study followed a single training session pattern in which the sessions were conducted every day in morning before breakfast. Of the six training days in a week, the athletes were involved in two short and long interval trainings, two long slow recovery runs and two fartlek trainings. During the entire study, no resistance or plyometric training sessions were conducted.

8.3 Statistical Analysis

Data are expressed as the mean ± SD as appropriate following a test for the normality of distribution. Independent sample t- test was used to compare the mean age, training age, body mass, and body mass index the two groups.A repeated measure ANOVA with LSD post-hoc tests was then employed to identify any significant changes within each subject's data and between subjects and over time in the training load response data. Statistical significance was set at $p < 0.05$. Statistical analyses were performed using the IBM SPSS Statistics for Windows, Version 23.0. (Armonk, NY: IBM Corp).

8.4 Results

Personal characteristics

The sample size for this study was 20 long distance athletes (male = 16 and female = 4) who lived and trained in the national athletics training centre (TDNATC). In each group, eight male and two female athletes successfully completed the overall study that lasted for eight consecutive weeks. The age of these participants ranged from 17 – 20 years; for all the study participants (18.4 ±1.18 years), and the experimental (18.4±1.18years) and control (18.3±1.25years) groups. The mean body mass (BM) for the total, experimental and control groups was 54.4±6.4kg, 53.6±5.01kg, and 55.3±7.73kg, respectively. The descriptive data for the other anthropometric and personal characteristics of the study participants at baseline are presented in Table 8.1.

Based on the base line data there were no statistically significant differences between the two study groups at in body mass (p = 0.706), and body mass index (p = 0.724); or in their age (p = 0.856) or years in training (p = 0.556).

Table 8-1: Personal characteristics of the study participants

Characteristics	Descriptive Statistics	Control (n=10)	Experimental (n=10)	Total (n=20)
Age (years)	Mean	18.3	18.4	18.4
	SD	1.25	1.18	1.18
	Min - Max	17 – 20	17 - 20	17-20
Body mass (kg)	Mean	55.3	53.6	54.4
	SD	7.73	5.01	6.4
	Min-Max	40-62.7	46 - 60.7	40.0 - 62.7
Height (m)	Mean	1.7	1.7	1.7
	SD	0.06	0.056	0.056
	Min-Max	1.60 - 1.80	1.6 - 1.78	1.6 - 1.78
Body Mass Index ($kg.m^{-2}$)	Mean	18.9	18.6	18.8
	SD	1.7	1.36	1.53
	Min-Max	14.9 - 20.7	15.6 - 20.3	14.9 - 20.7
Period in training (years)	Mean	4.8	4.4	4.6
	SD	1.4	1.47	1.47
	Min-Max	3.0 - 6.0	2.0-6.0	14.9-20.7
5km personal best (sec.ms)	Mean	918.9	914.3	916.6
	SD	69.4	51.5	59.5
	Min-Max	864.2 - 1062.11	865.05 - 1011.20	864.2 - 1062.1

Weekly training load responses and training load distribution

The analyses for the weekly training loads across the eight study weeks were performed from two perspectives. The first analysis focused on examining the weekly load responses of the two study groups (control and experimental) by taking the athletes' overall responses to light, moderate and high intensity training sessions. The second analysis ran to investigate the effects of the light and moderate intensity training at high altitude (2500m) on the weekly load responses of the athletes. The third analysis was performed for all high intensity interval training sessions performed separately at

2500m (control group) and 1470m (experimental group). The athletes all trained three light and one moderate intensity training sessions at 2500m; and then two high intensity training sessions at 2500m (control group) and 1470m (experimental group) separately. Throughout the study, the athletes in both study groups were receiving the same contents, volume (duration and distance) and intensity of training. In order to see differences between the two groups in their responses to the weekly training, repeated measure ANOVA with the least significant difference (LSD) post-hoc tests were used.

The results of the analysis (Figure 8.1A – C) for the weekly training load responses for all training sessions (light, moderate and high intensities) identified significant differences between the two study groups (p = 0.019), with time having a highly significant effect ($p < 0.001$). However, there was not group by time interaction (p = 0.073). When the weekly training load for high intensity training sessions was analysed, there was a highly significant difference between the two study groups ($p < 0.001$), in the effect of time (p = 0.000) and in group by time interaction (p = 0.001). The effect of time (p = 0.001) and a group by time interaction (p = 0.019) were observed in the light and moderate training session weekly load responses, respectively. However, the ANOVA analysis reported no substantial difference between groups (p = 0.133) for the light and moderate intensity training sessions' weekly load responses.

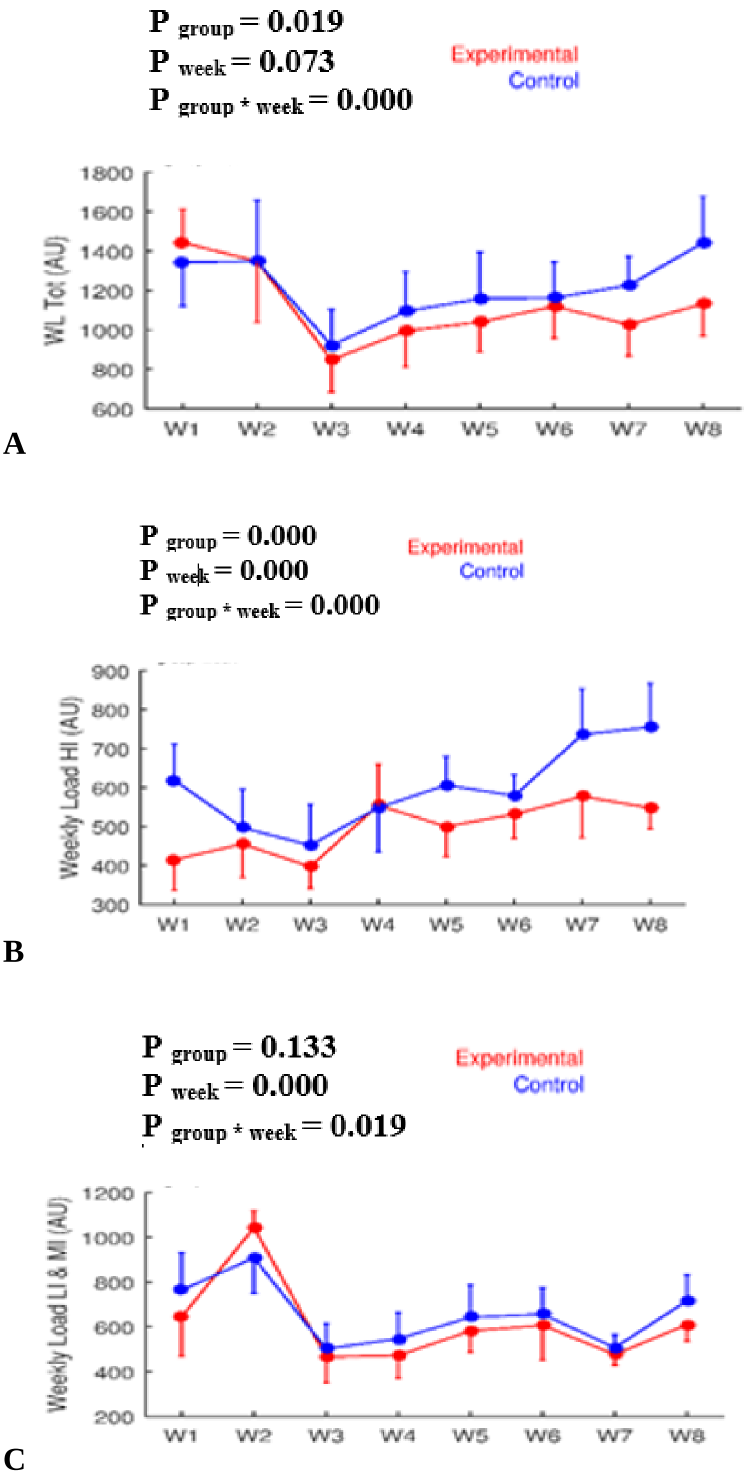

Figure 8.1 Session-RPE based weekly training load responses - All intensity sessions (A), and high intensity (B) and light and moderate intensity (C) sessions

Table 8-2: Descriptive statistics and ANOVA with LSD analysis results for weekly load responses

Weeks	Study Groups	Total weekly load (AU)			High intensity weekly load (AU)			Light and moderate intensity weekly load (AU)		
		Mean	SD	Sig.	Mean	SD	Sig.	Mean	SD	Sig.
Week	Control	1343	222	0.277	619	91.9	0.001*	764	168	0.028*
	Experimental	1000	168		414	77.2		644	176	
	Total	1171	198		517	134		704	179	
Week2	Control	1349	310	0.999	497	98	0.300	908	157	0.013*
	Experimental	1443	168		455	86		1043	75	
	Total	1394	254		476	92		975	139	
Week3	Control	922	181	0.417	452	106	0.172	502	111	0.502
	Experimental	848	164		397	55.4		466	115	
	Total	885	172		424	86.7		484	111	
Week4	Control	1094	201	0.277	548	114	0.871	546	118	0.171
	Experimental	994	184		555	106		472	101	
	Total	1044	194		551	107		509	114	
Week5	Control	1157	239	0.202	606	73.7	0.009*	643	145	0.258
	Experimental	1040	153		500	77.8		582	94.1	
	Total	1099	204		553	91.9		612	123	
Week6	Control	1163	182	0.632	579	54.1	0.242	656	116	0.355
	Experimental	1119	162		532	62.5		606	155	
	Total	1141	169		555	61.8		631	136	
Week7	Control	1226	146	0.031*	736	117	0.001**	507	59.2	0.569
	Experimental	1027	160		577	107		476	47.6	
	Total	1127	181		656	136		491	54.6	
Week8	Control	1442	235	0.001*	755	111	0.001**	716	116	0.049*
	Experimental	1131	161		548	54.2		610	74.6	
	Total	1287	253		651	136		663	109	

*p < 0.05, **p < 0.001

Week-to-week significant differences were observed (Table 8.2) between the two study groups in the total weekly training load responses at week seven and week eight. Moreover, from the eight consecutive training weeks, significant differences in weekly training load responses for high intensity training sessions were observed between the control and experimental groups during week one week five, week seven, and week eight. When the weekly training load responses for the light and moderate intensity training sessions were examined, no significant differences between the two groups in general were seen, but the LSD post-hoc test results revealed substantial differences at week one, week two, and week eight. The descriptive statistics for the weekly training load for the total, high intensity, and light and moderate intensity training sessions are presented in Table 8.2.

Table 8-3: RPE based training load distribution

RPE	No. of training sessions		Percentage	
	Experimental	Control	Experimental	Control
≤4	32	41	68.1	87.2
>4 to < 7	15	6	31.9	12.8
≥7	0	0	0	0
Total	47	47	100	100

In this study the athletes in both study groups effectively trained for a total of 47 training sessions. Of these sessions, the athletes in both groups trained together and separately for 16 (34.1%) and 31 (65.9%) training sessions, respectively. In all training sessions the predefined training plan approach was used. Due to this, throughout the study the six weekly training sessions were designated as three light, one moderate and two high intensity training sessions.

The average ratings of perceived exertion for the three light intensity training sessions (day two, day four and day five), one moderate intensity training session (day one), and two high intensity training sessions (day three and day six) for all the study weeks are presented in Table 8.4. By taking all the RPE responses of the athletes, the mean weekly training load distribution was categorised based on the 10-point scale categorical ratio (CR) with rating of perceived exertion as light (less or equal to four RPE), moderate (between four and seven RPE), and high intensity (greater than or equal to seven RPE). Based on these classifications, 87.2 % and 68.1% of the total training sessions were light training sessions for the experimental and control groups, respectively. Of the total training sessions during the study, 12.8% (for the experimental group) and 31.9% (for the control group) were devoted to moderate intensity training (Table 8.3). Based on the means of the athletes RPE responses, there was no single training session that was perceived as a high intensity training session in both the experimental and control groups. However, this does not mean that there were no athletes who responded with a perceived exertion greater than seven. The mean and standard deviation of the RPE response is presented in Table 8.4.

Table 8-4: Daily training load distribution based on ratings of perceived exertion (RPE)

Weeks	Study Groups	Descriptive Statistics	Day1	Day2	Day3	Day4	Day5	Day6
Week1	Control	Mean	4.4	1.5	3	3.22	1.22	5.1
		SD	0.966	0.527	0.667	0.972	0.441	0.738
	Experimental	Mean	2.9	1.6	2.44	2.7	1.6	2.9
		SD	1.20	0.516	0.726	0.823	0.843	0.738
Week2	Control	Mean	3	1.8	2.5	2	2.1	5.4
		SD	1.32	0.422	0.527	0.5	0.568	1.17
	Experimental	Mean	3.11	1.8	3.5	1.89	3.4	4.3
		SD	0.928	0.422	0.850	0.333	0.843	0.949
Week3	Control	Mean	2.44	1.89	4.4	2.33	1.5	5.4
		SD	0.843	0.782	2.22	0.707	0.707	0.966
	Experimental	Mean	2.1	1.78	3.6	2.3	1.44	4.89
		SD	0.994	0.667	0.699	0.823	0.527	0.738
Week4	Control	Mean	3.6	2.7	3.3	3.7	2.4	5.22
		SD	0.843	0.675	1.06	0.823	1.51	1.37
	Experimental	Mean	3.4	2.5	2.8	3.67	1.5	4.89
		SD	1.17	0.527	1.14	0.789	0.707	1.27
Week5	Control	Mean	2.33	4	2.5	3	2.6	4.78
		SD	1	1	0.850	0.866	0.699	0.667
	Experimental	Mean	2	3.6	2.8	2.44	2.22	3.8
		SD	0.5	0.843	0.919	0.527	0.667	1.03
Week6	Control	Mean	3.1	4.67	5.2	2.67	--	4.44
		SD	1.29	0.707	0.789	0.5	--	0.882
	Experimental	Mean	2.6	4	5	3.22	--	3.6
		SD	1.07	1.25	0.667	0.972	--	0.699
Week7	Control	Mean	2.9	3.22	3.7	6.4	2.5	4.8
		SD	0.316	0.441	0.949	1.71	1.08	1.32
	Experimental	Mean	2.9	3.22	3.22	5.3	2	3.7
		SD	0.568	0.667	0.943	1.16	0.5	0.823
Week8	Control	Mean	4.6	2.4	4.7	3.89	4.9	3.6
		SD	1.07	0.699	0.949	0.782	1.29	0.966
	Experimental	Mean	3.44	2.2	3.33	3.4	3.9	2.6
		SD	1.42	0.632	0.707	0.516	1.20	0.516

8.5 Discussion

Many training load monitoring methods have been introduced to examine the short- and long-term effects of training (Halson, 2014). In this study, the RPE for each session (session-RPE) was employed to collect the training load responses of the study participants after each training session for eight consecutive study weeks. Currently, the use of session-RPE to assess the internal training load responses of endurance athletes is gaining acceptance as a monitoring method which is reliable, valid and ecologically useful in defining the work load of different intensity training (Haddad et al., 2017).

One of the objectives that were addressed by this study was the need to identify the weekly training load response differences between the LH-TH and LH-THTL study groups following eight week of endurance training. In order to meet this objective, a total 47 training sessions were assessed using the session-RPE method. At the beginning of the study, it was hypothesised that there were no significant differences between athletes in the two study groups in their responses to the predefined training loads, following eight weeks of endurance training. The findings of this study rejected the null hypotheses since significant differences were identified between the two study groups in the total intensity weekly load and high intensity weekly training load responses. However, no meaningful difference was identified for the light and moderate intensity weekly training load responses between the two study groups.

Based on the results of this test (LSD post-hoc), significant differences were identified between the groups for the total intensity weekly load response at weeks seven and eight. During the study, these weeks were characterised as relatively heavy training weeks in which the intensity of training increased by 10% from baseline and 5% from week five and week six. In the rest of the training weeks, no considerable load response differences were identified, although differences in the raw scores in arbitrary units (AU) were observed between the two groups (see Table 8.2). Like the total weekly training load responses, significant differences were identified between the groups for the high intensity weekly load responses. Throughout the study, two high intensity training sessions were included in each week as part of the overall weekly training plan. Of the eight consecutive study weeks, the LSD post-hoc test identified weekly load response differences at weeks one, five, seven and eight for the high intensity training sessions. Like the total weekly load responses, two of the weekly load differences for high intensity training sessions were at week seven and week eight. In relation to the light and moderate intensity weekly loads, no significant difference was identified between the two study groups. However, the LSD post-hoc test identified differences at weeks one, two and eight.

In comparison to the light and moderate intensity training sessions, in the current study the session-RPE clearly identified weekly load differences in the high intensity interval training sessions. Studies (Hernández-Cruz et al., 2017; Wallace et al., 2009) support the current findings that session-RPE is more sensitive in intensive interval training than continuous or low intensity training since clear significant differences were identified during the high intensity interval training sessions during the study weeks. Such an increase in session-RPE responses, and therefore weekly load responses, was taken as a reflection of the internal feelings and response of an athlete for a given training response.

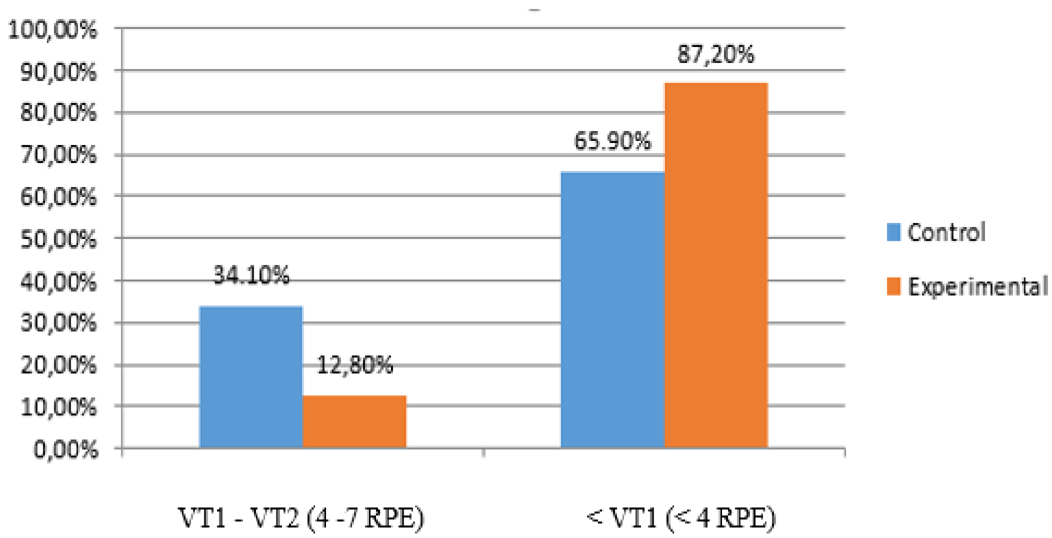

Figure 8.2 Rating of perceived exertion-based training load distribution

From the total training sessions that the athletes engaged in during the eight study weeks, the mean RPE responses of the athletes in the experimental and control groups were calculated (see Table 8.4). Of these total training sessions (47), athletes in the experimental and control groups completed 87.2% and 68.1% of the sessions, respectively; with light intensity training with $\leq$ 4 RPE (< VT_1). Whereas, athletes of both the experimental and control groups completed 12.8% and 31.9% of the total training sessions with a training load between VT_1 and VT_2 (> 4 and < 7 RPE) (Figure 8.2). In comparison to the experimental group, the athletes in the control group spent the longer time or devoted their time in moderate intensity training. When the overall training sessions during the study are categorised as below VT_1 and between VT_1 and VT_2 , it does not mean that all athletes were not responding for high intensity sessions

(>7 RPE). In each group there were athletes who perceived some of the training sessions as high intensity (> 7 RPE). For example, from the total athletes and total training sessions, 3.9% and 0.43% in the control and experimental group, respectively, rated the session load as high (>7 RPE).

When the current training load distribution of the athletes in the experimental and control group is compared, the number of training sessions devoted to light intensity training (< VT_1) was higher in the experimental group (87.2%) and relatively lower in the control group (65.96%). The findings of the current study also support past studies (Haddad et al., 2017; Borresen & Lambert, 2009; Seiler & Kjerland, 2006; Lucia et al., 2003), as the athletes in the experimental group spent the majority of their training sessions below VT_1 and improved their 5km performances more than the control group (see Table 9.5, Chapter Nine). The results, therefore, might explain why the experimental group achieved better 5km times than the control group.

In the current study, athletes' training load responses varied from week to week. This resulted in varying weekly load responses, although these load response differences between the two study groups were not significant every week. The light and longer endurance training sessions that had been conducted at the beginning of the preparation phase of training might be taken as one of the reasons for the higher weekly loads for both the control and experimental groups at the beginning of this study. Similar studies also confirmed that levels of training stress were higher during the preparation period of training when there is no regular intensive training and competition (Haddad et al., 2017).

No clear and satisfying reason can be provided for the load differences at the beginning of the study, although the training load response differences that were observed during the last two weeks of the study might be due to the training load increments that intentionally increased from week five of the study. During the first two weeks of the study, the weekly load was higher among athletes in the experimental group than the control. However, the load response differences that were observed during the last two weeks of the study time were higher among the athletes in the control group. These weekly load differences at the beginning and end of the study might be caused by the duration and intensity of training, respectively. The higher weekly load at the beginning of the study was expected due to longer training duration; whereas, the higher weekly loads at the end of the study was due to the increase in training intensity. The higher weekly load score among the control group might be attributed to cumulative fatigue due to all types of training intensity performed at a relatively higher altitude. In this regard, research has widely reported the effectiveness of session-RPE to quantify daily training stress and cumulative training fatigue in endurance athletes (Seiler & Kjerland, 2006).

As was indicated in the results of this study, the weekly training load differences were mainly attributed to high intensity training sessions. From the overall study, weekly load differences were observed in 50 % of the study weeks. In particular, the high intensity training sessions contributed a lot to the differences. These high intensity training sessions were intentionally designed to improve the athletes by increasing the weekly load as compared to the previous weeks. Thus, in order to achieve the targeted session goal, all athletes were expected to complete more difficult training sessions (~5% faster than the previous week). In the past, there have been similar studies, but with athletes native to low altitude. These studies (Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997) reported load response differences between athletes who trained high intensity interval trainings (10x1000m) at high (2500ml) and low altitude (1200m).

As compared to the baseline training load responses in both groups, an increase in weekly load response was identified between baseline and week eight. The enhanced training load, especially at the end of the eight-week experiment, was expected due to cumulative fatigue and/or increments in the intensity of training.

Although the weekly load responses in both study groups showed increments in all three intensity-based training sessions (total, light and moderate, and high intensity), the overall week-to-week training load increments in the experimental as compared to the control group, specifically for the total weekly load and high intensity training sessions, seemed progressively overloaded. As can be seen from the graphs (Figure 8.1), the differences in the weekly load responses, especially at weeks seven and eight, were getting wider and wider.

Although there are no similar studies that have been conducted based on altitude differences, there are a few studies (Bohner et al., 2015; Hamlin et al., 2015; Wehrlin & Hallén, 2006) that noted training load response and performance differences due to altitude in endurance athletes. Based on the results of these studies, as the elevation of training venues increase, the load imposed on the athlete also increases and the speed of running (leg turnover) decreases (Bohner et al., 2015; Hamlin et al., 2015; Wehrlin & Hallén, 2006). Anecdotal evidence and research-based results revealed that it is very common to see altitude-based load response differences, as well as endurance performance variations, regardless of the origin of the athletes (low altitude or high altitude native). These studies reported that when athletes train and compete at lower altitude, the physiological as well as the psychological stresses, were lower than at higher altitude (Wehrlin & Hallén, 2006; Niess et al., 2003; Levine & Stray-Gundersen, 1997). However, in these studies the session-RPE was not used to assess training responses; rather, physiological and psychological tools were used. The findings of these studies indicated that the high intensity training twice a week for eight consecutive weeks increased the effect of altitude-based training, expressed through the subjective feelings of athletes participating in the two altitude training models. Previous studies recommended the session-RPE based weekly load monitoring to protect athletes from non-functional over-reaching or even over-training (Haddad et al., 2017).

The results of the current study might indirectly indicate that athletes in the control group are experiencing a higher training load, particularly during the two heavy intensity training sessions, than the experimental group. Whereas, athletes in the experimental group, in addition to day-to-day training intensity variation, had the chance for high intensity interval training at a lower altitude (1470m; ~ 1000m lower than the control group). Anecdotal evidence and research findings also support the training difficulties and load response variations between the two study groups (LH-TH and LH-THTL).

Based on past study results, both training and competition times were compromised due to attitude changes. For example, a study by Wehrlin & Hallén (2006) reported that endurance performance and $\dot{V}O_2$ max decreases on average by 14.3% per 1000m increase in altitude. In another study, it was indicated that for every 100m increase in elevation above 1500m, a $\dot{V}O_2$ max decline of ~1% was identified (Kayser, 2005). In comparison to sea level, running velocity decreases by 4% at 1800m. At every 305m increase in elevation a 1% reduction in $\dot{V}O_2$ max was reported in a previous study (Niess et al., 2003). One of the possible explanations for a decline in $\dot{V}O_2$ max and endurance performance could be a decrease in arterial oxygen saturation (Wehrlin & Hallén, 2006).

Limitation

In addition to the small sample size, not using other internal training load monitoring tools like regular heart rate and heart rate variability assessments, biochemical and haematological tests to assist the session-RPE based weekly monitoring is a limitation of this study; hindering collection and comparison of the subjective responses with objective tools. Moreover, since the study was conducted during the early phase of the yearly training plan, the majority of the training sessions were dominated by light and moderate intensity training. This might affect the responses of the athletes to the weekly loads, since the majority of the training sessions consisted of slow and moderate running. The short duration of the study (eight weeks) meant that representative weekly load responses from year-round training, not only preparation, but also competition, could not be collected.

8.6 Conclusion

In this study clear differences in the weekly training load responses were identified between the two study groups mainly because of the two high intensity training sessions which were conducted separately at two different altitudes (live high- train high and live high-train high train low). This study also revealed the role of cumulative training at different altitudes in determining the training load distribution to enhance the endurance performance of long-distance runners native to high altitude. Variations in training elevation might lead to differences in internal load responses. In line with previous findings on athletes native to sea level or low altitude, Ethiopian junior long-distance athletes native to high altitude also respond differently to the two altitude training models (LH-TH and LH-THTL).

Future Research

Considering the suitability of the different altitudes at which this study was conducted, it is recommended that further year-round training load distribution is studied, using a large sample population and incorporating additional objective and subjective training load monitoring methods and additional altitude training models to research performance and over-training

CHAPTER NINE: ENDURANCE PERFORMANCE (MANUSCRIPT)

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This chapter reports on the research into the fifth hypothesis of the altitude study. To the best of our knowledge this study is the first of its type to investigate the effects of the live high-train high and live high-train high train low altitude training models on the endurance performance (5km time) of Ethiopian junior athletes native to high altitude following eight weeks of endurance training.

Target journal: Journal of Sport Science

Title: Differences in endurance performance between junior long-distance athletes after eight weeks of endurance training following the live high-train high or live high-train high train low altitude training models at altitude in Ethiopia.

Abstract

Background: Although studies in different sports have proved performance changes due to altitude variations, to date no experimental study has reported on differences in endurance performance of African athletes native to high altitude after an extended period using altitude training models. The purpose of this study was to identify endurance performance differences between the live high-train high and live high-train high train low groups following eight weeks of endurance training. **Methods:** A total of 20 well-trained junior long-distance athletes were assigned to the live high-train high (n=10) and live high-train high train low (n=10) groups. The study applied a balanced randomised experimental design. At the end of the four pre-experimental weeks, a 5km time trial was conducted and the athletes were equally grouped into two groups and then randomly assigned into the LH-TH and LH-THTL groups.Throughout the study time three 5km time trail tests (at baseline, week four and week eight) were conducted at an altitude of 2500m on a standardised 400m outdoor synthetic track in Asella (7°57′N latitude and 39°7′E longitude) where the training camp is located. **Results:**After eight weeks of endurance training, no significant difference was identified between the live high-train high and live high-train high train low study groups (Δ-12; CL±25s; p = 0.335). Even though the 5km time significantly decreased in the experimental group (Δ-19; CL ±18s; p = 0.037) from baseline to week eight, the performance change in the control group did not improve significantly (Δ-7; CL±18s; p = 0.440). **Conclusion:** Although no significant endurance performance (five kilometer) difference was observed between the groups, athletes in both study groups were able to improve their performance after eight weeks of altitude-based endurance training. Based on the current findings, athletes in the LH-THTL group had exhibited significant performance improvement than athletes in the LH-TH group.

Keywords: endurance performance, live high-train high, live high-train high train low

9.1 Introduction

Unlike the laboratory-based simulated altitude training studies, very few terrestrial altitude training studies are available in the existing literature (Wehrlin & Hallén, 2006; Wehrlin et al., 2006; Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997). Moreover, most of these studies targeted athletes native to sea level and low altitude and reported the physiological and performance effects of different altitude training models based on measurements like change in $\dot{V}O_2$ Max, lactate threshold, time to exhaustion, maximal aerobic speed, race performance and time trials (Wehrlin & Hallén, 2006; Niess et al., 2003; Stray-Gundersen et al., 2001).

Altitude-based studies have identified changes in performance due to altitude changes (Hamlin et al., 2015); and event-specific performance changes due to increases in altitude (Hamlin et al., 2015). There are also studies (Saunders et al., 2009; Brutsaert, 2008; Subudhi & Roach, 2008) that clearly indicated the challenges involved in achieving better endurance performance at higher altitude than lower altitude. The study by Brutsaert (2008) found that athletes native to high altitude had higher limits to work performance at higher altitudes; unlike their counterparts at sea level. A few studies (Wehrlin & Hallén, 2006; Kayser, 2005; Niess et al., 2003) noted the decreases in speed and performance following increases in altitude. A 4% decrease in running speed at 1800m, as compared to sea level, was measured; with a 1% decrease in $\dot{V}O_2$ Max for every 305m increase in altitude (Niess et al., 2003). In another study, it was reported that for every increase of 100m, above 1500m, a $\dot{V}O_2$ max decline of ~1% was identified (Kayser, 2005). In support of the above findings, a study by Wehrlin and Hallén (2006) identified decreases in endurance performance and $\dot{V}O_2$ Max, on average by 14.3% and 6.3%, respectively, per 1000m increase in altitude. Studies (Hamlin et al., 2013) revealed that a decrease in arterial oxygen concentration at altitude results from a drop in oxygen pressure in the inspired air (P_IO_2), leading to a subsequent drop in the amount of oxygen in the arterial blood (PaO2).

Although studies in different sports (Bohner et al., 2015; Hamlin et al., 2015; Saunders et al., 2009; Wehrlin & Hallén, 2006) proved performance changes due to altitude variations, to date no experimental study has reported on the endurance performance differences of African athletes native to high altitude after an extended period using altitude training models. Very few altitude studies have been conducted on endurance athletes that use natural altitude to assess the effects of different altitude models on performance outcomes (Wehrlin & Hallén, 2006; Niess et al., 2003; Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997). However, none of these studies targeted athletes native to high altitude; or tested the performance outcomes of the athletes at high altitudes.

Some experimental altitude studies in the literature that were conducted for an extended period noted endurance performance changes in athlete resident at sea level. One of the noteworthy studies which was conducted at natural altitudes was an experimental study by Levine and Stray-Gundersen (1997). In this seminal study, 39 athletes were initially matched, based on their fitness/performance levels, and randomly assigned into three groups: LL-TL (control), LH-TH (experimental), and LH-TL (experimental). After four weeks of the experiment, in comparison to the pre-altitude training values, significant changes were identified in the post-altitude tests (three days after the end of the experiment) at sea level in the LH-TL and LH-TH groups in hemoglobin concentration (5%), erythrocyte volume (9%), and $\dot{V}O_2$ Max (4%). In terms of the performance tests, however, only athletes in the LH-TL experimental group improved their 5000m performances, by an average of 13.4 seconds (1%).

In 2001, a similar, but modified form of the LH-TL altitude training model, the live high-train high train low (LH-THTL) model, was used to assess the possible physiological and performance changes. This experimental study, based on the initial findings of Levine and Stray-Gundersen (1997), was conducted at high altitude on long-distance runners native to low altitude. The findings of this study (Stray-Gundersen et al., 2001) indicated that after four weeks of LH-THTL training, significant improvements in haemoglobin concentration ($1.0\pm1.1 g.dL^{-1}$), red blood cell count (103±74%), and $\dot{V}O_2$ Max ($2.3\pm2.6 ml.kg^{-1}.min^{-1}$) were reported. Moreover, a 1.1% improvement in 3000m (pre: 8:45.2±0:39 to post: 8:39.6±0:39 min:s, $p \leq 0.05$) performances was observed following the four weeks' altitude training by all the athletes, with similar improvements by the male (pre: 8:18.4±0:14.0 and post: 8:12.6±0:10.8, $\boldsymbol{p < 0.10}$) and female (pre: 9:32.4±0:11.1 and post: 9:26.9±0:11.3 min:s, $p \leq 0.05$) athletes (Stray-Gundersen et al., 2001).

Despite the fact that these two studies (Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997) identified both positive physiological changes and performance improvements, to the best of our knowledge no similar study has been published which looks at athletes native to high altitude. The available altitude-based studies involving athletes native to high altitude were comparative studies with sea-level athletes (Wishnizer et al., 2013; Lucia et al., 2006; Weston et al., 2000; Saltin, Kim, et al., 1995; Saltin, Larsen, et al., 1995); and they mainly focused on identifying differences in selected haematological and non-haematological variables, rather than conducting intervention-based experimental studies. The primary focus of any altitude training model in endurance sports is to enhance the endurance performance of athletes. Therefore, the main objective of this study was to identify the endurance performance differences between two study groups (LH-TH vs LH-THTL) following eight weeks of endurance training. The endurance performance differences between the experimental and control groups were assessed using 5km time trial tests.

9.2 Methodology

Study Participants

The sample used for this study was 20 long-distance athletes who lived and trained in the national athletics training centre. The mean age, and years spent training, of the athletes were 18.4±1.2 years and 4.6±1.5 years, respectively. The research protocol was approved by the biomedical research ethics committee of UKZN and the AAU-CNS research ethics committee. Before the study began, all athletes signed written, informed consent forms and the research protocol was conducted in accordance with the Helsinki declaration. The athletes who participated in the study were living and training in the national athletics training centre (TDNATC) which is located at an altitude of 2500m (7°57′N latitude and 39°7′E longitude). These athletes joined the training centre from all over the country after they had competed in their appropriate endurance-trained age groups.

Study Design

This study applied a balanced randomised experimental design. Before the eight weeks of the experiment, all the athletes were trained together for four continuous weeks.

During the four weeks before the study attempts were made to train all athletes in the same training venues; to provide the same frequency, volume and intensity of training; to train similar content and methods; to consume the same nutrition and to receive similar recovery strategies. At the end of the four pre-study weeks, the athletes were matched based on their performance and equally assigned into control and experimental groups using a simple random sampling method. There was no difference in gender balance between the groups, with two female athletes in each group.

Study Protocol

The three 5km time trials were conducted at an altitude of 2500m on a standardized 400m outdoor synthetic track in Asella (7°57′N latitude and 39°7′E longitude) where the training camp is located; between 07:00 and 08:00am. The time trials were conducted at baseline, and in the fourth and eight weeks. Before the tests all the athletes were in good health. Athletes had a rest day on the day before the tests and were told not to take any stimulants or alcohol 24 hours before the test. Before every test the athletes engaged in 25 – 30 minutes of dynamic warm-up activities. In order to avoid the pacing, as well as the group, effect on the performance of the athletes, the time trials started every 20secs. During all the tests, athletes were individually motivated to run as best they could to improve their previous 5km times. The temperature, humidity and wind speed at the time of the three time trials were recorded using a portable weather tracker (Oregon, USA). During the three time trials the temperatures and relative humidity ranged between 15 and 16°C and 31 to 50%, respectively; and the wind speed varied between 3 to 4 $km.h^{-1}$.

Training

Throughout the eight study weeks all the athletes in both groups (experimental and control) received similar training (mostly endurance/aerobic training with continuous, fartlek and interval variations). The study followed a single training session pattern in which the sessions were conducted every day in the morning before breakfast. Of the six training days a week, the athletes were involved in two short and long interval trainings, two long slow recovery runs and two fartlek training sessions. During the entire study, no resistance or plyometric training sessions were conducted.

9.3 Statistical Analysis

Data are expressed as the mean ± SD as appropriate following a test for the normality of distribution. Independent sample t- test was used to compare the mean age, training age, body mass, body mass index and 5km personal best time. Regression analysis was then used to identify any significant changes within each subject's set of data, between subjects and over time. Cohen's *d* effect sizes (ES) and 95% confidence intervals (CI) were also calculated for all measurements. Magnitudes of the standardised effects were interpreted using thresholds of d <0.2, 0.2-0.6, 0.6-1.2, 1.2-2.0, 2.0-4.0. These values correspond to trivial, small, moderate, large and very large ES, respectively. Statistical significance was set at $p < 0.05$. Statistical analyses were performed using the IBM SPSS Statistics for Windows, Version 23.0. (Armonk, NY: IBM Corp).

9.4 Results

Personal Characteristics

The sample size for this study was 20 long distance athletes (male = 16 and female = 4) who lived and trained in the national athletics training centre (TDNATC). In each group, eight male and two female athletes successfully completed the overall study that lasted for eight weeks.

At baseline there were no statistically significant differences between the two study groups in their body mass (p = 0.706), body mass index (p = 0.724), age (p = 0.856), and years in training (p = 0.556). The descriptive data for the other anthropometric and personal characteristics of the study participants at baseline are presented in Table 9.1.

Table 9-1: Personal characteristics of the study participants

Characteristics	Descriptive Statistics	Control (n=10)	Experimental (n=10)	Total (n=20)
Age (years)	Mean	18.3	18.4	18.4
	SD	1.25	1.18	1.18
	Min – Max	17 – 20	17 - 20	17-20
Body mass (kg)	Mean	55.3	53.6	54.4
	SD	7.73	5.01	6.4
	Min-Max	40-62.7	46 - 60.7	40.0 - 62.7
Height (m)	Mean	1.7	1.7	1.7
	SD	0.06	0.056	0.056
	Min-Max	1.60 - 1.80	1.6 - 1.78	1.6 - 1.78
Body Mass Index (kg.m^{-2})	Mean	18.9	18.6	18.8
	SD	1.7	1.36	1.53
	Min-Max	14.9 - 20.7	15.6 - 20.3	14.9 - 20.7
Period in training (years)	Mean	4.8	4.4	4.6
	SD	1.4	1.47	1.47
	Min-Max	3.0 - 6.0	2.0-6.0	14.9-20.7
5km personal best (sec.ms)	Mean	918.9	914.3	916.6
	SD	69.4	51.5	59.5
	Min-Max	864.2 - 1062.11	865.05 - 1011.20	864.2 - 1062.1

The means for the 5km personal best times for all the athletes are presented in Table 9.2. The mean for the 5km personal best times of all the athletes was 916.6±59.5s.ms (15:16.6±0:59.5 min:s.ms). The mean ± SD for 5km personal best times for the control and experimental groups were 15:14.3±0:51.5min: s.ms and 15:18.9±1:09.4 min:s.ms, respectively. No significant difference was identified in 5km personal best times between the control and experimental groups (p = 0.869).

Table 9-2: Five kilometres (5km) personal best times based on study groups and gender

Control			Experimental		
Code	Personal Best (Min: sec. ms)	Personal Best (Sec. ms)	Code	Personal Best (Min: sec. ms)	Personal Best (Sec. ms)
TD3	14:33.3	873.3	TD1	14:46.92	886.92
TD4	14:29.00	869	TD2	14:27.67	867.67
TD11	14:24.20	864.2	TD6	14:25.05	865.05
TD13	14:25.30	865.3	TD10	14:48.47	888.47
TD14	15:21.62	921.62	TD12	15:11.94	911.94
TD18	14:44.18	884.18	TD15	15:02.76	902.76
TD19	15:03.85	903.85	TD 16	15:12.23	912.23
TD20	15:22.0	922	TD17	14:53.60	893.6
TD5	17:03.3	1023.3	TD8	16:51.20	1011.2
TD7	17:42.11	1062.11	TD9	16:43.20	1003.2
Total (Mean)	15:14.3	914.3		15:18.9	918.9
Total (SD)	0:51.5	51.5		1:09.4	69.4
Male (Mean)	14:47.9	887.9		14:51.1	891.1
Male (SD)	0:24.5	24.5		0:18.0	18.0
Female(Mean)	17:22.7	1042.7		16:47.2	1007.2
Female (SD)	0:27.4	27.4		0:05.7	5.7

5km Time Trials

The differences between the experimental and control groups, as well as the changes within each study group, for the 5km endurance performances were analyzed using regression analysis. After eight weeks of endurance training, no significant difference was identified between the LH-TH and LH-THTL study groups (Δ-12; CL ±25s; p = 0.335). Even though the 5km time significantly decreased in the experimental group from baseline to week eight, the performance in the control group did not improve significantly (Table 9.3). Although the improvement was not significant in the control group, the mean time taken to cover the 5km time decreased. The effect size (ES) for changes in the 5km performances, and its respective rating for the experimental, control and the difference between the experimental and control subjects was -0.20 (small), -0.07 (trivial), and -0.13 (trivial) respectively (see Table 9.5). The mean time taken to cover 5km in both the experimental and control groups is presented in Table 9.3.

Table 9-3: Five kilometres (5km) time trial results

Time of trial	Study groups	Mean	SD	95% CI for mean	
				Lower	Upper
BL	Control	951.0	97.3	881.4	1020.6
	Experimental	945.8	95.6	877.4	1014.2
	Total	948.4	93.9	904.4	992.4
Week 4	Control	941.5	99.3	870.5	1012.5
	Experimental	928.1	68.2	879.3	976.9
	Total	934.8	83.2	895.9	973.7
Week 8	Control	944.2	86.3	882.5	1005.9
	Experimental	926.9	62.0	882.5	971.2
	Total	935.5	73.7	901.0	970.0

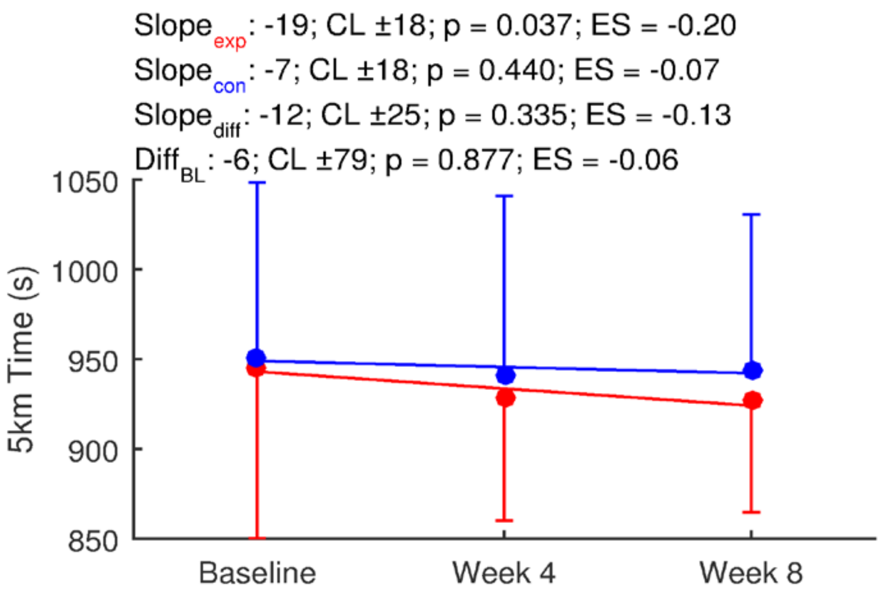

Figure 9.1 Regression analysis results for the 5km time trials

The mean performance improvement of all 20 athletes in their 5km performance from baseline to week eight was 1.16%. In the experimental group, seven athletes improved their 5km time; and seven in the control group did the same; by (-) 3.03% and (-) 1.93%, respectively. At the same time, 30% of the athletes in the experimental and control groups scored below their baseline results. The mean relative decline by these athletes (30%) in the experimental and control groups was (+) 1.35% and (+) 2.47%, respectively (Table 9.4).

Table 9-4: Change in 5km time trials from baseline to week eight

		Control	Experimental
Δ in 5km BL – Week 8 (athletes improved their time)	N	7	7
	Δ % (-)	- 3.03	- 1.93
Δ in 5km BL – Week 8 (athletes did not improve their time)	N	3	3
	Δ % (+)	+ 1.35	+ 2.47

9.5 Discussion

The objective of this study was to identify endurance performance difference between the junior long-distance athletes following eight weeks of endurance training using the LH-TH and LH-THTL altitude training models. The five kilometer endurance performance tests at the three time points were the primary outcome measurements of this study. At the beginning of the study, it was hypothesized that there would be no significant difference between the two study groups in their endurance performance (5km) following eight weeks of endurance training. The findings of this study supported the null hypothesis since no significant endurance performance difference was identified between the experimental and control groups (p = 0.335). However, in comparison to the control group (p = 0.440), the athletes in the experimental group significantly improved their 5km times (p = 0.037, with small effect size = -0.2) from baseline to week eight (Table 9.5). The results of this study also revealed that 70% and 30% of the athletes in both study groups (experimental and control) registered positive (decrease in the time to cover 5km) and negative (increase in the time to cover 5km) performance changes, respectively (Table 9.4)

Table 9-5: Regression analysis summary for 5km time trials

Variable	Groups	Slope	95% CL	Sig.	ES	Interpretation
5km Time Trial (seconds)	Control	-7	±18	0.440	-0.07	Trivial
	Experimental	-19	±18	0.037*	-0.2	Small
	Δ (Exp. – Control.)	-12	±25	0.335	-0.13	Trivial

The mean relative performance improvements in the 70% of athletes in the experimental and control groups were (-) 3.03 and (-) 1.93%, respectively. In those 30% of the athletes who did not improve their endurance performance, their mean relative 5km performance declined by (+) 1.35 and (+) 2.47% in the experimental and control groups, respectively (Table 9.4). When the pattern of the performance changes for the three consecutive 5km tests (BL, week four, and week eight) is compared, more consistent improvements were observed in the experimental (BL: 945.8 ±95.6s.ms; week 4: 928.1±68.2s.ms; week 8: 926.9±62.0s.ms) group than in the control group (BL: 951.0 ±97.3s.ms, Week 4: 941.5± 99.3s.ms; Week 8: 944.2±86.3s.ms) (Table 9.3).

To the best of our knowledge, no altitude-based study (using any altitude training models) has been conducted on the performance changes in any middle- and long-distance events that involved African athletes native to high altitude, following an extended period of endurance training. However, a few similar studies were conducted on athletes native to low altitude using different natural altitude and/or altitude simulation methods (Robertson, 2009; Wilber, 2007). Among these altitude training models, studies proved the dual physiological and performance benefits of the LH-TL and LH-THTL altitude training models (Stray-Gundersen & Levine, 2008; Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997).

In terms of study design and duration of the study, the current study was also in line with some of these studies (Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997). Based on the results of these studies (Stray-Gundersen et al., 2001; Levine & Stray-Gundersen, 1997), endurance athletes in the LH-TL group (who lived and trained light and moderate intensity endurance training at high altitude (2500m), and high intensity interval training at low altitude (1200m)) improved their 5km times more than the other groups. Although the athletes in the LH-TL group improved their 5km times significantly more than the LH-TH and LL-TL groups, both the LH-TL and LH-TH groups showed improvements in haemoglobin concentration, red blood cell volume and $\dot{V}O_2$ Max. In another study (Stray-Gundersen et al., 2001), athletes who trained under the LH-THTL altitude training model improved their 3km times significantly more than athletes in the other groups (LH-TH and LL-TL). Robertson (2009) employed a similar LH-THTL study protocol with Stray-Gundersen et al. (2001) on endurance runners native to low altitude and reported improvements in $\dot{V}O_2$ Max and 3km time trials (-1.1%±1.0%) at the end of three weeks of altitude training, which was better than the other groups (LH-TH, LH-TL and control). The findings of the current study on

Ethiopian junior long-distance athletes match the findings of these two studies (Robertson, 2009; Stray-Gundersen & Levine, 2008) since the endurance athletes in the LH-THTL groups improved their race performances more than the other groups, although the time trial venues (low vs high altitude) and origin of the athletes (lowlanders vs highlanders) were different, making it difficult to exactly compare the performance changes.

This study identified no significant difference between the two study groups in the 5km endurance performance test following eight week of training. However, when the pattern of the 5km time trial results over the course of the study (baseline to week eight) was examined, differences were observed between the two groups.

Table 9-6: Absolute and relative performance changes (5km)

Change in time	Control		Experimental		All	
	Absolute	Absolute	%	%	Absolute	%
ΔBL – W4	- 9.5	- 17.7	- 1.87	- 0.99	- 13.6	- 1.43
ΔW4 – W8	+2.7	- 1.2	- 0.129	+0.286	+ 0.7	+ 0.074
ΔBL – W8	- 6.8	- 18.9	- 1.99	- 0.715	- 12.9	-1.36

As is indicated in Table 9.6, the 5km times did not change uniformly from baseline to week eight in the two groups. While the magnitude of the improvements lack consistency in both groups, athletes in the experimental group showed more consistent improvement (time improvements) in their 5km time trials from BL to week four, week four to week eight, and from BL to week eight, respectively. However, the changes in the control group were not progressive. Although the mean time taken to cover the 5km improved from baseline to week four by -9.5s (-0.99%), the time to cover the same distance (5km) from week four to week eight increased by +2.7s (+0.286%). During the eight weeks of the study, athletes in the control group showed both positive and negative performance changes from baseline to week eight; with overall improvement. However, when the overall performance changes (baseline to week eight) of the athletes in the two study groups are compared, athletes in the control group (-0.715%) were slower than the experimental group (-1.99%). The 5km performance deterioration from week four to week eight in the control group might be associated with cumulative fatigue, particularly in the last two weeks of the study. The effects of this cumulative fatigue on the endurance performance can be expressed by the increase in the weekly training load response scores (see Table 8.2, Chapter Eight) during weeks seven and eight in the control group, compared to the experimental group.

In the current study, athletes in the control group produced slower 5km performances than the experimental group, although these athletes improved from their baseline performance (Table 9.6). Athletes in the control group spent all 47 training sessions, including the high intensity interval training sessions, at higher altitude (2500m.). Different studies (Bohner et al., 2015; Hamlin et al., 2015; Saunders et al., 2009; Wehrlin & Hallén, 2006; Rusko et al., 2004) at different times reported the training challenges and related limitations of high altitude endurance training, regardless of the origin of the athletes (low altitude and high altitude).

Studies reported that, in comparison to lower altitude training, interval training was substantially compromised at moderate-to-high altitudes (Kayser, 2005; Niess et al., 2003; Levine & Stray-Gundersen, 1997). The cumulative effects of high oxygen flux at higher altitude, and the challenge to maintain high intensity running speed in the same way as at low altitude, might contribute to a reduction in work capacity and a detraining effect; more in the LH-TH group than the LH-THTL group. The major findings that were reported in previous studies (Hamlin et al., 2015; Saunders et al., 2009; Wehrlin & Hallén, 2006; Rusko et al., 2004; Niess et al., 2003; Desplanches et al., 1996) might hint at an explanation for the erratic 5km performances by athletes in the control group (the current study) who trained the 16 high intensity interval training sessions at 2500m.

Although numerous altitude-based studies have been conducted targeting athletes native to sea level and low altitude, some studies (Desplanches et al., 1996) have reported that both sea level and high altitude athletes respond similarly to a standard endurance training protocol at both low and high altitude; or at hypobaric hypoxia and hypobaric normoxia. As this study indicated, the way high altitude residents improve maximal oxygen uptake, oxidative enzyme capacity, capillary supply and mitochondrial content was similar to sea level residents (Desplanches et al., 1996).

The overall endurance performance results revealed no significant difference between the two study groups, although athletes in both groups improved on their baseline performances. In comparison to the control group, however, better performance changes were observed in the experimental group. The results of vagal-related heart rate measurements (Chapter Six), the neuromuscular indices (Chapter Seven) as well as the weekly load response (Chapter Eight) data of the athletes in the current study might provide supporting evidences for the positive performance changes within, and between, the two study groups. Athletes in both groups showed signs of positive adaptation for their eight weeks of training, as the test results for both the vagal-related heart rate and neuromuscular measurements improved; although differences were observed in the weekly training load responses between the two groups (Athletes in the control group improved better than the experimental). The first two positive physiological and performance changes can be taken as the reason for the improvement from baseline in the 5km endurance performances by both the experimental and control groups; and the higher weekly load responses account for the smaller performance improvement by the control group.

Anecdotal evidence and study results reveal significant performance changes when athletes train and compete at venues with difference elevations. A study by Niess et al. (2003), for example, indicated that in comparison to running at sea level, running velocity decreases by 4% at 1800m; and a 1% $\dot{V}O_2$ Max reduction was reported with every 305m increase in altitude. In another study, it was reported that for every 100m increase in altitude above 1500m, a $\dot{V}O_2$ Max decline of ~1% was identified (Kayser, 2005). In support of the above findings, a study by Wehrlin and Hallén (2006) identified endurance performance and $\dot{V}O_2$ Max decreases; on average by 14.3% and 6.3%, respectively, for every 1000m increase in altitude. One of the possible explanations for this $\dot{V}O_2$ Max and endurance performance deterioration was a decrease in arterial oxygen saturation (Wehrlin & Hallén, 2006). As is indicated in the above section, the two study groups were involved in separate high intensity interval training sessions. During those 16 high intensity training sessions the athletes were trained at altitudes which differed by ~1000m. So, the cumulative effects of the high intensity interval training at 2500m experienced by the control group might be the reason for their higher weekly training load responses and slower 5km performance times. This can be seen in the wider gap between the groups in 5km performance at the end of the study (Δ 17.3seconds), as compared to baseline (Δ5.2 seconds) (Table 9.3).

Other studies have also clearly indicated the challenges in achieving better results at higher altitudes than at lower altitudes (Saunders et al., 2009; Brutsaert, 2008). The study by Brutsaert (2008) revealed that natives to high altitude had higher limits to work performance at altitude. In the current study, the athletes' responses supported the findings by Brutsaert (2008), since the session-RPE-based weekly load responses of the athletes (Chapter Eight) in the control group showed a higher level of training difficulty, particularly in the high intensity training sessions performed at 2500m., compared to the experimental group. Taking this fact into consideration, better performance changes might have been achieved had the tests been conducted at a relatively lower altitude. Without this option, this study has not had an opportunity to compare the current results with those from any previous studies to arrive at valid conclusions.

Limitations

In this study, three consecutive 5km time trials were conducted at high altitude (2500m). No similar and comparable tests were conducted at low altitude. However, existing data reveals that almost all the elite Ethiopian long-distance athletes have been competing at lower altitude or sea level, except for local competitions. The small sample size, the disproportionate gender balance, the quality of the testing equipment (using a stop-watch) is some of the limitations of this study. In addition to these limitations, the study was not able to identify altitude responders from non-responders before recruiting and assigning the athletes into the two study groups.

9.6 Conclusion

No significant endurance performance (five kilometer) difference was observed between Ethiopian junior long-distance athletes who trained under either the LH-TH or LH-THTL altitude training models. Although no performance difference was observed between the groups, athletes in both study groups were able to improve their performance after eight weeks of altitude-based endurance training. This study also identified that athletes in the LH-THTL altitude training group significantly and consistently improved the five kilometer endurance performance as compared with the LH-TH group.

Future Research

Results of this study were assessed by the time taken to cover 5km. In order to thoroughly assess the effects of different altitude training models on the endurance performance of Ethiopian junior athletes native to high altitude, further studies should be conducted using larger sample sizes and more than two altitude training models. In addition to the size of the sample and number of altitude training models, future studies should consider using both high and low altitude venues for time trials; as well as running the study during different phases of the yearly training plan.

CHAPTER TEN: CONCLUSION AND RECOMMENDATIONS

10.1 Synthesis

Since the early 1960s numerous altitude training studies have been conducted to enhance the middle- and long-distance performances of athletes native to sea level and low altitude (Saunders et al., 2009). These studies primarily assessed the hematological (Saugy et al., 2014; Stray-Gundersen et al., 2001), non-hematological (Lundby & Jacobs, 2016; Gore et al., 2007), neuromuscular (Lundby & Jacobs, 2016) and performance (Hamlin et al., 2015; Wehrlin & Hallén, 2006; Kayser, 2005) advantages of different natural and simulated altitude training methods (Saugy et al., 2014; Wilber, 2007). As studies (Saugy et al., 2014; Fudge et al., 2012; Stray-Gundersen & Levine, 2008) have indicated, endurance athletes native to low altitude benefited from these research-based altitude training models; although some studies reported the insignificant role of altitude training for enhancing performance (Lundby & Robach, 2016; Robert Jacobs, 2013). Few altitude-based studies have involved athletes from east African nations like Kenya and Eritrea who are native to high altitude (Wishnizer et al., 2013; Lucia et al., 2006; Saltin, Kim, et al., 1995; Saltin, Larsen, et al., 1995). The primary objectives of these previous east African studies were not to enhance or maintain long-distance performance of these high altitude living athletes or assess the possible negative effects of chronic high altitude training (live high – train high) on these athletes. There has been limited research assessing the benefits and limitations of different natural altitude training models on athletes native to high altitude.

The current altitude study aimed to identify optimal natural altitude training models that enhance the long-distance performance of Ethiopian junior athletes who lived and trained in and around the national athletics training camp (TDNATC). This aim was to be achieved through five altitude based specific objectives, designed to identify the haematological, autonomic (vagal-related heart rate), neuromuscular, subjective training load-response as well as endurance performance (5km) differences between two groups of junior athletes who trained using the live high-train high and live high-train high train low altitude training models. Based on the five specific objectives, five hypotheses were formulated and tested through designing a balanced, randomized, experimental study. In order to meet the five specific objectives of the altitude study and examine the direct effect of environmental factors and dietary practices on the existing physiological and performance level of the athletes, the demographic characteristics as well as the macronutrient intake and energy balance of the study subjects (athletes) were also assessed as separate, small studies (objective 1 and 2). In the following section the summary of the major findings of the demographic characteristics, macronutrient intake and energy balance; and altitude studies are presented.

Demographic Characteristics Study: Significantdifference was observed between the three groups in the age at which formal training started. However, no significant differences were identified between the three groups in the altitudes where the Ethiopian long-distance athletes were born and raised; the daily distance travelled to and from school; the modes of transportation used; and the major out-of-school activities during their childhood. Thus, the findings of this study confirmed that the 20 junior athletes who were involved in the study shared common demographic characteristics with the retired and current elite Ethiopian long-distance athletes.

Macronutrient Intake and Energy Balance Study: In line with the previous studies conducted on Kenyan and Ethiopian endurance athletes, the young Ethiopian athletes met the recommended daily macronutrient intake for carbohydrates and protein for endurance athletes. However, the study also identified that the athletes' dietary fat consumption was below the recommended amount for endurance athletes. In comparison with the other macronutrients, CHO were the major energy source consumed during the three days and the athletes' diet was primarily comprised of plant sources. Moreover, based on the three-day dietary assessment results, the young Ethiopian endurance athletes were found to be in a state of positive energy balance one week before their first major competition of the year (albeit during the preparation phase of their yearly training plan).

Altitude Study

Haematological Responses: No significant differences were identified in the selected haematological indices (RBC, Hgb, Hct) between athletes in the LH-TH and LH-THTL altitude training models. Although there were no significant difference between the two study groups, athletes in both groups showed declines in most of the selected haematological indices from baseline to week eight, without their endurance performances being negatively affected.

Vagal-Related Heart Rate Response: No substantial differences were observed in the selected vagal-related heart rate indices between the athletes in the LH -THTL and LH-TH groups. In comparison to the LH-THTL group, athletes in the LH-TH group improved their autonomic regulation (heart rate variability); though athletes in both groups positively improved their baseline autonomic regulation by the end of the experiment. The changes in the athletes' autonomic responses coincided with the endurance (5km) and neuromuscular (CMJ and SJ) performance changes but not with weekly training load response.

Neuromuscular Performances/Fatigue Response: No significant differences were observed between athletes in the LH-TH and LH-THTL study groups in their neuromuscular performance responses following eight weeks of endurance training. However, in terms of effect size and change in magnitude (slope), athletes in the LH-THTL experimental group improved their neuromuscular performance better than the LH-TH control group.

Training Load Response: Significantly higher training load response was identified in athletes in the LH-TH group as compared with athletes in the LH-THTL group. In this study, the cumulative training load responses of the athletes in the respective groups were also accompanied by proportionate endurance performance (5km) changes: the lower training load response, the better the endurance performance.

Five Kilometre Endurance Performance: No significant endurance performance difference between the two study groups was also confirmed following eight weeks of endurance training. However, taking the haematological, autonomic, neuromuscular and training load responses of the athletes into consideration, the performances of the athletes in the LH-THTL experimental group improved more from baseline to week eight than those of athletes in the LH-TH control group.

10.2 Conclusion

From the findings of the two smaller studies, together with the study that applied the two altitude training models to endurance athletes native to high altitude, this study has reached the following conclusions.

Haematological Responses

The findings of this study revealed no significant differences in RBC, haemoglobin concentration, and haematocrit levels between the two study groups following eight weeks of endurance training. This study underlined the insignificant effect of eight weeks of LH-TH and LH-LHTL altitude training on selected haematological variables. Therefore, from haematological perspectives, both altitude training models are preferable models for Ethiopian junior long- distance athletes since athletes in both groups were living throughout the study time at the same altitude.

Vagal-Related Heart Rate Response

From the autonomic regulation (vagal-related heart rate adaptation) perspective, in comparison to the LH-THTL altitude training model, the LH-TH altitude training model seemed the preferred altitude training model to benefit the autonomic responses of Ethiopian junior long distance athletes although it was not accompanied with better five kilometer endurance performance and lower training load response than LH-THTL group.

Neuromuscular Fitness/Fatigue Response

Regarding neuromuscular performance of the athletes, both altitude training models improved neuromuscular fitness. However, the improvements in the neuromuscular performance and the lower subjective training load responses of the athletes in the LH-THTL group were accompanied with significant improvement in endurance performance as compared with the LH-TH control group.

Training Load Response

The session-RPE based training load response results revealed that, as compared with the LH-TH model, the LH-THTL was the better altitude training model since it resulted with lower training load response. Thus, the LH-THTL altitude training model was the preferred altitude training model to run safe altitude training, maintain stress – recovery balance, improve long-distance performance, and there by minimize the athletes' susceptibility to non-functional overreaching and overtraining syndrome.

Five Kilometre Endurance Performance

Taking the importance of seconds and fraction of seconds in running events in to consideration; the results of the eight weeks natural altitude training study indicated that athletes in the LH-THTL altitude training model significantly improved the baseline performance compared with the LH-TH group. Moreover, as compared with the LH-TH group the endurance performance change was accompanied with enhanced neuromuscular fitness and lower training load response in the LH-THTL group. Thus, in terms of performance changes the LH-THTL altitude training model was the preferred altitude training model for Ethiopian junior long distance athletes.

In general, the overall results of the current altitude study revealed that in most of the study variables (i.e., haematological, autonomic, neuromuscular, and endurance performance), except the subjective based training load response, statistically insignificant results were identified between the two study groups. However, when the results of the altitude study variables across time (baseline to week eight) were examined, athletes in the LH-THTL experimental group showed better progress in neuromuscular and lower training load responses which were accompanied with significant five kilometer endurance performance change; and lower or similar progress in haematological and autonomic regulation responses as compared with the LH-TH control group. It is noted that the ultimate purpose of any type of altitude training is enhancing the running performance while minimizing athlete's susceptibility to injury. Taking these core concepts of athletic training and the physiological and performance change results of the current study in to consideration, the LH-THTL altitude training model was potentially the preferred optimal altitude training model to further enhance the past and existing long-distance performance of Ethiopian endurance athletes although further comprehensive studies are required to confirm the results.

10.3 Recommendations

Following eight weeks of endurance training the results of the haematological (indices) study revealed no significant differences between the two selected altitude training models. Thus, the current study recommends decision makers, coaches and sport scientists to further investigate the effects of the different altitude training models on the non-hematological and training related variables to further enhance the long distance performance of Ethiopian athletes.

Based on the results of the vagal-related studies athletes in the LH-TH altitude training model improved their autonomic responses following eight weeks of endurance training. The current study accepted the positive role of high intensity endurance training at a relatively high altitude on autonomic responses. Thus, taking the results into consideration, the current study recommends decision makers, coaches and sport scientists to further investigate the effects of high intensity endurance training at high altitude particularly during the most intense periods of the yearly training plan.

In relation to the neuromuscular performance indices, in the current study no significant differences were identified between the two study groups. However, athletes in both study groups significantly improved their neuromuscular performance. Taking these results into consideration, the current study recommends similar altitude training studies that incorporate other types of training that effect the neuromuscular system of athletes such as plyometric and power training along with endurance training.

Unlike other altitude studies, significant differences were identified between the two study groups for subjective training load responses. Therefore, based on the results, this study highly recommends decision makers, coaches and sport scientists to monitor the subjective feelings (internal load) of athletes when determining the loads of high-intensity training at different altitudes rather than simply relying on monitoring training load using external training quantification methods.

The ultimate objective of any altitude training in endurance sports is to enhance the performance of the athletes. In the current study significant endurance performance difference was identified between the two study groups. Taking the significant performance improvements in the LH-THTL altitude training groups into consideration, the current study recommends conducting research that tests the endurance performance of the Ethiopian long distance athletes both at high and low altitudes to make informed training decisions in the future.

In order to exhaustively investigate the optimal altitude training models that better enhance the long-distance performance of athletes’ native to high altitude, more comprehensive, similar studies should be designed. To achieve stronger results, further studies should be conducted using larger sample sizes with balanced gender proportions, along with more subjective and objective training monitoring methods. Moreover, future studies should consider additional altitude training models, and should be conducted over longer periods of time and in different phases of the yearly training plan (preparation, pre-competition, and competition). It is also recommended that future studies to design endurance performance tests at different altitude setups (low and high) to enhance the local and international competition performance of Ethiopian long-distance athletes.

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APPENDICES

Appendix I: Information Sheet

Appendix I: Information Sheet

Date__________________________

Hello, my respected athlete!

This is Zeru Bekele, an Ethiopian PhD candidate, from the University of KwaZulu-Natal, School of Health Sciences; discipline of Biokinetics, Exercise and Leisure Sciences.

Tel: +251911458414 (Ethiopia) or + 27843325620 (South Africa)

E-mail: tolazeru@gmail.com or 214555352@stu.ukzn.ac.za

Introduction

You are being invited to consider participating in a study that involves research 'Long distance running I Ethiopian athletes: a search for the optimal altitude training program'. The aim of the study is to search the optimal altitude training program that can maximize the competitive performance of Ethiopian long distance athletes. The study is expected to enroll 30 participants of 3 groups, 10 participants in each group. Of the three groups, one is control and the rest two are experimental. The duration of your participation if you choose to enroll and remain in the study expected to be 12 continuous weeks. If you decide to participate I thank you. If you decide not to take part in this study, there will be no disadvantage to you of any kind including your participation in any national and international competitions. Finally, I thank you for considering the request.

What type of participant is needed?

Young (18-24 years old) physically healthy male and female endurance athlete; with a minimum of one year training age; and who will live in Athlete Tirunesh Dibaba National Athletics Training Centre for a minimum of 10 continuous months (September 01/2015 to June 30/2016).

What will a participant is asked to do?

If you are interested to take part in this study, you will be asked to complete a personal information questionnaire and throughout the duration of the study will complete the Wisconsin Upper Respiratory Symptom Survey – 21. On four separate occasions you will have a blood test, provide a saliva sample, have anthropometric measurements taken, and perform fitness tests (a 4x300m speed endurance tests).

You will also be involved in a continuous regular endurance training program over 12 weeks and four 10km time trial tests.

The following tests and evaluations will be performed:

a. Pre-exercise evaluation: At the beginning of every phases of the study you will be required to perform a physical and medical examination that will be conducted by sports medicine physicians.

b. Anthropometric tests: Height (cm/m), weight (kg), body mass index (BMI), body composition, and girth measurements will be taken on weekly bases (for 8 weeks).

c. Heart rate measures: - every week as well as at every time trial resting and average heart rate will be measured, respectively. Moreover, peak heart rate and post time trial recovery heart rate at 1 and 2 minutes will be measured.

d. Hematological tests: At four select time points (baseline, 3rd, 6th, 8th weeks) venous blood draws (20 ml per time point) will be performed by a qualified medical laboratory technician at Asella referral hospital.

e. Saliva test: to assess the responses of the saliva biomarkers of immune function and the stress response (SIgA, cortisol and salivary Alpha-amylase) to training, saliva samples will be collected at baseline, 3rd , 6th, and 8th week.

f. Speed endurance and 10km time trial tests: In order to test the speed endurance and 10km performance changes of the subjects following 8 weeks of altitude training (LH-TH LH-TL and LH-TH/TL mixed), a 4x300m (10 minute recovery between sets) all-out speed endurance test on a 400m standardized synthetic track and a 10km road test will be conducted at baseline, 3rd , 6th , and 8th week.

Possible risks and discomforts:

Blood draws: Provide slight discomfort at the point of contact on the individual's skin.

Training at different altitudes: a mix of continuous, interval and fartlek training methods at different altitudes will be performed throughout the study times. Since it is difficult to avoid injury from sport, there may be very minor injuries, tiredness and muscle soreness following the training program.

Emergency plans

Throughout the study time (during training and time trial tests) a nurse assigned from Tirunesh Dibaba National Athletics Training Centre will assist the participants if medical attention is required. Moreover, two sports medicine physicians (one from Federal Sport Commission, national team physician and the other one from Asella Referral Hospital) will assist the participants whenever serious medical issues arise. First aid services will be provided by the coaches and principal investigator for all minor injuries during training and performance tests whereas if the injury is more serious the subjects will be taken to a clinic which is based at Athlete Tirunesh Dibaba National Athletics Training Centre. Any subject who will be severely injured or ill in relation to the proposed study will be admitted in Asella Referral Hospital. Regarding the health condition of the athletes, the medical clinic of the training camp has contract agreement with Asella Referral Hospital and any subject who will severely be injured and having a problem that is beyond the medical clinic of the training centre will be referred to the hospital.

Medical team contact details

Bezabih Wolde (Associate Professor) Physiotherapist Addis Ababa University, College of Natural Sciences Address:- Addis Ababa University College of Natural Sciences Department of Sport Science Addis Ababa, Ethiopia Tel:- +251911154802 Email:- bzbhwold32@yahoo.com	Ayalew Tilahun (Dr.) General Practitioner National Team Physician of the Ethiopian Athletics Team Federal Sport Commission Address:- Federal Sport Commission Addis Ababa, Ethiopia Tel:- +251911227821 Email: ayalewmami@gmail.com	Tewodros Gebru (Dr.) General Practitioner Asella Referral Hospital Address:- Asella Referral Hospital Kebele 10 Asella, Ethiopia Tel:- +251934552776 Email: teddo78brut@gmail.com

Potential benefits of this study:

The potential benefits for a subject who will involve in this study will include the following:

i. Train under IAAF certified coaches for a minimum of two months.

ii. Get local as well as national level competition opportunity.

iii. Will make a contribution to further understanding his/her hematological and immune status;

iv. Will receive information on his/her hematological condition, and some anthropometric variables without any cost (the usual charge for all such tests is approximately 1400.00 Ethiopian Birr or 800.00 South Africa Rand).

v. Monthly will receive 900.00 Ethiopian Birr or 450.00 South African Rand as a reimbursement for your local transportation cost and snack and bottled water at the time training and competitions.

vi. During every training time, transportation will be available for training sessions to be conducted outside of Asella town or far from the training camp.

Confidentiality

All the information to be provided and testing data to be collected by this study will be used for research purposes, including publications in research journals. All individual information will be coded and at no time personal identity will be revealed. All blood samples will be destroyed immediately after the analysis. However, saliva samples will be coded and stored in the Adds Ababa University College of Health Sciences laboratories for six months. After the analysis for salivary biomarkers are completed the saliva samples will also be destroyed. All test results/data to be collected from questionnaires, anthropometric, hematological, saliva and time trial tests will be recorded/coded and stored for five years in password protected computer in an excel database. It's only the supervisor and the principal investigator will have access to all hard and electronics copy of all the information gathered from the study participants in the process of the study. All types of questionnaires and data record sheets will be kept in the principal investigator's office in Ethiopia and then will be transferred and stored in the supervisor's office in UKZN for a period of five years and finally will be destroyed.

Can a participant change his/her mind and withdraw from the Project?

You may withdraw from participation in the study at any time and without any disadvantage to yourself of any kind.

What do participants have to avoid prior to testing?

You are expected to avoid exogenous EPO injection, caffeine consumption, eating too much, heavy training/physical activity, smoking, and alcohol intake not only before every test but also throughout the study time.

Liability

During the whole study time, maximum care will be taken to avoid/minimize injuries. In case injuries happen, you are insured against research related injuries. The training centre iisheld liable to cover all the medication cost for all research related injuries

What if a participant has any questions?

In the event of any problems or concerns/questions, you may contact the researcher at (provide contact details) or the UKZN Biomedical Research Ethics Committee, contact details as follows:

Zeru Bekele Tola Department of Biokinetics, Exercise and Leisure Sciences University of KwaZulu-Natal Telephone Number: +251911458414(Eth) +27843325620 (SA) Email: tolazeru@gmail.com	Professor Andrew McKune Discipline of Sport and Exercise Science University of Canberra Email: andrew.mckune@canberra.edu.au	BIOMEDICAL RESEARCH ETHICS ADMINISTRATION Research Office, Westville Campus Govan Mbeki Building Private Bag X 54001 Durban 4000 KwaZulu-Natal, SOUTH AFRICA Tel: 27 31 2604769 - Fax: 27 31 2604609 Email: BREC@ukzn.ac.za

Appendix II: Information Sheet in Amharic (Translated)

ስታዲየም የትርጉም ሥራ አገልግሎት
Stadium Translation Service
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መግለጫዎች

መግለጫ 1፡- ስለ ጥናቱ መረጃ

መግቢያ

የጥናቱ ርዕስ "የረጅም ርቀት ሩጫ በኢትዮጵያውያን አትሌቶች፡- ከባህር ወለል በላይ በሚገኙ የከፍታ ቦታዎች የሚደረግ ስኬታማ የልምምድ ፕሮግራም ጥናት"

በዚህ ጥናት ለመሳተፍ ተጋብዘሀል፡፡ የጥናቱ ዋና አላማ በኢትዮጵያ ተፈጥሮአዊ መልክዓ-ምድር በሚገኙ የተለያዩ የከፍታ ቦታዎች መካከል ላይ በመመስረት የተለያዩ የከፍታ ቦታ ልምምዶችን (altitude trainings) በማድረግ ለኢትዮጵያ የረጅም ርቀት ውድድር ስኬታማ የሆነ የልምምድ መርሃ-ግብር ለይቶ ማጥናት ነው፡፡ በጥናቱ የሚካተቱ የልምምድ ዓይነቶች ውጤት/ስኬት የሚወሰነው ከምራቅ በሚገኙ የበሽታ የመከላከል ብቃት መለያ ንጥረ ነገሮች፣ የሰውነት የጫና ምላሽ (የአትሌቶች የጤንነት ሁኔታ) እና የተለያዩ የረዥም ርቀት ብቃት መለኪያ ልኬቶችን በመጠቀም ነው፡፡በጥናቱ 30 የመካከለኛና የረጅም ርቀት አትሌቶች ይሳተፋሉ፡፡ በጥናቱ የሚሳተፉ አትሌቶች በሶስት ምድብ ተከፍለው ለ 12 ተከታታይ ሳምንታት ይሰለጥናሉ፡፡

በዚህ ጥናት ለመሳተፍ ፍላጐት በማሳየትህ እያመሰገንኩኝ በጥናቱ ለመሳተፍ ወይም ላለመሳተፍ ከመወሰንህ በፊት ከዚህ በታች የቀረቡትን መረጃዎች በጥንቃቄ እንድታነብ ትጠየቃለህ፡፡ በጥናቱ ለመሳተፍ ከተስማማህ ለፈቃድህ እያመሰገንኩኝ ነገር ግን በጥናቱ ላለመሳተፍ የምትወስን ከሆነ ባለመሳተፍህ የምታጣው ምንም ነገር እንደሌለ ለማሳወቅ እወዳለሁ፡፡

በጥናቱ እነማን ይካተታሉ /ይፈለጋሉ?

ማናቸውም እድሜያቸው ከ18-24 መካከል የሚገኙ ወንድና ሴት የረጅምና የመካከለኛ ርቀት አትሌቶች ነገር ግን ላለፉት 12 ወራት በመደበኛነት በልምምድ ላይ የቆዩ፣ በአሰላና አካባቢው በተከታታይ ቢያንስ ሦስት ወራት መኖር የሚችሉ ሁሉ በጥናቱ መሳተፍ ይችላሉ፡፡

ከተሳታፊው ምን ይጠበቃል?

በጥናቱ ለመሳተፍ ፈቃደኛ ከሆነስ የአንተን ማንነት የሚመለከት መጠይቅ፣ የላይኛው የመተንፈሻ ቧንቧየህመም ምልክቶችን የሚዳስስ መጠይቅ፣ የእለት ተእለት የህመም ምልክቶችን ሪፖርት ማድረጊያ

1

ዳንኤል ኃ/የሱስ ዋና
ዋና ሥራ አስኪያጅ
Daniel H/Yesus Wana
General Manager

መጠይቅ መሙላት፡፡ እንዲሁም በአራት የተለያዩ ጊዝያት የሚደረጉ የደም፣ የምራቅ፣ የሰውነት አቋም፣ የአካል ብቃትና የሰዓት ሙከራ ቴስቶች ላይ ትሳተፋለህ፡፡ በተጨማሪም ለተከታታይ 12 ሳምንታት በሚቆይ የልምምድ መርሃ ግብር ትሳተፋለህ፡፡

በጥናቱ የሚደረጉ ቴስቶች /ልኬቶችና ግምገማዎች

1. ቅድመ ኤክስርሳይስ ግምገማ፣ ወደ ጥናቱ ከመግባትህ በፊት የአካልና የህክምና ምርመራ ታደርጋለህ፡፡

2. የተክለ ሰውነት ቴስቶች፡- የቁመት፣ የሰውነት ክብደት፣ የሰውነት ክብደት ከቁመት ጋር ያለው ንፅፅር፣ የሰውነት የተከማቸ የቅባት መጠን ልኬቶች፤

3. የደም ልኬቶች፡- በአሰላ ሪፈራል ሆስፒታል በመገኘት አራት ተከታታይነት ያላቸው 20 ሚሊ የደም ቴስቶች /ልኬቶች/ ቴስት ማድግ፤

4. የምራቅ ልኬቶች፡- ለአራት ተከታታይ ጊዜያት በምራቅ ውስጥ ያሉ ንጥረ ነገሮችን ለማጥናት የሚደረጉ ቴስቶችን ማድረግ፤

5. የአካል ብቃት ልኬቶች፡- የ8 ሳምንት ልምምድን ተከትሎ በተሳታፊዎች የጡንቻ የነርቭ ውህደት የመጣን ለውጥ ለመለካት የሚደረግ ሁለት የአካል ብቃት ልኬት ማድረግ፡፡

በጥናቱ ወቅት ሊከሰቱ የሚችሉ ጉዳቶች

ለጥናቱ የሚሆን የደም ናሙና ሲወስድ መጠነኛ የሆነ ህመም መኖር፡፡ እንዲሁም ጥናቱ የአካል ብቃትልምምድ እንደመጠየቁ በተለያዩ መልክአ ምድር ላይ የሚደረጉ ልምምዶችን ተከትሎ ድካም፣ የጡንቻ መዛልና በጣም አነስተኛ ጉዳቶች ሊከሰቱ ይችላሉ፡፡

በጥናቱ ወቅት ልምምድን ወይም ውድድር ተከትሎ ሊከሰቱ የሚችሉ ጉዳቶችን ለመቆጣጠር የታሰቡ ስልቶች

በጥናቱ ወቅት ከጥናቱ ቡድን ጋር የሚቆይ አንድ ነርስ በመደበኛነት ከማዕከሉ የሚመደብ ሲሆን ለተጨማሪ የህክምና እርዳታ ሁለት የህክምና ዶክተሮች ከቡድኑ ጋር ይሠራሉ፡፡ የህክምና ዶክተሮቹ አንደኛ ከፌደራል ስፖርት ኮሚሽን የብሄራዊ ቡድን ሃኪም ሲሆን ሌላኛው በአሰላ ሪፈራል ሆስፒታል የሚያገለግል ባለሙያ ይሆናል፡፡ ተሳታፊው የተሻለ ህክምና የሚያስፈልገው ከሆነ በማዕከሉ ክሊኒክ የህክምና አገልግሎት እንዲያገኝ ይደረጋል፡፡ ነገር ግን ጉዳቱ የከፋ ከሆነ በቅርቡ በሚገኝ የአሰላ ሪፈራል ሆስፒታል የህክምና አገልግሎት እንደያገኝ ይደረጋል፡፡ በልምምድ ወይም ሰዓት ሙከራ ወቅት የሚከሰቱ በጣም አነስተኛ ጉዳቶች /የመጀመሪያ ደረጃ የህክምና ዕርዳታ በዋናው የጥናት አድራጊው አማካኝነት ይሰጣል፡፡

ስታዲየም የትርጉም ስራ አገልግሎት ★ Stadium Translation Service ★ 0930 098302 0911 66 7917

ዳንኤል ሀ/የሱስ ዋና
ዋና ሥራ አስኪያጅ
Daniel H/Yesus Wana
General Manager

የህክምና ባለሙያዎቹ ዝርዝር መረጃ

ዶ/ር በዛብህ ወልዴ ፊዚዮቴራፒስት አዲስ አበባ ዩንቨርሲቲ የተፈጥሮ ሳይንስ ኮሌጅ ስፖርት ሳይንስ ዲፓርትመንት ስ.ቁ +251911154802 Email:- bzabih32@yahoo.com	ዶ/ር አያሌው ጥላሁን ጠቅላላ ዶክተር የኢትዮጵያ አትሌቲክስ ብሄራዊ ቡድን የቡድን ሀኪም ፌደራል ስፖርት ኮሚሽን ስ.ቁ +251911227221 Email:- ayalewmam:@gmail.com	ዶ/ር ቴዎድሮስ ገብሩ ጠቅላላ ሀኪም አሰላ ሪፈራል ሆስፒታል አሰላ-ኢትዮጵያ ስ.ቁ +251934552776 Email:- teddo78brut@gmail.com

* ዶ/ር በዛብህ ወልዴ የጥናቱን ቡድን የጤንነት ሁኔታ በበላይነት ያማክራል።

በጥናቱ በመሳተፍ የሚገኝ ጥቅም

በዚህ ጥናት በመሳተፍ ተሳታፊዎች የሚከተሉትን ጥቅሞች ያገኛሉ ተብሎ ይታሰባል።

- በትንሹ ለሁለት ወራት በከፍተኛ ደረጃ በሰለጠኑ የIAAF አሰልጣኞች ይሠለጥናል።
- በአካባቢው ወይም በአገር አቀፍ ደረጃ በሚደረጉ ውድድሮች ይሳተፋሉ።
- የደምና የምራቅ ቴስት ውጤቶችን ተከትሎ የራሳቸው ወቅታዊ የደምና የበሽታ መካላከል መረጃዎችን ያገኛሉ።

- ለዚህ ምርመራ ለአንድ አትሌት ግምቱ 1400.00 የኢትዮጵያ ብር ይከፈላል።

- ለትራንስፖርትና ለውሀ የሚያወጡት ብር 900.00 በየወሩ ይከፈላል።
- በየልምምድ ወቅት ከቤት ወደ ልምምድ ስፍራ እንዲሁም ከልምምድ ስፍራ ወደ ቤት የሚመላለሱበት የትራንስፖርት አገልግሎት ይቀርባል።

ሚስጥራዊነትን በተመለከተ

ለዚህ ጥናት ሲባል የሚሰጥ ማንኛውም መረጃ ከጥናትና ምርምር እንዲሁም በተለያዩ የጥናት መፅሄቶች ላይ ለሚወጣ መረጃ ብቻ እንደሚውል እንዲሁም ማንኛውም የግል መረጃ በሚስጥር ኮድ ተለይቶ ይያዛል። ለጥናቱ ሲባል የሚሰበሰብ ማንኛውም የደም ናሙና በላቦራቶሪ ከተመረመረ በሁዋላ ወዲያው ይወገዳል። የምራቅ ናሙና ግን ከተሰበሰብ በሁዋላ በሚስሥጥር ተጠብቆ ለ6 ወራት በአዲስ አበባ ዩኒቨርሲቲ የጤና ሳይንስ ኮሌጅ በሚገኝ ላቦራቶሪ ሚስጥራዊነቱ ተጥብቆ ለ6ወራት ይቀመጣል። ምርመራውእንደተጠናቀቀ ወዲያው ይወገዳል። ሌሎች የሰውነት ልኬቶችና የብቃት ቴስት ውጤቶች ሚስጥራዊነታቸው ተጠብቆ የይለፍ ሚስጥር ባለው ካምፒውተር ለ5 ተከታታይ አመታት ይቀመጣል። ከተሳታፊዎችየሚገኝ ማንኛውም መረጃ ለጥናቱ አማካሪና ለዋናው ተተመራማ እጅ ብቻ ይያዛል። ሁሉም መጠይቆችና የመረጃ መሰብሰቢያ ቅጾች በዋናው ተመራማሪ ቢሮ ውስጥ ሚስጥራዊነቱ ተጠብቆ ይቀመጣል።

ከጥናቱ ስለመውጣት

ተሳታፊው በማንኛውም ወቅት ከጥናት አባልነቱ ወይም ተሳትፎው አቋርጦ መውጣት ቢፈልግ ያለምንም ቅድም ሁኔታ አቋርጦ መውጣት ይችላል።

ዳንኤል ኃ/የሱስ ዋና
ዋና ሥራ አስኪያጅ
Daniel H/Yesus Wana
General Manager

በጥናቱ ወቅት ከሚደረጉ ቴስቶች በፊት የሚከናወኑ ተግባራት

በልምምድ ወቅትም ይሁን ከቴስቶች በፊትና ከኋላ ማንኛቸውንም ሰው ሰራሽ አድገ ንጥር (Hormones) በተለይም EPO እንድን ንጥር፣ አነቃቂ ቅመሞችን፣ ሲጃራና አልኮል አለመውሰድ፤ ከባድ ልምምድ ማድረግና ብዙ አለመመገብ።

ሀላፊነትን ስለመውሰድ

በጥናቱ ወቅት ሊከስቱ የሚችሉ አደጋዎችን ለመቀነስ ከፍተኛ ጥንቃቄ ይደረጋል። ይህም ሆኖ ግን ከጥናቱ ጋር በተያያዘ ለሚከሰቱ አደጋዎች ወይንም ጉዳቶች የማስልጠኛ ማእከሉ የህክምና ወጪን ይሸፍናል።

ጥናቱን በተመለከተ ማንኛውም ተሳታፊ ጥያቄ ቢኖረውስ?

በጥናቱ የሚስተፍ ማንኛውም አትሌት በጥናቱ ሂደት ውስጥ ጥያቄ ቢኖረው ከሚከተሉትን አካላት ጋርበመደወል መረጃ ማግኘት ይቻላል።

ዘሩ በቀለ ቶላ በባዮ ካይኔቲክስ ኤክሰርሳይሰር ሌዥር ሳይንስ ዲፖርትመንት ኩዋዙሉ-ናታል ዩኒቨርሲቲ ስልክ ቁጥር +251911458414 ኢትዮጵያ +27843325620 ደቡብ አፍሪካ ኢሚል፡- tolazeru@gmail.com	ፕሮፌሰር አንድሪው ማኩኔ በስፖርትና ኤክሰርሳይስ ሳይንስ ዲስፕሊን ካንቤራ ዩኒቨርሲቲ አውስትራሊያ ኢሜል:- Andrew.mckune@canberra.edu.au	ባዮ ሜዲካል የምርምር ኤቲክስ አስተዳደር የምርምር ቢሮ ዌስት ቪል ካምፓስ ጉቫን ምቤኬ ህንፃ ፖ.ሣ.ቁ X54001 ደርባን 4000 ኩዋዙሉ ናታል, ደቡብ አፍሪካ ስልክ፡- +27312604769 ፋክስ፡- +27312604609 ኢሜል፡- BREC@ukzn.ac.za

ዳንኤል ኃ/የሱስ ዋና
ዋና ሥራ አስኪያጅ
Daniel H/Yesus Wana
General Manager

Appendix III: General Consent Form

Appendix II: General Informed Consent

I, ____ have been informed about the study entitled 'Long distance running in Ethiopian athletes: a search for the optimal altitude training program' by Zeru Bekele Tola.

1. I understand the purpose and procedures of the study.
2. I have had all medical risks explained to me.
3. I declare that my participation in this study is entirely voluntary and that I may withdraw at any time without affecting any treatment or care that I would usually be entitled to.
4. I understand that if I decide not to take part in this study or withdraw from the study at any time, there will be no disadvantage of any kind to me including my participation in any national and international competitions.
5. I have been informed about any available compensation or medical treatment if injury occurs to me as a result of study-related procedures.
6. If I have any further questions/concerns or queries related to the study I understand that I may contact the researcher at the given detail address.
7. I recognize my right to a copy of my test results and consent form if I so desire.
8. I understand that all information obtained is confidential.
9. I recognize that all the test results/data (both soft and hard copies) to be collected from questionnaires, anthropometric, hematological, saliva and time trial tests will be recorded/coded and stored for five years in password protected computer in an excel database.
10. I have been informed that I will be provided a medical cover if injury occurs to me as a result of study-related procedures.
11. I have been given an opportunity to answer questions about the study and have had answers to my satisfaction.
12. If I have any questions or concerns about my rights as a study participant, or if I am concerned about an aspect of the study or the researchers then I may contact:
    BIOMEDICAL RESEARCH ETIHICS ADMINISTRATION
    Research Office, Westville Campus
    Govan Mbeki Building
    Private Bag X 54001
    4000
    KwaZulu-Natal, SOUTH AFRICA
    Tel: 27 31 2604769 - Fax: 27 31 2604609
    Email: BREC@ukzn.ac.za

Signature of Participant	Date
Signature of Witness (Where applicable)	Date
Signature of Translator (Where applicable)	Date

Appendix IV: General Consent Form in Amharic (Translated)

መግለጫ II - የስምምነት ይሁንታ

እኔ____በጥናቱ ዋና ተመራማሪ ዘሩ በቀለ ቶላ "የረጅም ርቀት ሩጫ በኢትዮጵያን አትሌቶች፡- ከባህር ጠለል በላይ በሚገኙ የከፍታ ቦታዎች የሚደረግ ስኬታማ የልምምድ ኘሮግራም ጥናት" በሚል ርዕስ ስለሚደረግ ምርምር ገለፃ ተደርጉልኛል፡፡ በዚሁ መሰረት፡-

1. የጥናቱን ዓላማና አካሄድ /ቅደም ተከተል የተረዳሁ መሆኔ፤
2. በጥናቱ ወቅት ሊኖር ስለሚችል መለስተኛ ጉዳቶችና አደጋዎች የተገለፀልኝ መሆኑን፤
3. በዚህ ጥናት ለመካተት በሙሉ ፈቃደኝነት የተስማማሁ መሆኔን እንዲሁም በፈለግኩኝ ሰዓት ከጥናቱ ተሳታፊነት አቋርጬ መውጣት እንደምችል፤
4. በማንኛውም ሰዓት ከጥናት አባልነት አቋርጬ ብወጣ ምንም ዓይነት መገለልና መድሎ በብሄራዊ አለማቀፋዊ ውድድሮች መሳተፍን ጭምር የመሳተፍ መብት እንዳለኝ ተረድቼ፣
5. በጥናቱ ወቅት ስሳተፍ ለሚደርስብኝ ማንኛውም ጉዳት ለሚደርስብኝ የኩዋዙሉ ናታል ዩኒቨርሲቲ በኩል የዋስትና ጥያቄ ማቅረብ እንደማልችል ተረድቼ፣
6. በጥናቱ ወቅት ጥናቱን በተመለከተ ለሚነሱ ግልፅ ያልሆኑ ጥያቄዎች የሚመለከታቸውን (ጥናቱ የሚመለከታቸውን) አካላት ዋና ተመራማሪ አድራሻ መሠረት መገናኘት እንደሚቻል፤
7. የቴስት ውጤቶቼንና የዚህን ስምምነት ቅጽ ኮፒ እንደሚሰጠኝ ወይንም እንዲሰጠኝ በጠየኩኝ ጊዜ እንደሚሰጠኝ ተረድቼ፤
8. የምሠጠው ማንኛውም የደምና የምራቅ ናሙና ሚስጥራዊነቱ ተጠብቆ እንደሚቆይ ተረድቼ፣
9. ለጥናቱ ሲባል የሰጠሁት ማንኛውም መረጃ ሚስጥራዊነቱ በተጠበቀ፣ አስተማማኝ በሆነ ሁኔታ በይለፍ የሚስጥር በሚከፈት ኮምፒውተር ለ5 ተከታታይ አመታት እንደሚቀመጥ አውቄ፤
10. በጥናቱ ወቅት ከጥናቱ ጋር ተያይዞ ለሚከሰት ማንኛውም ጉዳት የልምምድ ማእከሉ የህክምና ሽፋን እንደሚችለኝ ተረድቼ፣
11. ማብራሪያና መልስ ለሚያስፈልጋቸው ጥያቄዎች በቂ ምላሽና ማብራሪያ የተሠጠኝ መሆኑ፤በጥናቱ ወቅት ለጥናቱ ማካሄጃ የሚያስፈልግ በግሌ ያወጣሁ ገንዘብ እንደሚተካልኝ እንዲሁም፤
12. በጥናቱ ውስጥ በምሳተፍበት ወቅት ከጥናቱ ለሚነሱ የአሠራር ግልፅነት ወይንም የመብት ጥሰት በሚከተለው አድራሻ መጠቆም እንደምችል፡፡

ባዮ ሜዲካል የምርምር ኤቲክስ አስተዳደር
የምርምር ቢሮ ዌስት ቪል ካምፓስ
ጐቫን ምቤኬ ህንፃ
ፖ.ሣ.ቁ X54001 ደርባን 4000
ኩዋዙሉ ናታል, ደቡብ አፍሪካ
ስልክ፡- +27312604769 ፋክስ፡- +27312604609
ኢሜል፡- BREC@ukzn.ac.za

____________________ ____________________
የተሳታፊው ፊርማ ቀን

____________________ ____________________
የታዛቢ ፊርማ ቀን

____________________ ____________________
የተርጓሚው ፊርማ ቀን

5

ዳንኤል ኃ/የሱስ ዋና
ዋና ሥራ አስኪያጅ
Daniel H/Yesus Wana
General Manager

Appendix V: Consent Form for Haematology Samples

Appendix III:

Informed Consent for Blood (Ferritin, Hematocrit, and Hemoglobin) and Saliva (Cortisol, SIgA and Alpha-amylase) Tests

I, ____, hereby authorize the laboratory the principal investigator to draw a sample of my blood for ferritin, hematocrit and hemoglobin and saliva sample for cortisol, SIgA and alpha-amylase testing as part of the study entitled 'Long distance running in Ethiopian athletes: a search for the optimal altitude training program'.

1. I understand that my participation in the procedure is entirely voluntary.
2. I recognize that blood samples will be drawn four times.
3. I understand that saliva sample collection procedure require unstimulated and will be performed four times throughout the study and three times each day.
4. I understand that blood collection procedures involve venipuncture and the risk involved.
5. I recognize my right for refusal or to withdraw from the program at any time.
6. I recognize my right to a copy of my test results and consent form if I so desire.
7. I understand that all information obtained is confidential.
8. I authorize release of ferritin, hematocrit and hemoglobin testing results only to the principal investigator. Other requests for results will be released only with my signed consent.
9. I authorize release of salivary cortisol, SIgA and alpha-amylase testing results only to the principal investigator. Other requests for results will be released only with my signed consent.
10. I understand that this authorization does not expire unless canceled in writing by the undersigned.
11. I understand I have the right to retain a copy of this authorization. I understand that I have the right to withdraw this authorization at any time by writing to:

    Biomedical Research Ethics Administration
    Research Office, Westville Campus
    Govan Mbeki Building
    Private Bag X 54001
    4000
    KwaZulu-Natal, SOUTH AFRICA
    Tel: 27 31 2604769 - Fax: 27 31 2604609
    Email: BREC@ukzn.ac.za

My signature below indicates that:

I have read or have had read to me, the above information and I understand it. I have had an opportunity to discuss it and my questions have been answered.

______________________ ______________________

Signature of Participant Date

Appendix VI: Consent Form for Haematology Sample in Amharic (Translated)

መግለጫ III - <u>የደምና የምራቅ ናሙናን ለምርመራ ስራ ለመስጠት የተደረገ የይሁንታ ቅፅ</u>

እኔ_________________________ “የረጅም ርቀት ሩጫ በኢትዮጵያን አትሌቶች ከባህር ጠለል በላይ በሚገኙ የከፍታ ቦታዎች የሚደረግ ስኬታማ የልምምድ ኘሮግራም ጥናት” በሚል ርዕስ ለሚደግ ጥናት የደምና የምራቅ ናሙና ለመስጠት ስወስን፤

1. በጥናቱ ለመካተት ሙሉ ፈቃደኛ መሆኔን ተረድቼ፣
2. የደም ናሙና ለአራት ጊዜ ለመስጠት ተስማምቼ፣
3. የምራቅ ናሙና ለአራት የተለያዩ ጊዜያት እንደምሰጥ ተረድቼ፣
4. የደም ናሙና በሚወሰድበት ጊዜ መጠነኛ የሆነ ህመም እንደሚኖር አውቄ፣
5. በማንኛውም ጊዜ ከጥናቱ መውጣት እንደምችል አውቄ፣
6. በፈለኩኝ ሰዓት የዚህ የይንታ ስምምነት ቅፅንና የደምና የምራቅ ናሙና ቴስት ውጤቶችን ማግኘት እንደምችል ተገንዘቤ፣
7. የምሠጠው ማንኛውም የደምና የምራቅ ናሙና ሚስጥራዊነቱ ተጠብቆ እንደሚቆይ ተረድቼ፣
8. ከደም ናሙና የሚገኙ የቴስት ውጤቶች ለዋናው ተመራማሪ እንዲሰጥ ፈቅጄ ነገር ግን ከዚያ ውጪ ባሉ ነገሮች ያለኔ ፈቃድ እንደማይሰጥ ተረድቼ፣
9. ከምራቅ ናሙና የሚገኙ የቴስት ውጤቶች ለዋናው ተመራማሪ እንዲሰጥ ፈቅጄ ነገር ግን ከዚያ ውጪ ባሉ ነገሮች ያለኔ ፈቃድ እንደማይሰጥ ተረድቼ፣
10. ይህ የይሁንታ ውል በፅሁፍ ካልሆኑ እንደማይሰረዝ ተገንዝቤ፣
11. በማንኛውም ሰዓት በፈቃዴ ለመስጠት የተስማማሁትን በፅሁፍ

    ለባዮሜዲካል የምርምር ሥነ-ምግባር አስተዳደር
    የምርምር ቢሮ፤ ዌስትቪል ካምፓስ
    ጐቫን ምቤኪ ህንፃ
    ፖ.ሣ.ቁ X54001
    4000 ኩዋዙሉ ናታል፤ ደቡብ አፍሪካ
    የስ.ቁ፡ +27312604769 - ፋክስ፡ +27312604609
    ኢሜል፡ BREC@ukzn.ac.za በመፃፍ

ከዚህ በላይ የተዘረዘሩትን ነጥቦች በአግባቡ አንብቤ ወይንም ተነቦልኝ እንዲሁም ከዋናው ተመራማሪ ጋር ተወያይቼና ላልገቡኝ ጥያቄዎች በቂ ማብራሪያ ተሰጥቶኝ የፈረምኩ መሆኔን አረጋግጣለሁ።

_____________________ _____________________

ፊርማ ቀን

6

ዳንኤል ሀ/የሱስ ዋና
ዋና ሥራ አስኪያጅ
Daniel H/Yesus Wana
General Manager

Appendix VII: Questionnaire for Demographic Study

UNIVERSITY OF KWAZULU-NATAL

University of KwaZulu-Natal College of Health Sciences Department of Biokinetics, Exercise and Leisure Sciences

Introduction

Dear respected athlete,

First of all, I would like to thank you in advance for your willingness to participate in this study. The purpose of this study is to assess and compare the differences in some selected demographic characteristics among retired, current elite and junior Ethiopian long distance athletes. The study is designed to include elite level endurance runners who were and are members of the Ethiopian athletics national team and those who are training in the national athletics training center run under the Ethiopian Youth Sport Academy. All the necessary information to be obtained from you will be used only for research purpose and the output of the study may be disclosed and published in research journals keeping your identity confidential.

Instruction

Put a '√' mark in the box in front of the given response that expresses you.

Part I: Personal Characteristics

1. Sex ☐ Male ☐ Female
2. Age __________
3. Education Level

   ☐ ≤ Grade 6 ☐ 7 – 8 ☐ 9 – 10 ☐ 11 – 12 ☐ >12

4. Family Size ____________
5. Recent athletics status

   ☐ Retired ☐ Current Elite ☐ Academy Junior

Part II: Demographic characteristics

1. Place of birth

☐ Arsi ☐ West – Shoa ☐ Gojam ☐ Tigray ☐ Benishangul

☐ North-Shoa ☐ Addis Ababa ☐ South-Shoa ☐ Wollo ☐ Others

2. Altitude at birth _______________

3. Is the altitude raised at childhood different from altitude at birth?

   ☐ Yes ☐ No

4. If your answer for question no. 3 (Part II) is yes, please mention____

5. Frequent mode of transportation to and from school during primary education

   ☐ Always walking ☐ Walking and sometime jogging ☐ Frequently jogging

   ☐ Running ☐ Transportation

6. Daily distance travelled to and from school during primary education in kilometer

   ____

7. Average time to cover distance travelled to and from school during primary education in minutes __________________________

8. Frequent mode of transportation to and from school during secondary education

   ☐ Always walking ☐ Walking and sometime jogging ☐ Frequently jogging

   ☐ Running ☐ Transportation and walking

9. Daily distance travelled to and from school during secondary education in kilometer ____

10. Average time to cover distance travelled to and from school during secondary education in minutes____

11. Region where you are represented before joining the national team

☐ Central Ethiopia ☐ North and North-West Ethiopia

☐ Western Ethiopia ☐ South and South-West Ethiopia

12. Dominant out-of-school activities during childhood

☐ Housework ☐ House work & water fetching ☐ Housework &Cattle

☐ Farming ☐ Cattle Herding ☐ Farming & Cattle Herding

☐ Housework & Other activities ☐ Farming and Other activities

13. Track and road races most frequently participated in international competitions (Put a '√' Mark)

Event	Yes	No
800m		
1500m		
2000m		
3000m		
5000m		
10000m		
Half-marathon		
Marathon		
Others		

Dear respected athlete, I thank you again!

Appendix VIII: Questionnaire for Demographic Study (Amharic Version)

አርማ

ክዋዙሉ-ናታል ዩኒቨርሲቲ

ክዋዙሉ-ናታል ዩኒቨርሲቲ የሂውማኒቲስ፣ ሊዠርሳይዝና

ሊይዠር ሳይንስ ጤና ሳይንስ መመሪያ ኮሌጅ

መግቢያ

የተከበሩ አትሌት፣

በቅድሚያ በዚህ ጥናት ላይ ለመሳተፍ ፈቃደኛ ስለሆኑ እናመሰግናለን። የዚህ ጥናት ዓላማ ሩጫ ያቋረጡ፣ በአሁኑ ጊዜ ታዋቂ የሆኑትን እና ታዳጊ የሆኑ እና ከተለያዩ ስፍራዎች የተመረጡትን የኢትዮጵያ የረዥም ርቀት ሯጮች ላይ ጥናት ለማካሄድ እና ለማወዳደር ነዉ። ይህ ጥናት ብቁ የሆኑትን አትሌቶች እና የኢትዮጵያ ብሔራዊ አትሌቲክስ ፌዴሬሽን አባላት የሆኑት እና በኢትዮጵያ ስፖርት አካዳሚ ስር የሚሰለጥኑትን ለማሳተፍ ያቀደ ነዉ። ከእርስዎ የሚገኘዉ ማንኛዉም መረጃ ለጥናት ዓላማ የሚዉልና ከዚህ ጥናት የሚገኝ ውጤትም በሚስጥራዊነት ተይዞ በጥናት መፅሔት ውስጥ ለህትመት ይውላል።

መመሪያ፡ያንብቡ

በመረጡት ምርጫ ላይ "√ "ያድርጉ።

I: የግል መረጃ

1. ፆታ ወንድ☐ ☐ሴት
2. ዕድሜ:____________________________
3. የትምህርት ደረጃ
   ☐ 6 ክፍል እና ከዚያ በታች ☐ከ7-8 ☐9-10 ☐11-12 ☐ከ12ክፍል በላይ
4. የቤተሰብ ብዛት:________________________
5. አትሌቱ አሁን ያለበት ሁኔታ
   ☐ሩጫ ያቆመ ☐በአሁኑ ጊዜ ብቃት ያለዉ ☐አካዳሚ የገባ

ዩኒቨርሳል ትርጉም ቤት
Universal Translation Office

ክፍል II: የአኗኗር ሁኔታ

1. የተወለዱበት ቦታ

   ☐አርሲ ☐ምዕራብ ሸዋ ☐ጎጃም ☐ትግራይ ☐ቤንሻንጉል

   ☐ሰሜን ሸዋ ☐አዲስ አበባ ☐ደቡብ ሸዋ ☐ወሎ ☐ሌሎች

2. የተወለዱበት ቦታ ከፍታ:______________________

3. በሕፃንነት የነበረዉ የቦታ ከፍታ አሁን ከፍታ አሳይቷል ወይ?

   ☐አዎ ☐አይደለም

4. ለተራ ጥር 3 (ክፍል II)አዎ ከሆነ፣ እባክዎን4 ይግለፁ:____

5. አንደኛ ደረጃ ት/ት በሚማሩበት ጊዜ ወደ ት/ቤት ለመሄድና ለመመለስ በአዘውትሮ የሚጠቀሙበት የትራንስፖርት ዘዴ የትኛዉ ነዉ?

   ☐ሁል ጊዜ በቀስታ መሄድ ☐በቀስታ መሄድ ወይም አንድ አንድ በቀስታ በመሮጥ ☐ሁል ጊዜ የቀስታ ሩጫ

   ☐ሩጫ ☐ትራንስፖረትና የእግር ጉዞ

6. አንደኛ ደረጃ ት/ት በሚማሩበት ጊዜ ወደ ት/ቤት ለመሄድና ለመመለስ የሚፈጀዉ ርቀት በኪ.ሜ

   ____

7. አንደኛ ደረጃ ት/ት በሚማሩበት ጊዜ ወደ ት/ቤት ለመሄድና ለመመለስ የሚፈጀዉ ደቂቃዎች ብዛት____

8. ሁለተኛ ደረጃ ት/ት በሚማሩበት ጊዜ ወደ ት/ቤት ለመሄድና ለመመለስ በአዘውትሮ የሚጠቀሙበት የትራንስፖርት ዘዴ የትኛዉ ነዉ?

   ☐ሁል ጊዜ በቀስታ መሄድ ☐በቀስታ መሄድ ወይም አንድ አንድ በቀስታ በመሮጥ ☐ሁል ጊዜ የቀስታ ሩጫ

   ☐ሩጫ ☐ትራንስፖረትና የእግር ጉዞ

9. ሁለተኛ ደረጃ ት/ት በሚማሩበት ጊዜ ወደ ት/ቤት ለመሄድና ለመመለስ የሚፈጀዉ ርቀት በኪ.ሜ

____

10. ሁለተኛ ደረጃ ት/ት በሚማሩበት ጊዜ ወደ ት/ቤት ለመሄድና ለመመለስ የሚፈጀዉ ደቂቃዎች

ብዛት______________________________________

11. ወደ ብሔራዊ ቡድን ከመግባትዎ በፊት የወከሉት አካባቢ የት ነዉ?

☐መካከለኛ ኢትዮጵያ ☐ሰሜን እና ሰሜን ምዕራብ ኢትዮጵያ/የሠምዕራብ

☐ምዕራብ ኢትዮጵያ ☐ደቡብ እና ደቡብ ምዕራብ ኢትዮጵያ

12. በልጅነትዎ ጊዜ ከት/ቤት በኋላ አዘውትሮ ሲፈፅሙ የነበሩት ተግባራት፡ -

☐የቤት ሥራ ☐የቤት ሥራና ውኃ መቅዳት ☐የቤት ስራና እረኝነት

☐እርሻ ☐እረኝነት ☐እርሻ እና እረኝነት

☐የቤት ስራና ሌሎች ☐እርሻና ሌሎች ሥራዎች

13. በዓለም ዓቀፍ መድረክ ላይ በትራክ እና በጎዳና በሚሳተፉበት ርቀት ላይ የሚወዳደሩበት ላይ (√ ምልክት አድርጉ)

ርቀት	አዎ	አይደለም
800ሜ		
1500ሜ		
2000ሜ		
3000ሜ		
5000ሜ		
10000ሜ		
ግማሽ ማራቶን		
ማራቶን		
ሌሎች		

ክቡር አትሌት፣ እናመሰግናለን

Appendix IX: Questionnaire for Demographic Study (Afan Oromo Version)

YUUNIVARSITII KWAZULU-NATAL

KOOLLEEJI FAYYAA MUUMMEE BAAYOKAAYINEETIIKSII, EKSARSAAYISII FI SAAYINSII LEEYIZYARII YUUNIVARSITII KWAZULU-NATAL

Seensa

Kabajamoo Atileetii,

Duraan dursee qo'annaa kana irratti hirmaachuudhaaf heeyyamamoo waan taataniif isin galateeffanna. Kaayyoon qo'annaa kana Atileetota Fageenya Fagoo Itoophiyaa kan fiigicha dhaaban, kan yeroo ammaa beekkamoo ta'anii fi guddataa jiran iddoowwan garaagaraa irraa filataman irratti qorannaa geggeessuu fi wal madaalsisuu dha.Qo'annaan kuni atileetota beekkamoo gahuumsa gahaa ta'e qabanii fi miseensa Federeeshinii Atileetiksii Biyyoolessaa fi Akkaadamii Ispoortii Dargaggoo Itoophiyaa jalatti leenjii'an hirmaachisuudhaaf karoorfatee jira. Odeeffannoon isin irraa argamu kamiyyuu faayidaa qo'annaatiif kan ooluu fi bu'aan qo'annaa kana irraa argamus iccitiidhaan kan eeggamu ta'ee barruulee qo'annaa keessatti kan barreeffamu ta'a.

Qajeelfama:

Filannoo filattan irratti mallattoo "√ " kaa'aa.

Kutaa I: Amala Dhuunfaa

1. Saala ☐ Dhiira ☐Dhalaa
2. Umurii:____________________________

3. Sadarkaa Barnootaa

☐ Kutaa 6 fi isaa gadi ☐7-8 ☐9-10 ☐11-12 ☐12 ol

4. Baay'ina Maatii:____________________

5. Haala Atileetiin amma irra jiru

☐Fiigicha kan dhaabe ☐Yeroo ammaa gahuumsa kan qabu ☐Akkadamii kan eegale

Kutaa II: HaalaJireenyaa

1. Iddoo Itti Dhalate

   ☐Arsi ☐Shawaa Lixaa ☐Gojjaam ☐Tigraay ☐Beenishangul ☐Shawaa Kaabaa ☐Finfinnee ☐Shawaa Kibbaa ☐Walloo ☐Kan Biroo

2. Iddoo itti dhalattanitti Ol-fageenya iddichaa:______________________

3. Ol –fageenya iddoo itti dhalattan kan itti guddattan ni caalaa?

   ☐Eyyee ☐Lakkii

4. Yoo deebiin keessan gaaffii lakk. 3(Kutaa II) eyyee, yoo ta'e, maaloo ibsaa:____

5. Yeroo barnoota sadarkaa duraatti gara mana barnootaatti fi deebi'uuf irra deddeebiidhaan geejjiba kam fayyadamtuu?

   ☐Yeroo hunda miilaa suuta deemuu ☐Miilaan suuta deemuu ykn yeroo tokko tokko fiigicha suutaa ☐Yeroo hedduu fiigicha suutaa ☐Fiigicha

   ☐Geejjibaa fi Deemsa miilaa

6. Yeroo barnoota sadarkaa duraatti gara mana barnootaatti fi deebi'uuf irra deddeebiidhaan fageenya kiiloomeetiraa

----
------

7. Yeroo barnoota sadarkaa duraatti gara mana barnootaatti fi deebi'uuf irra deddeebiidhaan baa'ina daqiiqaawwan fudhatu

----
------

8. Yeroo barnoota sadarkaa lammaffaatti gara mana barnootaatti fi deebi'uuf irra deddeebiidhaan geejjiba kam fayyadamtuu?
☐Yeroo hunda miilaa suuta deemuu ☐Miilaan suuta deemuu ykn yeroo tokko tokko fiigicha suutaa ☐Yeroo hedduu fiigicha suutaa ☐Fiigicha
☐Geejjibaa fi Deemsa miilaa
9. Yeroo barnoota sadarkaa lammaffaatti gara mana barnootaatti fi deebi'uuf irra deddeebiidhaan fageenya kiiloomeetiraa

----
------

10. Yeroo barnoota sadarkaa lammaffaatti gara mana barnootaatti fi deebi'uuf irra deddeebiidhaan baa'ina daqiiqaawwan fudhatu

----
------

11. Garee biyyoolessaa kana osoo hin seeniin dura Naannoon bakka buutan essaa?
☐Giddu Gala Itoophiyaa ☐Kaabaa fi Kaaba Lixa Itoophiyaa
☐Lixa Itoophiyaa ☐Kibbaa fi Kibba Lixa Itoophiyaa
12. Yeroo ijoolummaa hojii mana barnootaan ala hedduumminaan raawwachaa turtan:

☐Hojii Manaa ☐Hojii Manaa fi Bishaan Waraabuu☐Hojii Manaa fi Tika

☐Qonna ☐Tika ☐Qonnaa fi Tika

☐Hojii Manaa fi Hojiilee Biroo ☐Qonnaa fi Hojiilee Biroo

13. Dorgoommiiwwan Idila Addunyaa irratti hedduumminaan tiraakii fi dorgoommii daandiiwwanii hirmaattan (Mallattoo √ kaa'aa)

Fageenya	Eyyee	Lakkii
800m		
1500m		
2000m		
3000m		
5000m		
10000m		
Walakkaa Maaraatoonii		
Guutuu Maaratoonii		
Kanneen Biroo		

Kabajamoo Atileetii, Galatoomaa!

Appendix X: Daily Menu Recording Form

ATHLETE TIRUNESH DIBABA NATIONAL ATHLETICS TRAINING CENTRE

DAILY MEAL RECORDING FORMAT

CODE________________________DATE__________________________

TIME	FOOD TYPE /COMPOSITION	WEIGHT BEFORE	WEIGHT AFTER	DIFFERENCE	REMARK
BREAKFAST					
LUNCH					
DINNER					
OTHER IN THE CAMP					
OTHER OUT OF CAMPUS					

Appendix XI: Weekly Menu

ATHLETE TIRUNESH DIBABA NATIONAL ATHLETICS TRAINING CENTRE

WEEKLY MENU

Days	Breakfast	Lunch	Dinner
Monday	Fried egg	Enjera	Macaroni
	Whole grain bread	Beef Sauce	Vegetable Sauce (Potato, Carrot, Cabbage)
	Besso Solution (Barely powder + water+ sugar)	Banana	
	Tea		
Tuesday	Boiled Wheat – split	Lamb Sauce	Spaghetti
	Whole-grain bread	Bread	Tomato Sauce
	Tea	Enjera	Bread
			Tuna
Wednesday	Strawberry Jam	Enjera	Rice
	Bread	Shiro/Pea Sauce	Vegetable Sauce
	Tea	Kik Wet/Split pea	Bread
		Vegitable Sauce/Potato, carrot, cabbage	
		Banana	
Thursday	Minestrone	Spaghetti	Enjera
	Bread	Tomato Sauce	Lamb Sauce
	Tea	Bread	Bread
		Tuna	
Friday	Strawberry Jam	Enjera	Rice
	Bread	Shiro/Pea Sauce	Vegetable Sauce
	Tea	Kik Wet/Split pea	Bread
		Vegitable Sauce/Potato, carrot, cabbage	
		Banana	
Saturday	Fried egg	Macaroni	Enjera
	Bread	Tomato Sauce	Beef Sauce
	Tea	Bread	
		Tuna	
Sunday	Oat Soup	Spaghetti	Rice
	Bread	Tomato Sauce	Beef Sauce
	Tea	Bread	Bread

Appendix XII: Daily Training Load Monitoring and Training Diary

ATHLETE TIRUNESH DIBABA NATIONAL ATHLETICS TRAINING CENTRE

TRAINING DIARY/INDIVIDUAL TRAINING LOAD MONITORING FORMAT

Month:________ Week:_____ Date:___________

Training Time:________ Altitude___________ Training Venue___________

Training Venue Type: (Track, Asphalt, Grass, Gravel, Forest, short Hill, Long Hill)

No.	Code	Attendance	Total Training Duration	Total Distance Covered	RPE response	No. of Sets	No. of Reps	Injury Report in the middle of training	Injury Type	Injury report at the end of training	Remark
1											
2											
3											
4											
5											
6											
7											
8											
9											
10											
11											
12											
13											
14											
15											
16											
17											
18											
19											
20											
21											
22											

Appendix XIII: Biomedical Research Ethics Committee (BREC) Approval

UNIVERSITY OF KWAZULU-NATAL
INYUVESI YAKWAZULU-NATALI

16 October 2015

Mr ZB Tola (214555352)
Biokinetics, Exercise and Leisure Sciences
School of Health Sciences
tolazeru@gmail.com

Protocol: Long distance running in Ethiopian athletes: a search for the optimal altitude training program.
Degree: PhD
BREC reference number: BFC193/15

The Biomedical Research Ethics Committee (BREC) has considered the abovementioned application at a meeting held on 12 May 2015.

The study was provisionally approved pending appropriate responses to queries raised. Your response dated 07 October to BREC letter dated 30 June 2015 has been noted and approved by a sub-committee of the Biomedical Research Ethics Committee.

This approval is valid for one year from **16 October 2015.** To ensure uninterrupted approval of this study beyond the approval expiry date, an application for recertification must be submitted to BREC on the appropriate BREC form 2-3 months before the expiry date.

Any amendments to this study, unless urgently required to ensure safety of participants, must be approved by BREC prior to implementation.

Your acceptance of this approval denotes your compliance with South African National Research Ethics Guidelines (2015), South African National Good Clinical Practice Guidelines (2006) (if applicable) and with UKZN BREC ethics requirements as contained in the UKZN BREC Terms of Reference and Standard Operating Procedures, all available at http://research.ukzn.ac.za/Research-Ethics/Biomedical-Research-Ethics.aspx. BREC is registered with the South African National Health Research Ethics Council (REC-290408-009). BREC has US Office for Human Research Protections (OHRP) Federal-wide Assurance (FWA 678).

Pg. 2/...

The following Committee members were present at the meeting that took place on 12 May 2015:

Prof J Tsoka-Gwegweni	Chair
Dr C Aldous	Genetics
Dr T Hardcastle	Surgery - Trauma
Dr Z Khumalo	KZN Health (External) General Medicine
Dr K Naidoo	Family Medicine
Dr G Nair	HIV - Medicine
Dr A Noorbhai	Surgery
Prof V Rambiritch	Pharmacology (Deputy Chair)
Dr S Singh	Dentistry

We wish you well with this study. We would appreciate receiving copies of all publications arising out of this study.

Yours sincerely

PROFESSOR J Toska-Gwegweni
Chair: Biomedical Research Ethics Committee

cc: supervisor: mckunee@ukzn.ac.za

Appendix XIV: Local Research Ethics Committee Approval

COLLEGE OF NATURAL SCIENCES
Addis Ababa University

OFFICE OF THE DEAN
የዲን ጽ/ቤት

የተፈጥሮ ሳይንስ ኮሌጅ
አዲስ አበባ ዩኒቨርሲቲ

Ref:
ቁጥር: CNSDO/20/08/15
Date:
ቀን: October 1, 2015

To Whom It May Concern

The Ethical Committee of the College of Natural Sciences in its meeting held on September 30,2015 (Minutes: CNS-IRB/018/2015) has examined the PhD dissertation project of **Mr. Zeru Bekele Tola**, entitled **'Long distance running in Ethiopian athletes: a search form the optimal altitude training program'**. The Proposal is approved for implementation.

With regards,

Negussie Retta, (Professor)
Dean, College of Natural Sciences

Encl: RERC minutes

Appendix XV: Gatekeeper Letter

የኢትዮጵያ ወጣቶች የስፖርት አካዳሚ
ETHIOPIAN YOUTH SPORT ACADEMY

ቁጥር / Ref. 1.1/EYSA/5-4/6
ቀን / Date 25/12/2014

To: Biomedical Ethical Committee

College of Health Sciences

University of KwaZulu-Natal

Subject:- Letter of Support to Conduct Study

Athlete Tirunesh Dibaba National Athletics Training Centre is a national training center that is run under the Ethiopian Youth Sport Academy of Ethiopia. aAt this time a total of 171 athletes who are selected from all over the country are taking training in running, jumping and throwing events.

Currently, one of your PhD candidates, Zeru Bekele Tola has requested our sport training center to conduct his PhD study under a title "Long distance running in Ethiopian athletes: a search for the optimal altitude training program". The candidate has a plan to recruit our 30 middle and long distance athletes as a study subjects. Taking the importance of the study for our country into consideration the training centre has fully accepted his request and is committed to support his study through availing the study subjects although the final decision to participate in the study is determined by individual subjects. Meanwhile, we would like to inform the committee that the training centre is well equipped with medical clinic and the training is provided with qualified coaches.

Sincerely,

GEBREGEBREAL MEZGEBO
Ethiopian Youth Sports Academy
V/General Director

ETHIOPIAN YOUTH SPORTS ACADEMY

Department of Biokinetics, Exercise and Leisure Sciences

Durban

Mr. Zeru Bekele Tola

Durban

Appendix XVI: Letter of Evidence for conducting the study

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Date JULY.5, 2017

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Ethiopian Youth Sports Academy
Athlete Tirunesh Dibaba Sport Training
Center

To: University of Kwazulu-Natal

College of Health sciences

Department of Biokinetics, Leisure and Exercise Science

Subject: Letter of Evidence

Mr Zeru bekele, one of your University Phd candidates, has asked our office (application letter dated on July o4, 2017) to write a letter of support that states his stay in our training centre for data collection.

This is, therefore, to certify that Mr Zeru had been engaged in data collation for his experimental study entitled 'Long Distance Running in Ethiopian Athletes: a search for optimal altitude training' since November 2016 to February 2017. During his stay in our training center he collected all the necessary data from 21 long distance trainees. Finally, I wish Mr Zeru Bekele all the best in his study and come up with very useful research outcomes that can contribute for the development of athletics in the country.

Ministry of Youth and Sport
Athlete Tirunesh Dibaba National Athletics
Training Center
Asela

With Regard,

Gosa Molla

Education Training competition and Research vice Director

022331 7718/022331 7722/0223317723 Fax. 022331 7719 ✉ 615
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Appendix XVII: Daily Training Session Tracking Form

Date________________ Training Venue______________ Altitude _______________Time______

Distance ____________ Training area type (Track, Grass, Gravel, Asphalt, Hill,

Name	Training Duration	Distance Covered per session	Pain/Injury Report before training	Injury Time during Training (if any)	Injury Type	Pain or injury	Session RPE Response (1-10)

Appendix XVIII: Modified Categorical Ratio of Perceived Exertion Scale

Rating	Descriptor
0	Rest
1	Very, Very Easy
2	Easy
3	Moderate
4	Somewhat Hard
5	Hard
6	
7	Very Hard
8	
9	
10	Maximal

Appendix XIX: Modified Categorical Ratio of Perceived Exertion Scale in Amharic

ልኬት	መግለጫ
0	እረፈት
1	በጣምበጣምቀላል
2	ቀላል
3	መካከለኛ
4	በመጠኑከባድ
5	ከባድ
6	
7	በጣምከባድ
8	
9	
10	ከአቅምበላይ