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Effects of Uphill Training on Bio-motor Skills, Physiological, and Biomechanical Metrics of Moderately Trained Middle-Distance Runners

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BAHIR DAR UNIVERSITY
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By:
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January 2026,
Bahir Dar

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Effects of Uphill Training on Bio-motor Skills, Physiological, and Biomechanical Metrics of Moderately Trained Middle-Distance Runners

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A dissertation submitted

in Partial Fulfillment of the Requirements for the Degree of Doctor of Philosophy in Athletics Coaching

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January 2026,

BAHIR DAR

Declaration

This is to certify that the dissertation entitled “Effects of Uphill Training on Bio-motor skills, Physiological, and Biomechanical Metrics of Middle-Distance Runners”, submitted in partial fulfillment of the requirements for the degree of Doctor of Philosophy in Athletics Coaching, Department of sport science, Bahir Dar University, is a record of original work carried out by me and has never been submitted to this or any other institution to get any other degree or certificates. The assistance and help I received during the course of this investigation have been duly acknowledged.

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Approval of Dissertation/Thesis for Defense

I hereby certify that I have supervised, read, and evaluated this dissertation titled **"Effects of Uphill Training on Bio-motor skills, Physiological, and Biomechanical Metrics of Middle-Distance Runners"** by Yehualaw Alemu prepared under my guidance. I recommend the dissertation be submitted for oral defense.

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Approval of Dissertation for defense result

As members of the board of examiners, we examined this dissertation entitled "Effects of Uphill Training on Bio-motor Skills, Physiological, and Biomechanical Metrics of Middle-Distance Runners**"** by *Yehualaw Alemu.* We hereby certify that the dissertation is accepted for fulfilling the requirements for the award of the degree of "phylosophy in Athletics coaching".

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Chair person's name	Signature	Date
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Table of contents

LIST OF FIGURES

LIST OF TABLES

LIST OF ACRONYMS AND ABBREVIATIONS

Item	Description
%SaO2	Percent arterial oxygen saturation
%VO_2max	Fractional utilization of maximal oxygen uptake
(Ca – CvO2) max	Maximal arterial venous oxygen content difference
(CaO2)	Arterial oxygen content
ADP	Adenosine diphosphate
ATP	Adenosine triphosphate
a-v O2	Arterio-venous oxygen difference
BM	Body mass
BMI	Body mass index
CK	Creatine kinase
CG	Control group
CMJ	Counter movement jump
CoM	Center of mass
Cr	Energy coast of running
CT	Contact time
DNA	Deoxyribonucleic Acid
DOMS	Delayed-onset muscle soreness
DR	Downhill running
DV	Dependent variable
EMG	Electromyography
FIO2	Fraction of inspired oxygen
FT	Flight time
GCT	Ground contact time
GRF	Ground reaction force
Hb	Arterial hemoglobin contents
HIIT	High-intensity interval training
HRmax	Maximal heart rate
HRR	Recovery heart rate

HRV	Heart rate variable
IHG	Intermediate hill group
ISSN	International Society of Sports Nutrition
IV	Independent variable
J/kg/m	Joule per kilogram per minute
L/m	Litre per minute
LA	Lactate accumulation
LR	Level running
LT	Lactate threshold
MHR	Maximal heart rate
$mL/kg^{-1}/min^{-1}$	Millilitre per kilogram per minute
MLSS	Maximal lactate steady state
NADH	Nicotinamide adenine dinucleotide
PFK	Phospho-fructose kinase
PO2	Partial pressure of oxygen
RE	Running economy
RED-S	Relative energy deficiency in sports
RHR	Resting heart rate
RM-ANOVA	Repeated measure-Analysis of Variance
SE	Strength endurance
SHG	Shallow Hill Group
SSC	Stretch–shortening cycle
SL	Step length
SR	Step rate
ST	Strength training
STHG	Steeper hill group
SVmax	Maximal stroke volume
T_{lim}	Time limit
TT	Time trial
UR	Uphill running

vAT	Velocity at the anaerobic threshold
Vmax	Maximal velocity
VO_2max	Maximal oxygen consumption
vVO_2max	Minimum velocity at VO2max

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Abstract

Numerous academics and research findings have described the purpose and benefits of hill training. However, the current body of knowledge is insufficient to confidently inform the formulation of suggestions that explain which hills repeat, long-gradual, intermediate or short-steeps provide the most benefits. Therefore, the aim of this study was to investigate the effects of eight-week uphill training: shallow hill training (~ 2.5%), intermediate hill training (~ 5.1%), and steeper hill training (~ 7.6%) on bio-motor skills (maximal velocity, running performance, and strength endurance performance), physiological (maximal oxygen consumption, the velocity at maximal oxygen consumption, resting heart rate, and recovery heart rate), and biomechanical (step rate, step length, contact time, and flight time) of middle-distance runners. A pre-post parallel true experimental research design was employed. Forty moderately trained middle-distance runners were selected using a cencus sampling technique and randomly assigned to the three intervention groups, or control groups (n = 10 each). Over 8 weeks, participants completed gradient-specific training and outcomes were assessed. The result in two-way mixed RM-ANOVA revealed a significant main effect of time and hill gradients on bio-motor skills, physiological and biomechanical measures of middle-distance runners. The findings showed that uphill training has a significant positive effect on bio-motor skills, physiological and biomechanical measures of running performance, while the steeper uphill shows the most significant benefit compared to the lower hill gradients. Therefore, coaches and athletes should customize uphill training programs while carefully matching the strengths and weaknesses of the athlete and the demands of the event.

Keywords: Uphill training, Running performance, bio-motor skills, Middle distance, Hill gradients, physiology, biomechanics

CHAPTER 1: INTRODUCTION

1.1 Background

Running involves a complex interplay among various muscle–tendon units, which adapt their mechano-morphological properties in response to the chronic stress imposed by repeated running (Konrad et al., 2021). Numerous studies have shown that elite sporting performance arises from the interaction of multiple factors, including genetics, training (Tucker & Collins, 2012), and nutrition (Rodriguez et al., 2009), which interact with one another in an inadequately understood but complicated way to shape a gifted athlete into a winner. Human traits (such as muscular power, skeletal structure, tendon flexibility, and heart and lung capacity), each of which is the outcome of a complicated interplay between numerous anatomical, biochemical, and physiological systems that determines sport performance (Puthucheary et al., 2011). According to Rodriguez et al. (2009), proper nutrition enhances physical exertion, athletic ability, and recovery from exercise. Therefore, optimal running performance requires selecting appropriate foods and fluids, consuming them at the right times, and incorporating suitable supplements. While nutrition provides the necessary fuel and recovery support, training serves as the mechanism through which these physiological advantages are translated into improved performance.

Tucker and Collins (2012) characterized training as the method by which genetic potential is achieved. Engaging in any type of physical activity subjects the body to a stimulation that promotes bio-motor abilities, physiological, psychological, and biomechanical development of the person (Gordon, 2009). The goal of training is to give the athlete the best chance of achieving their performance goal or target, whether that be winning an Olympic medal or setting a personal record in a competition; in either case, the athlete will need to be in a "trained state" to reach these levels of athletic performance (Bangsbo et al., 2006). To make this a reality, the athlete must grow on all levels, but most importantly, there must be deep physiological, biomechanical, muscular, and psychological development.

Bio-motor skills, including strength, endurance, speed, coordination, flexibility, and agility, are the basis of an individual's capacity to do an exercise (Kanniyan et al., 2012). “The contribution of the bio-motor abilities to the attainment of high performance is determined by 2 factors: the ratio between them as a reflection of the specifics of the sport and, by the level of development of each ability according to its degree of participation in performing the sport/event" (Dawson, 2003).

According to de Waal et al. (2021), the key physiological parameters that contribute to successful running performance is often attributed to VO_2 max, running the steady state oxygen consumption, lactate threshold, velocity at VO_2max, and recovery time (HRR), (Dixon et al., 1992), and resting heart rate (RHR) (Sugawara et al., 2001).

The first physiological component is VO2 max, which is the highest quantity of oxygen a person can inhale and whose value remains constant over time, despite an increase in workload (Buttar et al., 2019). It is expressed as liters/min as an absolute value or in milliliters /kg/min as relative VO2 max. In a heterogeneous group of runners, VO_2max is strongly related to running performance (Pollock, 1977).

The second physiological factor is running economy, which is the energy requirement for a given velocity of submaximal running, or the steady-state oxygen usage (VO2) at a given running velocity (Kyle R Barnes & Andrew E Kilding, 2015b). The rate of oxygen consumption at a specific submaximal running pace is a metric that can differentiate between proficient and ineffective runners (Heise & Martin, 2001). RE varies significantly between top, skilled (recreational), and untrained athletes, as well as between men and women (Kyle R Barnes & Andrew E Kilding, 2015a). It is also determined by: training, environment, physiology, anthropometry, and running biomechanics (Saunders et al., 2004).

The other physiological factor is lactate threshold, which is the exercise effort at a given blood lactate level or the maximum lactate steady-state, and is used as a criterion measure of endurance fitness (Billat, 1996). It is the moment during intense, all-out activity when lactate accumulates in the bloodstream faster than the body can remove it. With modest increases in exercise intensity, blood lactate accumulation rises little, but there is a power output above which blood lactate accumulation accelerates in reaction to further increases in exercise power output (Messonnier et al., 2013). As Messonnier et al. (1997) indicated that a higher lactate threshold allows an endurance exercise to be continued without the accumulation of blood lactate, allowing the athlete's speed to be kept for an extended period of time.

Another physiological measure that better predicts endurance success in middle and long distance running is minimum velocity at VO2max (vVO2max) (Denadai & Greco, 2022; Paavolainen et al., 2000). It is the pace at which oxygen consumption ceases to increase; it is definitely possible to run faster, but the energy consumed is no longer supplied solely by aerobic processes, but also by anaerobic processes that produce lactic acid (Mackenzie, 2000). Running at vVO2 max enhances efficiency because stronger muscles require fewer muscle cells to maintain a given speed (Denadai et al., 2006), and therefore require less energy to maintain that speed. vVO2 max-effort improves neuromuscular coordination and reactivity, which lowers energy consumption (Hayes et al., 2004). Therefore, peak running velocity during a maximum aerobic power test (vVO2max) is a superior indicator of endurance success in middle- and long-distance running performance (Billat & Koralsztein, 1996; Billat et al., 2003; Noakes et al., 1990) because it is affected by anaerobic and neuromuscular characteristics in addition to aerobic power and running efficiency (Hill & Rowell, 1996; Paavolainen et al., 1999).

The heart rate variables, including maximal heart rate, resting heart rate, and recovery heart rate, are also the metabolic variables that could indicate performance improvement in athletes. For instance, according to Carter et al. (2003), a 12-week endurance training program will reduce both the resting and submaximal heart rates in younger and older adults. As a result, heart rate variable (HRV) measurement appears to offer a useful, noninvasive way to measure the cardiovascular adaptation to aerobic exercise. Another research examining the degree of parasympathetic control of resting heart rate in connection to aerobic power found that people with greater aerobic power keep their resting heart rates lower primarily through an increase in parasympathetic tone (Kenney, 1985). On the other hand, a study conducted on heart rate recovery following maximal exercise in continuous versus intermittent endurance athletes suggests that intermittent athletes are more likely to have faster HRR during the first 20 s than their counterparts trained for continuous performance (Djokic & Zagatto, 2019; Ostojic et al., 2010).

Finally, biomechanical factors such as spatiotemporal variables, including stride length, cadence, ground contact time, flight time, and vertical oscillation, are some of the variables determining running performance (Perrotin et al., 2021). Spatiotemporal factors, stride frequency, and stride length are mutually reliant and determine running pace (Moore et al., 2012). If stride frequency or stride length is both increased while maintaining the same pace, the other will be reduced; therefore, it appears that runners typically select a stride frequency or length that is either economically optimal or extremely close to being economically optimal (Moore, 2016).

Short ground-contact periods are thought to entail a high metabolic cost because quicker force generation is needed, implying that metabolically costly fast-twitch muscle fibers are activated (Roberts et al., 1998). Long ground-contact periods, on the other hand, may entail a high metabolic cost because force is generated slowly, resulting in prolonged stopping stages when runners decelerate (Nummela et al., 2006). Numerous studies have found that better RE is related to lengthening the total amount of time spent in the swing period (Barnes et al., 2014; Santos-Concejero et al., 2014). Others, however, have not discovered a connection between the two (Barnes et al., 2014). It is possible that athletes who have lengthier absolute swing times spend less time on the ground during their gait cycle, which is thought to be the most metabolically taxing part of the cycle. The frequency and length of a runner's strides will be influenced by their swing and ground contact periods, so it is perhaps essential to take into account how these factors interact.

Through a hard training program made up of various training techniques that have a larger effect on it, these aforementioned physical, physiological, and biomechanical variables can be improved. Although level running has been the focus of the majority of running research, exploring how locomotor behavior is regulated during incline and downhill running is essential to improving our knowledge of human locomotion (Vernillo et al., 2017).

Vernillo et al. (2017), also indicated that, in comparison to running on flat ground, uphill running is characterized by a higher step frequency, more internal mechanical work, a shorter swing/aerial phase duration, and a higher duty factor, whereas downhill running is characterized by a longer aerial time, a lower step frequency, and a lower duty factor. Incline running also affects foot strike patterns, which gradually assume a mid- to forefoot strike pattern for uphill running and a rearfoot strike pattern for downhill running. In order to raise the body's potential energy during uphill running, lower limb muscles must perform a greater total mechanical effort than they do during level or downward running. Energy dissipation is typically more common in downhill running than energy production. One of the best methods to improve a particular muscle and conditioning that will immediately translate to enhance such physical, physiological, and biomechanical variables in running performance is through hill running training (Barnes et al., 2013).

Hill training is simply running drills that athletes perform at an elevation while moving at a modest to quick speed, either on a real hill or on a machine. For the machine, they simply have to change the incline for uphill and downhill (Konstantinidou, 2022). It blends very specific strength training with the advantages of interval training (improved efficiency, aerobic capacity, cadence, and stride length). It improves physical (strength and speed), physiological (VO_2max, lactate threshold, and Running economy), and biomechanical (stride length and stride frequency). In reality, hill training has received a poor reputation at the beginning because some experts have argued that the advantages are unproven and the risk of injury is too high, but current researches indicate that hill training is now more crucial than ever (Harper, 2007). Higdon (2016) A renowned trainer and editor of Runner's World adds that hills help to build stronger legs, particularly the quadriceps, which reduces the risk of knee injuries.

Most elite runners use hills in their preparation, whether to increase stamina or prepare for hilly events. This could be attributed to the unique physiological advantages that hill training offers, such as increased VO2 max, improved running economy, increased anaerobic threshold, improved running technique, and a tool for strength training. A study published by Barnes et al. (2013), reported that any type of high-intensity uphill interval exercise improves 5-km time-trial speed and running efficiency. Additionally, Burfoot (2005) found that runners who engaged in a rigorous six-week program of challenging uphill running experienced noticeable gains in training distances, anaerobic ability, and muscle strength.

1.2 Statement of the problem

The growing popularity of hill running in recent decades has sparked interest in specific cardiorespiratory performance characterization of athletes (Lemire, Falbriard, et al., 2021; Vernillo et al., 2017). Uphill running is a common and frequently recommended training strategy in the growth of elite distance runners, but it is mainly unstudied and unsubstantiated as a training modality (Ferley et al., 2013). Although trainers and runners are conscious of the advantages of hill training, they occasionally struggle with how to implement it rather than why. According to

Anderson (2013), coaches and athletes frequently have a variety of slopes to choose from for hill training, but they are unsure of the ideal hill length and slope. He also stated that one benefit of relatively short inclines is that higher average running speeds can often be maintained because the shorter lengths of the uphill bursts keep exhaustion at reasonable levels, allowing for quicker running. When compared to running more slowly on lengthier slopes, faster-running velocities train the neuromuscular system to work with greater motor-unit activation and power outputs, which can produce higher heart rates and higher percentages of VO2max, as well as higher amounts of blood lactate (Laursen, 2010; Theofilidis et al., 2021). Longer slopes, on the other hand, may produce greater bodily demands, such as higher pulse and oxygen consumption rates, due to the more prolonged nature of the exertion (Dermack, 2015).

Given the constraints of current research, it is believed that there is little clear empirical proof to enable the determination of the most effective training techniques to improve endurance athletes' VO2max, lactate threshold, and running economy (Billat, 2001; Midgley et al., 2007). Prior studies found that VO2max was similar for both level and uphill running (Balducci et al., 2016; Lemire et al., 2020); however, Cassirame et al. (2022), found that the physiological demands during uphill sections were different from those under level conditions. Hill training may increase sprint and distance running power, but the quantity and optimum elevation required for both are unknown (Anderson, 2013). Few studies have examined the effects of an incline on physiological parameters, like VO2max, during progressive running tests, and the literature currently available demonstrates conflicting findings and lacks agreement due to various athletic populations and/or testing approaches (Cassirame et al., 2022) .

There have been relatively few training studies involving experienced athletes, and these studies have frequently included methodological variables that make analysis of the results challenging (Midgley et al., 2007). For example, the runners' training period during the research time was rarely mentioned (e.g., transition, preparation, or competition), and only a few trials included more than one experimental group; as a result, no comparison can be made to assess the relative effectiveness of the specific training approach. Other variables, including the inability to regulate the runners' exercise load during the research time, and the use of a small sample size, result in poor statistical power. The other problem is that much of the current knowledge pertaining to persistent adaptive reactions to physical training has come from studies using inactive people; however, simply employing this knowledge to create training suggestions for runners is unlikely to be viable. In addition to that, existing studies mainly focused on the acute effects of hill training on running performance determinants.

Moreover, most performance studies have been conducted in North America and Europe at or near sea level, making their findings difficult to generalize to athletes training at high altitudes. For instance, sea-level natives showed significant sleep disturbances at 3,600 m, while high-altitude natives did not, highlighting fundamentally different physiological responses (Roach et al., 2013). Likewise, endurance runners living closer to competition altitude experienced smaller performance decrements than those living higher, demonstrating that baseline altitude exposure alters outcomes (Chapman et al., 2016). Reviews further note that "live high, train low" protocols developed in sea-level cohorts may not apply to altitude-acclimatized athletes, who already possess many hematological and ventilatory adaptations (Saunders et al., 2013).

As a result, the current body of knowledge is insufficient to confidently inform the formulation of training suggestions that explain which hill repeats, long-gradual, intermediate, or short-steeps provide the most benefits, the ideal incline of hills, how frequently hill training should be conducted, and when hill training should be included in an overall program. Therefore, the purpose of this study was to examine the effects of eight-week uphill training on bio-motor skills (maximal speed (Vmax), speed endurance, and strength endurance), physiological (VO2max, vVO2max, RHR, and HRR), and biomechanical (step length, cadence, ground contact time, and flight time) metrics of middle-distance runners. Additionally, the study aimed at determining the relative effects of the three uphill gradients on these outcome variables.

1.3 General objective

The general objective of this study was to investigate the effects of 8-week uphill training on bio-motor skills, physiological, and biomechanical metrics of middle-distance runners.

1.3.1 Specific objectives

- ✓ To examine the effects of steep, intermediate and shallow hill training on bio-motor skills (Vmax, TT, and SE) of middle-distance runners.
- ✓ To determine the effects of steep, intermediate, and shallow hill training on physiological measures (VO_2 max, vVo2max, RHR, and HRR) of middle-distance runners.
- ✓ To evaluate the effects of steep, intermediate, and shallow hill training on biomechanical or spatiotemporal measures (step length, cadence, ground contact time, and flight time) of middle-distance runners.
- ✓ To compare the effects of steep, intermediate, and shallow hill training on bio-motor skills, physiological, and biomechanical metrics of middle-distance runners.

1.4 Research Hypotheses

Hill training offers many advantages, including improving running economy, raising lactate-threshold velocity, improving resistance to fatigue, increasing maximal running speed, increasing VO2max, and vVO2max. it also helps protect against soreness and injury, while preparing runners to compete on hilly racecourses. These benefits are widely recognized by both coaches and athletes, which is supported by scientific research (Ferley et al., 2016; Fleckenstein et al., 2021; Johnny Padulo et al., 2013).

A study conducted by Selvan and Sundar (2018) found that hill training has a substantial effect on speed endurance, cardiorespiratory endurance, resting pulse rate, and VO2 max in long-distance runners. Another study by Paradisis et al. (2015), found that combining uphill and downhill training improved experienced sprinters' maximal running speeds significantly more than a conventional horizontal training program, but the biomechanical variables step rate, step length, step time, contact time, braking, and propulsive phase of contact time, and flight time did not change. Runners must exert more effort per step on steeper slopes than they do on slopes of gentle gradients (Vernillo et al., 2017). However, a possible drawback of steeper inclines is that they frequently limit stride length and running speed compared to exercises on gentle slopes (Rankinen et al., 2006).

Furthermore, research by Paradisis and Cooke (2006) on a slope of 3^0, uphill sprint training significantly increased maximal running speed and step rate by 3.5% and 3.4%, respectively. Dintiman and Ward (2003) also indicated that a high angle of 8° is good for reaction time ability and acceleration, while angles of 1, 2.5, and 3° are good for speed improvement and speed endurance, and an elevation larger than 3% is good for building hip extensor strength (Faccioni, 1994). Therefore, based on the empirical evidence sought from the literature in this field, the researcher formulated the following hypotheses.

- H_{a1}: Steep, intermediate, and shallow uphill training will have a significant positive effect on bio-motor skills (Vmax, TT, and SE) performance of middle-distance runners.
- H_{a2}: Steep, intermediate, and shallow uphill training will significantly enhance physiological variables (VO2 max, vVo2max, RHR, and HRR) of middle-distance runners.
- H_{a3}: Steep, intermediate and shallow uphill training will have a significant positive effect on biomechanical or spatiotemporal measures (step length, cadence, ground contact time, and flight time) of middle-distance runners.
- H_{01}: There is no significance mean difference between steeper, intermediate and shallow hill training modalities on bio-motor skills, physiological and biomechanical measures of middle-distance runners.

1.5 Scope of the study

Whilst the positive effect of uphill training on running performance has been well documented, the optimal hill gradient which best improves the bio-motor skills, physiological and biomechanical metrics of middle-distance runners are still poorly understood. The main purpose of this study was to investigate the effect of three different uphill training gradients (steep, intermediate and shallow hills) on bio-motor skills (Vmax, TT, and SE), physiological (VO_2 max, vVo2max, RHR and recovery time (HRR)), and biomechanical (step length, cadence, ground contact time, and flight time), measures of moderately trained middle-distance runners. The study was delimited in scope in terms of, time, and concept to make it manageable. Therefore, the study was conducted on Bahir Dar University youth athletics project athletes. The study was conducted from 21 Jun 2024 to 10 September 2024, and the intervention was conducted for 8 weeks. The area and the participants had been selected deliberately, because the investigator of the study was familiar with the area, to make the study more feasible and manageable in terms of resources (cost, time, and facilities).

1.6 Significance of the study

‘This study is significant as it examines how uphill training affects the bio-motor skills, physiological responses, and biomechanical metrics of moderately trained middle-distance runners. By investigating these multidimensional effects, the research provides a comprehensive understanding of training adaptations that can inform both theory and practice. The findings have the potential to provide evidence-based insights for coaches, athletes, and sports scientists seeking to enhance training efficiency and performance outcomes in middle-distance running and related disciplines.

The study will contribute to a deeper understanding of how specific training modalities, particularly specific uphill training, influence performance and offer practical guidelines for athletes and coaches seeking evidence-based methods to optimize training outcomes. Coaches can incorporate uphill training not only to develop running-specific strength but also to improve stride mechanics, cadence, and overall efficiency, which are essential for middle-distance events. Additionally, the study provides practical applications for situations where natural hills are unavailable, offering guidance for constructing simulated or artificial hills that meet optimal gradient specifications. This practical aspect ensures that athletes and clubs can implement effective hill training regardless of geographic limitations.

Moreover, the results of this study will serve as a foundation for future research exploring the benefits of hill training across different running distances and other sports disciplines. By highlighting the physical, physiological and biomechanical adaptations induced by various hill gradients, the study may stimulate further investigations into sport-specific applications, injury prevention strategies, and performance optimization. Ultimately, this research aims to bridge the gap between scientific evidence and practical training methods, promoting the wider adoption of hill training as a key component of athletic development programs.

1.7 Definitions of terms

- **Uphill Training:** A form of running or exercise performed on a positively inclined surface, designed to enhance strength, power, and cardiovascular endurance.
- **Downhill Training:** A form of running or exercise performed on a negatively inclined surface, often used to improve eccentric muscle control, running economy, and speed.
- **Level Running Training:** Running or training conducted on a flat, horizontal surface, typically focusing on maintaining consistent pace, aerobic endurance, and running mechanics.
- **Steep hill:** A hill with a gradient of $\geq 7\%$, typically covered in 30 seconds or over a distance of 40–80 meters, used for high-intensity uphill efforts.
- **Intermediate hill:** A hill with a gradient of 5–7%, usually taking 30–90 seconds or 100–150 meters to ascend, suitable for moderate-intensity uphill training.
- **Shallow hill:** A hill with a gradient of 2–4%, typically taking 90 seconds to 3 minutes or 200–300 meters to run up, appropriate for longer, lower-intensity uphill sessions.
- **Moderately Trained Athletes:** Individuals who have developed basic athletic skills and conditioning but are below the advanced or elite performance stage in their sport.
- **Step Length:** The linear distance covered from the initial contact of one foot to the subsequent contact of the same foot (toe-to-toe or heel-to-heel), reflecting stride length during running or walking.
- **Step Rate (Cadence):** The number of steps or strides an athlete takes per unit of time, typically measured in steps per minute.
- **Spatial Variables:** Measurements related to distance, such as step length, stride length, and running distance.
- **Temporal Variables:** Measurements related to time, including step duration, stride time, and running speed.

CHAPTER 2: REVIEW OF RELATED LITERATURE

Overview

There is limited literature available exploring the impact of uphill training on trained athletes. Researchers in the area were focused on the acute effects of training on positive, negative hill gradients, and level running in various performance parameters. This section of the study provides a narrative review of training studies that are directly or indirectly related to running performance. The review specifically addresses factors influencing aerobic and anaerobic running performance; adaptations to hill training and training modalities for developing aerobic and anaerobic running performance.

2.1 Factors affecting running performance

Athletic performance is a complex phenotype that is affected by a variety of variables, including anthropometric, morphological, and muscle traits, energy supply and usage, biomechanical, emotional, and social elements, as well as thermoregulatory reactions (Denadai & Greco, 2022). Each of us is defined as human by the roughly 20,000 DNA that we all share. However, individual human genes differ significantly from one another. Sports performance is influenced by a wide range of human traits (such as muscular power, skeletal structure, tendon flexibility, and heart and lung capacity), each of which is the outcome of a complicated interplay between numerous anatomical, biochemical, and physiological systems (Puthucheary et al., 2011).

Genetics plays a great role in your fitness ceiling; how good you can get as a runner. Numerous phenotypes linked to exercise and athletic success have long been thought to be genetically influenced, due to the heritability of traits linked to endurance; there is a genetic foundation for top world marathon running success (Moir et al., 2019). For instance, the supremacy of sprinters of West African descent and distance runners from East Africa raises questions about how much genetic and environmental variables affect performance (Tucker et al., 2013). Your unique physical ability is influenced by your genetic makeup in a variety of ways, including your VO2max, muscle fiber variability, body type and strength, exercise capacity and adaptation, and psychological reaction to training.

Research suggests that the amount by which you can improve your VO2max, or ability to utilize oxygen while exercising, is influenced up to ~ 23% and 57% by your genetics (Klevjer et al., 2023). Other studies found that heredity accounts for 45% of a person's fast-twitch to slow-twitch muscle fiber ratio (Semenova et al., 2022). In the instance of Body Type and Strength, a 2008 research of one million Swedish men discovered that genetics account for 81% of the variance in height, 59% in BMI, and 50-60% in strength metrics (Zempo et al., 2017). When it comes to exercise tolerance and adaptation, however, studies continue to find genetic indicators that determine how well an individual tolerates and reacts to training. While some of these indicators are prevalent and thought to be associated with top athletic standing, others may actually be associated with exercise intolerance (Bray et al., 2009).

When it comes to Psychological Response to Training, even your feelings, attitude, and mental approach to training can be genetic. According to research, genetics can impact how individuals react psychologically during and after training by 12-37%. According to the research, greater levels of regular exercise engagement were linked with positive affective reactions (Schutte et al., 2017). Hence, while training has an impact on athletic ability, the degree to which a runner can or will progress is heavily influenced by the genes you were born with.

Enormous research showed that athletes of all levels are searching for methods to improve their efficiency through training and nutrition as endurance sports gain in prominence. The American Dietetic Association, Dietitians of Canada, and the American College of Sports Medicine all hold that proper nutrition improves physical exertion, sports ability, and exercise recuperation (Rodriguez et al., 2009). These groups advise that for optimum health and exercise efficiency, choosing the right foods and liquids, consuming them at the right times, and choosing the right supplements. Dehydration has been shown to have negative impacts on health, and it has been shown that both loss of carbohydrates and dehydration lower efficiency (Cheuvront & Kenefick, 2014). Dehydration and carbohydrate depletion are the most probable causes of exhaustion for endurance exercises lasting 30 minutes or longer (Jeukendrup, 2013).

Dietary carbohydrate loading enhances endurance performance during extended exercise, and candy can be a useful addition to the regular carbohydrate consumption in order to prepare for endurance events (Burke et al., 2013). Due to the high training loads and intensities experienced by elite power sport competitors in middle-distance running, track cycling, rowing, and swimming for the majority of the training season, adequate energy consumption is necessary to support recuperation and adaptation, because low pre-exercise muscle glycogen reduces high-intensity performance (Stellingwerff et al., 2013).

2.1.1 Physiological factors

The maximum oxygen uptake (VO2max), running economy (RE), lactate threshold(LT), fractional utilization (sustainable percentage of VO2max), and velocity at VO2max are key physiological variables that Blagrove et al. (2018) identify as having a significant impact on middle and long distance running performance. In well-trained athletes, the sum of these factors can predict long-distance running performance with greater than 95% accuracy (McLaughlin et al., 2010). The aerobic energy system contributes the majority of the energy throughout long distance running events, ranging from 3000 meters to the marathon (42.195 meters) (Busso & Chatagnon, 2006). Enhancing performance over these distances must have an impact on one or more physiological elements that are essential to distance running success.

According to research by Saunders et al. (2004), trained runners with identical VO2max might experience RE variations of up to 30% (Saunders et al., 2004). Additionally, it has been demonstrated that running economy can be a good predictor of endurance running performance, particularly in runners whose VO2max is homogeneous (Kyle R. Barnes & Andrew E. Kilding, 2015).

Top, talented (recreational), and untrained athletes' RE differs greatly from that of men and women, as well as from that of amateur and untrained athletes (Kyle R Barnes & Andrew E Kilding, 2015a). In addition Saunders et al. (2004) found that running economy is also influenced by training, environment, physiology, anthropometry, running biomechanics, and neuromuscular variables. Long-term running training has traditionally been utilized to increase RE (Rodríguez-Barbero et al., 2025); however, cutting-edge methods like strength training (ST) modalities have also been found to provide benefits (Denadai et al., 2017). Almstedt et al. (2018), explains how VO2max and running economy interact to impact running velocity in their description of "velocity at VO2max" (vVO2max).

Lactate threshold is another physiological parameter that determines running performance. The speed at the LT is considered as the speed at which the lactate concentration changes in some way, such as to an absolute concentration, a break in the curve, or a delta amount, and is used as a predictor of performance. For both trained and untrained populations, several studies have demonstrated that the different LT markers are accurate predictors of performance in a range of endurance sports (such as running, cycling, and race walking), (Faude et al., 2009). Fast rates of oxidative ATP synthesis must be sustained in order to maintain a fast-running pace. For some time, it has been understood that the synthesis of lactate is influenced by a variety of factors, including the number of mitochondria present in the muscle, as determined by the activity of mitochondrial enzymes (Zhang et al., 2024). According to (Maruo et al., 2018), successful runners have distinct physiological traits from sprinters and long-distance runners. Maximal oxygen uptake ($\dot{V}O2max$), percentage of $\dot{V}O_{2max}$ a runner can sustain without accumulating lactic acid (%VO2max), a runner's ability to use fat as a fuel at high work rates and thereby "spare" carbohydrate and run at race pace with relatively low energy expenditure (i.e. good running economy), the velocity associated with attaining VO2max (v-V-O2max), and the velocity at lactate threshold are factors that have been shown to limit performance during long distance races (Blagrove et al., 2018; Eihara et al., 2022), and rapid velocity and anaerobic variables have been shown to limit performance during sprinting (Jiménez-Reyes et al., 2022).

However, middle-distance running performance is predicated on an integrative contribution from aerobic and anaerobic factors that allow a runner to sustain a quick pace during a race. The respective contributions of the two energy systems are determined by distance, intensity, and the runner's physiological capacities. Middle-distance runners with physiological profiles that encompass a variety of aerobic and anaerobic capacities can be successful.

According to (Lazzer et al., 2012), the competition will likely be won by the runner with the greatest VO2max, who can use the highest percentage of their maximum oxygen consumption for a sustained length of time and who has the lowest O2 cost of running per meter. In addition to the previously described performance-predicting parameters, several studies have demonstrated that elite runners are capable of using a significant portion of their maximum oxygen consumption for a longer period of time (Howe et al., 2021).

2.1.1.1 Maximum oxygen uptake (VO_2max)

Maximum oxygen uptake (VO2max) is the maximum rate at which oxygen can be taken in and used by the body during strenuous activity (Buttar et al., 2019). It is one of the key factors in the study of exercise physiology and is usually used to assess a person's level of cardiorespiratory fitness. The most frequent way to show a training impact in the scientific literature is an improvement in VO2max (Saunders et al., 2004).

High VO2max is a requirement for success in middle and long-distance running. VO2max is restricted by the body's capacity to transport oxygen to the muscles (Bassett & Howley, 2000), muscle capillary density, hemoglobin mass, stroke volume, aerobic enzyme activity, and the composition of the muscle fiber types (Coyle, 1999). However, there is an upper limit to oxygen uptake, and there are inter-individual differences in VO2max.

There isn't much evidence in the scientific literature on the best training intensity to increase VO2max in experienced distance runners; however, in untrained people, training intensities of 40–50% VO2max can significantly raise VO2max. Though well-trained distance runners likely need to exercise at relatively high percentages of VO2max to elicit additional increments, the minimum training intensity that results in the enhancement of VO2max is greatly dependent on the initial VO2max. Training at a VO2max of 70–80% is ideal, and it has been noted that the VO2max augmentation of well-trained distance runners reaches a plateau; nevertheless, several studies have shown that the VO2max of well-trained runners may be increased when training procedures known to elicit 95–100% VO2max are added in their training regimens (Midgley et al. (2006),. This supports the idea that for experienced distance runners, high-intensity training at or close to VO2max may be the most beneficial intensity for increasing VO2max.

2.1.1.1.1 Role of Maximum Oxygen Uptake in Running Performance

Bassett and Howley (2000) disclosed that maximum oxygen uptake (VO2max) is constrained by the cardiorespiratory system's capacity to provide oxygen to working muscles. For example, when oxygen delivery is changed (e.g., by blood doping, hypoxia, or beta-blockade), VO2max changes accordingly. Also, the increase in VO2max with training is primarily due to an increase in maximal cardiac output (rather than an increase in the a-v O2 difference). Furthermore, when a small muscle mass is over perfused during exercise, it has an extremely high capacity for consuming oxygen. Therefore, this is why it is believed that O2 supply, rather than skeletal muscle O2 extraction, is the main factor limiting VO2max in physically active adults. However, enhancing submaximal endurance performance requires skeletal muscle metabolic changes. As a result of increased mitochondrial enzyme activity brought on by endurance training, performance is enhanced through increased fat oxidation and decreased lactic acid buildup at a given VO2. An athlete cannot function at 100% of VO2max for long periods of time, making it a crucial variable that determines the top bound for endurance performance.

Even though distance races are not raced at 100% of one's maximum oxygen consumption (VO2max), this percentage is closely related to the rate of ATP synthesis that can be sustained during a race. The amount of VO2 ($mL/kg^{-1}/min^{-1}$) that the subject can sustain during the run and the percentage of VO2max that the subject can perform at are what define the rate of ATP synthesis (Ma et al., 2023). For instance, a VO2 of around 60 $mL.kg^{-1}.min^{-1}$ must be maintained the whole run in order to finish a 2:15 marathon. Thus, even if a marathon could be completed at 100% VO2 max, the runner would still require a VO2 max of 60 $mL.kg^{-1}.min^{-1}$ to achieve the performance stated. The VO2 max levels required for such performance would be 70.5-75 mL.kg-1.min-1, however, as the marathon is normally run at roughly 80-85% of VO2 max. In this way, VO2max sets the upper limit for energy production in endurance events.

Now the ideal strategy to increase VO2 max is to perform three to five-minute efforts with a one-to-one work-to-rest ratio. For example, if you just finished a four-minute interval, you should take four minutes to rest before beginning your next interval. The important thing to remember is that in order to reap the greatest advantages, these intervals' intensities should be as near as possible to VO2 max or maximum heart rate.

2.1.1.2 Fractional utilization of maximal oxygen uptake (%VO_2max)

The average VO2max a runner can maintain over a specific distance or amount of time is known as %VO2max (Joyner & Coyle, 2008). Accordingly, for endurance sports, percent VO2 is highly correlated with the VO2 measured at the lactate threshold (LT) (Bassett & Howley, 2000). The VO2 max is generally constrained by central circulatory variables, whereas the percentage of VO2 max that can be maintained is mostly tied to muscle adaptations brought on by repeated training (Bassett & Howley, 2000). VO2max for the trained participants was 87% and 83% for 1 and 2 hours, respectively, but it was only 50% and 35% for the untrained ones. This clearly demonstrates the influence that VO2max has on the amount of real (performance) VO2 that a person can sustain throughout an endurance activity (Bassett & Howley, 2000).

As an indirect representation of %VO2max, the average percentage of VO2max that a runner uses at velocity at anaerobic threshold (vAT) during a laboratory test is frequently utilized (Impellizzeri et al., 2005). %VO2max at vAT and %VO2max in competitions are shown to be highly correlated (Warburton et al., 2000). Proficient distance runners can often sustain their running speed at VO2max for five to seven minutes (Bosquet et al. (2002), . In races longer than seven minutes, %VO2max decreases as race distance and duration increase (Saunders et al., 2004). The athlete must thus work as closely as possible to VO2max to get strong performances in aerobic endurance races (Bosquet et al., 2002). translates to the fact that VO2max is a significant influence in longer events like the half-marathon and marathon (Noakes, 2001). According to Svedenhag (2000), elite distance runners frequently have high %VO2max values. Average%VO2max was a little bit higher for Kenyan male distance runners running at a speed equivalent to vAT pace when using a high training volume training program as opposed to runners using a slightly lower training volume and higher intensity program (Billat et al., 2003).

Støa et al. (2010), have demonstrated that the relationship between fractional utilization (%_VO2max) and performance depends more on the amount of time spent running during a competition than it does on the distance covered. Another research showed that the runners in the studies had lower %_VO2max, which was reflected in their poorer performance levels and, as a result, their longer time spent competing when compared to other runners Sta et al. (2010). Male marathon runners used 80–87 percent of their maximum oxygen uptake, whereas female runners used 68–86 percent,(Venturini & Giallauria, 2022). They demonstrated that both the VO2 max and the percentage of VO2 max that could be used were greater in the faster runners. The workload for the quickest runners corresponded to a speed requiring around 75% of VO2 max, whereas for the slowest runners it corresponded to a pace requiring roughly 60% of VO2 max.

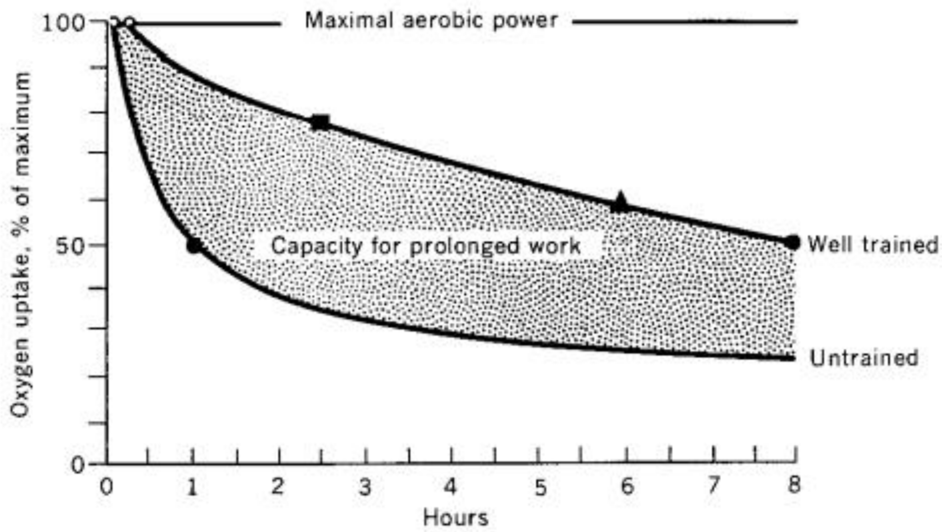


Figure 1 Percentage of a subject's maximal aerobic power he/she can tax during work of different duration and how this is affected by training experience. Adopted from Bassett and Howley (2000).

2.1.1.3 Minimum velocity at maximal oxygen uptake (vVO_2max)

It is the pace at which oxygen consumption ceases to increase; it is definitely possible to run faster, but the energy consumed is no longer supplied solely by aerobic processes, but also by anaerobic processes that produce lactic acid (Mackenzie, 2000). Running at vVO2 max enhances efficiency because stronger muscles require fewer muscle cells to maintain a given speed (Denadai et al., 2006), and therefore require less energy to maintain that speed. vVO2 max-effort improves neuromuscular coordination and reactivity, which lowers energy consumption (Hayes et al., 2004). Therefore, peak running velocity during a maximum aerobic power test (vVO2max) is a superior indicator of endurance success in middle- and long-distance running performance (Billat et al., 2003) because it is affected by anaerobic and neuromuscular characteristics in addition to aerobic power and running efficiency (Paavolainen et al., 1999).

The vVO2max or 'critical speed' is the lowest speed that causes VO2max, and it is used to assess the maximal aerobic capacity, or the total amount of oxygen consumed at VO2max, by asking the participant to keep going at that pace for as long as they can. As the speed of exercise increases, the rate of oxygen consumption increases as well, and reaching a maximum for speeds above around 256 m/min. Thus the heart, lungs, circulation, and diffusion of oxygen to the active muscle fibers have reached their maximal activity at this particular pace, for which no further increases in O2 intake are possible (Billat & Koralsztein, 1996).

The body's need for oxygen is much larger at faster speeds, yet it cannot be satisfied, therefore the oxygen debt keeps growing. According to Paradisis et al. (2014), the useful variable vVO2max combines VO2max and economy into a single component that may be used to determine aerobic variations between different runners or types of runners. Individual variations in performance were better explained by vVO2max rather than VO2max or running economy alone. It is computed as the ratio of VO2max (ml/kg/min) minus oxygen consumption at rest and running energy cost (ml/kg/sec).

According to (McLaughlin et al., 2010), velocity associated with VO2max (vVO2max) gives a composite measure of VO2max and RE and has been used to explain disparities in performance among trained distance runners. Maximizing vVO2max via training will enhance the running speeds that correlate to a particular percentage of VO2max and will improve performance since athletes prefer to employ equivalent percentages of VO2max for a given workout period (Carter et al., 2000). Thus, vVO2max can be highly beneficial for determining the intensity of training programs. vVO2max is directly assessed in a laboratory-based test in which the running pace is steadily increased until the athlete hits VO2max (Billat & Koralsztein, 1996).

2.1.1.4 Heart rate variables

Athletic performance improvement may be indicated by heart rate variables such as maximum heart rate, resting heart rate, and recovery heart rate. For instance, a 12-week endurance training program, according to Carter et al. (2003); will lower both the resting and submaximal heart rates in both younger and older persons. Monitoring heart rate variable (HRV) thus looks to provide a practical, noninvasive method for assessing the cardiovascular response to aerobic exercise. According to another study looking at how much the parasympathetic nervous system controls resting heart rate in relation to aerobic power, those with higher levels of aerobic power largely maintain lower resting heart rates through an increase in parasympathetic tone (Kenney, 1985). A study on heart rate recovery following maximal exercise in continuous versus intermittent endurance athletes, on the other hand, suggests that intermittent athletes are more likely to have faster HRR during the first 20s than their continuous counterparts (Djokic & Zagatto, 2019; Ostojic et al., 2010).

2.1.2 Biomechanical factors (running dynamics)

Running performance is affected by biomechanical characteristics such as stride length (in meters), stride rate or cadence (the number of steps per minute), ground contact time and swing time or GCT & ST (in milliseconds), and vertical movement of upper body oscillation (in centimeters). Running pace is determined by the primary spatiotemporal parameters, stride frequency, and stride length (Moore et al., 2012; Tseh et al., 2008).

If both stride frequency and stride length are raised while keeping the same speed, the other will be lowered; hence, it appears that runners often choose a stride frequency or duration that is either economically ideal or very near to being economically optimal (Moore, 2016). Self-optimization refers to the natural, unconscious fine-tuning of running biomechanics (Moore et al., 2012). The ideal frequency or length of an experienced runner's stride is generally 3% faster or 3% shorter than the theoretically optimal value (Connick & Li, 2014; De Ruiter et al., 2014). Stride length variances of more than 6% are harmful to RE (De Ruiter et al., 2014), although acute and short-term treatments that lower stride length by 3% reveal RE to be unaffected(Craighead et al., 2014). These findings collectively imply that trained runners may adopt a specific stride length range without endangering their RE. It seems that this range corresponds to the desired stride length minus 3%.

Importantly, trained runners lower their stride frequency even when they are exhausted relative to a non-fatigued condition and create a preferred stride frequency that is comparable to their ideal stride frequency even when they are fatigued (Hunter & Smith, 2007). These findings that experienced runners have the ability to dynamically self-optimize their running biomechanics in response to their physiological state. The discrepancy between desired and theoretically ideal stride frequencies is higher for inexperienced runners than for experienced ones (8 vs. 3%) (De Ruiter et al., 2014). Therefore, it is important to exercise care when applying the idea of an ideal stride length range to all runners because self-optimization seems to be a physiological adaptation brought on by increased running experience.

The flight phase is when both feet are off the ground, while the stance phase is when one foot is in touch with the ground (Van Dijk & Van Megen, 2017). Because one foot is consistently on the ground during this phase, the stance phase is also often referred to as the support phase. A stride combines the stance and flight phases; hence, the length of a stride is equal to the sum of the step and flight lengths.

Findings in connection with running economy (RE) and the lengths of time the foot spends in contact with the ground are inconclusive. In contrast to some research (Heise & Martin, 2001; Kyröläinen et al., 2001; Støren et al., 2011), which showed no relationship between ground contact time and RE, others discovered that longer contact times are associated with greater RE (Di Michele & Merni, 2014) as well as others (Nummela et al., 2007; Santos-Concejero et al., 2014), have discovered the contrary to be true. Since quicker force production is required during short ground contact intervals, it is assumed that metabolically expensive fast-twitch muscle fibers are recruited (Roberts et al., 1998). On the other hand, because force is produced slowly with extended ground contact, this may result in a high metabolic cost and longer halting phases when runners slow down (Nummela et al., 2006). Studies showed that longer swing periods are associated with better RE (Barnes et al., 2014; Santos-Concejero et al., 2014), , while others haven't found a link between the two (Barnes et al., 2014; Williams & Cavanagh, 1987).

The results of Barnes et al. suggest that sex may also play a role in this connection, but other studies have not validated this. It is probable that individuals with longer absolute swing durations spend less time on the ground throughout their gait cycle, which is regarded as the physiologically heaviest portion of the cycle. The swing and ground contact times of a runner will affect the frequency and length of their strides; thus, it is potentially crucial to consider how these variables interact.

Finally, studies using short-term treatments have demonstrated that increasing vertical oscillation causes VO2 to rise (Egbuonu et al., 1990; Tseh et al., 2008). Additionally, when jogging until you are exhausted, vertical oscillation rises. However, it has been demonstrated that when people run barefoot, their RE improves, and there is a decrease in vertical oscillation (Moore et al., 2014). This is most likely because there is a reduced vertical displacement during stance (Divert et al., 2008).

Another research (Halvorsen et al., 2012) has demonstrated that reducing vertical oscillation can only marginally enhance RE if the absolute height of the body's center of mass (COM) is left unchanged. These findings suggest that efforts should be made to decrease the vertical displacement's overall size. As a smaller vertical impulse would be generated, it is plausible that decreasing vertical displacement enhances RE by lowering the metabolic expenditure associated with sustaining body weight (Teunissen et al., 2007). Furthermore, it could increase a runner's mechanical efficiency since a low displacement of the center of mass (COM) results in a low mechanical energy cost because the body is exerting less force against gravity (Slawinski & Billat, 2004).

Another study indicates that female runners had a lower vertical oscillation than their male counterparts; however, research on the subject is contradictory (Helgerud et al., 2010). Runners preferred to modify vertical oscillation rather than step frequency, and this could be accomplished by providing both visual and audible feedback (Eriksson et al. (2011). No sufficient research, however, has attempted to manipulate vertical oscillation in a manner similar to stride frequency and stride length to ascertain whether runners have an optimal magnitude of vertical oscillation or whether runners would merely benefit from lowering their vertical oscillation to improve RE.

2.1.3 Training

There are numerous perspectives on training theory. At a basic level, we understand that engaging in any type of physical activity subjects the body to a stimulation that promotes physical, physiological, psychological, and biomechanical development of the person (Gordon, 2009). The goal of training is to give the athlete the best chance of achieving their performance goal or target, whether that be winning an Olympic medal or setting a personal record in a competition; in either case, the athlete will need to be in a "trained state" to reach these levels of athletic performance (Bangsbo et al., 2006). To make this a reality, the athlete must grow on all levels, but most importantly, there must be deep physiological, biomechanical, muscular, and psychological development.

If an athlete adheres to an organized and well-developed training regimen, they will gradually improve their general physical fitness as well as the components of fitness related to the training done (specific fitness)(Faigenbaum et al., 2011). These sports changes can be observed at all cellular, physiological, and morphological stages in the athletes (Akubat et al., 2012).

Every training session will typically build a specific physical component (Thompson, 2009); for instance, an activity becomes endurance-based when the distance or time is increased to its maximum, the ability to move quickly and frequently would be a speed exercise, while the ability to move through a wide range of joint motion would be a flexibility exercise, activities with relatively complex movements are referred to as coordination exercises and if the load of an exercise is high or maximal, it is a strength exercise. Fitness requirements vary depending on the event (Hewson & Hopkins, 1996). For example, a sprinter's endurance is very different from that of a distance runner, so the coach must be aware of the characteristics of each component of fitness and know how to develop them in order to set a basis for fitness for all athletes and subsequently to develop the particular fitness needed for an event.

As a result of training, according to Andrew and Helen (2000) the key physiological parameters that contribute to successful running performance are often attributed to VO_2 max, running economy the steady state oxygen consumption, and lactate threshold (Tzvetkov, 2017), velocity at

VO_2max (Denadai & Greco, 2022) recovery time (HRR), (Dixon et al., 1992), and resting heart rate (RHR) (Sugawara et al., 2001).

Training frequency, quality, and quantity (the combination of volume and intensity), load distribution, periodization, the use of resistance and plyometric training, and the harmony between training stress and recovery are all significant factors that affect running performance, whether it be aerobic or anaerobic, and should be carefully considered (Tola, 2018).

Long-term performance development is only possible when athletes are subjected to a gradual increase in training load over time, while sufficient recovery is assured. However, excessive and fast increases in training loads are likely to be the cause of a large percentage of soft-tissue injuries (Haugen et al., 2019; Windt & Gabbett, 2017).

The volume (how much), intensity (how hard), and frequency (how often) of exercise practices are the most important aspects of any training regimen. These 'training impulses' decide the amount of adaptive reactions that either increase (fitness) or reduce (fatigue) exercise capability(Hawley, 2002).

The muscle movements and muscle groups used, the pace of movement, the range of motion, the training burden, and the energy systems involved all contribute to training changes that are unique to the stimulus applied (Sale & MacDougall, 1981). Only the muscle fibers that were engaged during the exercise routine experience the overwhelming majority of training-induced adaptations, while untrained muscle tissue undergoes little to no adaptive change(Hawley, 2008).

Individual performance capability and predispositions must be taken into account when determining the best course of training, including anthropometric variables, training status/age, sex, recovery/injury status, and force-velocity profiles. For example, the kinematics of sprinting vary according to performance level and anthropometric factors (Morin & Samozino, 2016). Total training volume generally increases with training age, but as athletes approach their maximum potential at the end of their career, training volume may decrease to accommodate increased need for recovery time between high-intensity sessions(Lester).

Improvements in physical ability in high-performance sports are primarily accomplished by improving training quality (Muller et al., 2000). Training science will be relied upon to add to the optimization of training techniques in high-performance sport more than ever before. In the future, increasing the quality of training rather than the quantity of training will probably be the best method for enhancing physical ability (Muller & Wachter, 1989). In terms of physical preparation, using specialized exercises and assessments designed for a particular activity will most likely enhance the standard of training.

The most popular training techniques for enhancing performance in endurance competitive running events include continuous exercise done at both low and high effort levels and interval training, which includes periods of varying intensity (Boullosa et al., 2020). Studies mixing continuous submaximal running (CT) and high-intensity interval training (HIIT) discovered additional gains in performance (Bangsbo et al., 2009; Faelli et al., 2019). It should be noted that some earlier studies employed sprint interval training (SIT, all-out efforts lasting 20–30 s with lengthy resting intervals of 5–10 min), which also led to increases in performance in 3 and 10 km races(Faelli et al., 2019).

Furthermore, research on aerobic HIIT (2-4 minutes at 100% of the velocity linked with maximal oxygen intake (vVO2max)) discovered increases in performance in running contests ranging from 1.5 to 10 km(Smith et al., 2003), while short HIIT bursts, spanning 20 to 60 seconds, also showed increases in performance over distances of 1.5 to 10 kilometers (Faelli et al., 2019; Vezzoli et al., 2014). Anecdotal evidence suggests that incorporating high-intensity uphill interval training into distance runners' training programs can also improve physiological parameters related to running performance (Barnes et al., 2013). However, a combination of several techniques may be the best choice for improving adaptation to endurance running workouts.

2.2 Training to enhance bio-motor skills, physiological, biomechanical, and performance parameters

Although genetic and training-related factors are known to affect athletic performance (Midgley et al., 2007), the former is typically a fixed factor with the latter being the exception (Tucker & Collins, 2012). Physical training, however, has the potential to have a significant impact on both physiological adaptation and athletic performance (Midgley et al., 2007). This is arguably most obvious in elite runners, where the pace of training adaptation and performance enhancement may have hit a plateau (Midgley et al., 2006). Distance runners frequently look for the most efficient training strategies to improve performance. According to de Carvalho e Silva et al. (2022), professional runners use techniques of motor skills training, such as continuous, interval, and mixed training, to enhance physiological, neuromuscular, and performance characteristics (Berryman et al., 2019). The best way to enhance and sustain the physical, physiological, and biomechanical parameters of running performance, however, remains a significant but unanswered question (Billat, 2001).

The most popular forms of endurance training involve both continuous and interval running. Training volume and intensity are the two key factors that may be used to characterize any approach. Running without stopping is known as continuous training and may be used to build both general and specific endurance, as well as for recovery (Thompson, 2009). It often occurs off track and offers a diversity of speed, setting, and running surface for the athlete's preparation. Runs can be short, medium-length, or long, however the terms "long" and "short" depend on the athlete's fitness level and stage of development. For one athlete, a certain distance could be considered "short," whereas for another, it might be "long."

In the 1970s, it was a common method of endurance training. According to (Powers et al., 2007), this training strategy entails exercising at low intensity (i.e., 50%–65% VO2 max or around 60%–70% of max HR) for durations that are typically longer than the typical competition distance. Although it makes sense that this type of training would be helpful in preparing an athlete to compete in long endurance events (such as marathon running), research suggests that short-term, high-intensity exercise is superior to long-term, low-intensity exercise in improving VO2 max (Hickson et al., 1977)

Exercise is easily maintained and may thus be done continuously when the scheduled intensity is moderate (50-80% O2max). Contrarily, in order to complete a suitable training volume during high-intensity exercise (90-120% O2max), it is required to fractionate the distance (i.e., interval training), (Tuimil et al., 2011).

Performing repeated exercise bouts with only a few seconds of rest in between is known as interval training (Powers et al., 2007). Interval training entails repeating brief to lengthy bursts of relatively intense exercise (equal to or greater than maximal lactate steady-state velocity), separated by recovery intervals (Light exercise or rest), (Billat, 2001). It includes running on flat, uphill, and surfaces, and it was termed ‘natural interval training’.

Depending on the athlete's goals, the work interval's length and intensity will vary. For example, a longer work period necessitates higher aerobic energy production engagement, whereas a shorter, more intensive interval promotes greater anaerobic metabolism involvement. In order to boost the contribution of aerobic ATP generation, interval training intended to increase VO2 max often uses intervals longer than 50 to 60 seconds. Furthermore, it is thought that (Esfarjani & Laursen, 2007; Fox et al., 1975). These gains are probably attributable to the fast-twitch (types IIa and IIx) fibers being recruited during this kind of high-intensity exercise (Deschenes, 1989).

High-intensity intervals lasting 30 to 120 seconds are referred to as HIIT, or high-intensity interval training. Anaerobic energy sources would be anticipated to contribute significantly to energy generation during a very brief, 30-second bout of high-intensity exercise(Ma et al., 2013). However, a large body of research suggests that HIIT encourages appreciable enhancements in the aerobic capacity (i.e., increased mitochondrial volume) in the trained skeletal muscles (Gibala et al., 2012; Ma et al., 2013). According to research, even 30 seconds of high-intensity exercise can hasten and significantly improve physiological responses. In particular, even low-volume HIIT causes trained skeletal muscles' mitochondrial volume to grow, improve maximal aerobic capacity, and peak running velocity (Gibala et al., 2012).

While submaximal endurance training has been shown to significantly improve endurance performance and related physiological markers in sedentary and recreationally active groups, in highly trained individuals, an additional increase in submaximal training (i.e., volume) does not seem to further improve either endurance performance or related physiological variables [e.g., peak oxygen uptake (VO2peak), oxidative enzyme activity]. It appears that for athletes who have previously received training, the only way to increase endurance performance is through high-intensity interval training (HIT), (Laursen & Jenkins, 2002).

Investigations on the responses of the highly trained athlete to HIT have not yet focused on changes in plasma volume, stroke volume, muscle cation pumps, myoglobin, capillary density, or fiber type characteristics. It is also quite difficult to get information on how to optimize HIT programs for endurance athletes. Long-distance runners have seen increases in performance in preliminary studies utilizing the velocity at which VO2max is attained (V(max)) as the interval intensity and fractions (50 to 75%) of the time to exhaustion at V(max) (T(max)) as the interval duration (Laursen & Jenkins, 2002).

Despite requiring less overall energy consumption, Billat also stated that interval training is more efficient than continuous training by raising rates of fatty acid oxidation. In line with this, short aerobic interval training has been shown to avoid glycogen depletion by using lipids when compared to continuous exercise done at the same rate. For example, a high intensity exercise (100 to 102% of pVO2max) performed continuously (time limit = 4 to 6 minutes) or intermittently (112% of pVO2max) for 60 minutes (15 seconds of work and 15 seconds of recovery) did not deplete muscle fibers in the same manner (Essén, 1978).

Interval training at speeds near the velocity associated with VO2max (vVO2max) may maximize VO2max improvement while also resulting in substantial increases in mitochondrial density. In addition, Interval exercise will promote lactate removal while raising blood lactate levels (Brooks et al., 1996).

Short interval training has occasionally been thought to be ineffective at increasing VO2max (Franch et al., 1998), whereas long aerobic interval training, which entails repeating 1- to 8-minute runs at 90 to 100% vVO2max, has been shown to be the most successful at boosting VO2max and performance in middle-distance runners (Fox et al., 1975).

In the past, researches (Billat, Flechet, et al., 1999; Overend et al., 1992) have been conducted to ascertain the impact that both continuous and intermittent training approaches have on the parameters that restrict endurance performance. Most investigations found no discernible changes in either method on VO2max, ventilatory threshold, lactate threshold, maximum work capacity, performance, or O2 kinetics. In contrast, several researches revealed that interval training significantly improved _VO2max, ventilator threshold, O2 kinetics, and lactate elimination capacity when compared to the continuous technique (Falz et al., 2019; Gharbi et al., 2008).

Although some of these studies were conducted without matching workloads for appropriate comparisons, it may be inferred from these contradictory results that the degree of exercise intensity and the subjects' prior training experience influence the subsequent adaptations to endurance training (Kubukeli et al., 2002; Laursen & Jenkins, 2002).

The body of studies contrasting continuous versus interval training has significantly expanded in recent years. Studies have shown that both techniques increase MAS (Maximal Aerobic Speed) in a comparable manner; however, larger gains have been seen with the interval method, according to (Gharbi et al., 2008). Other studies have shown that both approaches have a similar positive impact on VO2max and running economy (Bhambhani & Singh, 1985). For instance, a study on the impact of interval and continuous training regimens on the maximal aerobic speed (MAS), time limit at MAS (Tlim), and countermovement jump (CMJ) revealed a significant and similar improvement (p 0.01) on maximal aerobic speed (MAS) for both the interval training group (5.8%) and continuous training group (8.3%), whereas time limit at MAS (Tlim), and countermovement jump (CMJ) did not change significantly for either group after the training regimen (Tuimil et al., 2011).

Another study by González-Mohno et al. (2016) examined the effects of continuous and interval training on running economy, maximal aerobic speed, and gait kinematics in recreational runners. The results showed that the continuous group significantly improved (p 0.05) running economy at 60 and 90% of maximal aerobic speed (MAS) without affecting gait, while the interval group significantly increased maximal aerobic speed and stride length at 80, 90, and 100% of MAS and had lower contact time at 100% of MAS.

2.2.1 Strength training

For all serious athletes and sports teams, strength training is now a crucial component of athletic preparation. The optimal way to train for athletic competition, nevertheless, is a hotly debated topic. Athletes, coaches, and exercise scientists disagree on topics including the volume and frequency of training, the type of exercise chosen, and movement tempo(Bruce-Low & Smith, 2007).

According to Blagrove et al. (2018), running economy is enhanced through improvements in mechanical (frequency and stride length), neuromuscular (stretch-shortening cycle, muscle-tendon stiffness, and muscle strength), and morphological (fiber type distribution) aspects. Additionally, an increased mitochondrial density is another crucial factor for middle and long distance running performance (Kravitz & Dalleck, 2002; Pösö et al., 2008).

Other factors, such as the capacity for high power output, are crucial for the final sprint or for times when the athlete executes brief sprints to close the gap between platoons throughout a race (Denadai et al., 2017). In this regard, strength training (ST) is frequently utilized to enhance neuromuscular adaptation in order to boost anaerobic and speed capacity (Cormie et al., 2011; Komi, 1986). Currently, ST is advised in conjunction with cardiopulmonary training and running (Rønnestad & Mujika, 2014).

ST is recommendations for sessions of two to three times a week, with moderate loads (40–70% RM) without reaching concentric failure (Balsalobre-Fernández et al., 2016) or the association of sessions with high loads (> 80%RM) with explosive exercises (Denadai et al., 2017), and in programming the combination of different modalities that is concurrent training session can negatively impact a subsequent session or performance and generate residual acute fatigue (Berryman et al., 2019). This is because different physiological changes, including muscle damage (higher creatine kinase (CK) levels, delayed-onset muscle soreness (DOMS)), kinematic change, higher energy expenditure, neural fatigue, and muscle glycogen depletion, can lead to lower aerobic and anaerobic performance (Doma et al., 2019).

Acute Resistance training causes: increased muscle damage, kinematic changes, increased energy expenditure, increased neural fatigue, and decreased muscle glycogen supply, which leads to poor recovery, less submaximal muscle contractility, and less available energy substrate, resulting in a loss of running session quality. Finally, the repeated decline in quality can impair the development of endurance capacity over time. Regardless of this understanding, many ST protocols, including cross-training exercises, are commonly performed before the practice of running, as identified after the warm-up (Doma et al., 2019). The "acute hypothesis" on the interference of ST adaptation in endurance development would better elucidate the impact that individual training sessions have on the level of endurance response in long-distance runners during running competitions or recreational practice (Doma & Deakin, 2015).

On the other hand, ST could have beneficial effects on variables that are considered to be connected with running performance. Enhancements to the eccentric-concentric transition, such as the activation of a powerful stretch-shortening cycle (Foster & Lucia, 2007); longer strides are the result of force buildup during a brief ground contact (Karp, 2010), and an improvement in force transfer to the inferior segments while running is made possible by greater awareness of the core musculature, which is essential for the transfer of energy from the trunk to the smaller extremities (Kibler et al., 2006).

Strength training, which includes heavy resistance, explosive resistance, and plyometric training that are effective to enhance neuromuscular function, has recently caught the attention of researchers as a potential training modality that improves running economy and running time trial performance for endurance athletes (Cormie et al., 2011; Rønnestad & Mujika, 2014). Middle and long-distance runners of all abilities should consider strength training as a crucial addition to a well-planned training schedule because it can help runners run more effectively, perform better in time trials, and dash with greater speed (Alexander et al., 2020).

This interest is motivated by the fact that the bulk of the energy required for running is used by skeletal muscle (Balsalobre-Fernández et al., 2016; Doma et al., 2019). By altering motor unit recruitment patterns and firing frequency during voluntary muscle contractions, heavy resistance training can enhance muscular strength and/or power (Doma & Deakin, 2015; Foster & Lucia, 2007). The relative intensity of the load placed on the muscles while running may decrease with an increase in muscular strength (Balsalobre-Fernández et al., 2016). As a result, it could aid in enhancing running economy and time trial performance (Karp, 2010).

The capacity to store and use elastic energy more effectively is improved by plyometric training, which primarily entails a variety of jumping activities using the stretch-shortening cycle (SSC) (Kibler et al., 2006), This decreases the amount of energy used when running (Berryman et al., 2018). In order to increase running economy and running time trial performance, high resistance and plyometric training may both be useful training techniques. While both heavy resistance and plyometric training can be used by strength and conditioning specialists to improve running performance, (Page et al., 2021) suggest that plyometric training would be more advantageous for enhancing running economy at faster running speeds.

2.2.2 Hill training

Today's runners are becoming more and more aware of the value of mixing strength training with regular running. It improves general running form, strengthens tendons and ligaments, and lowers the chance of injury (Lehnhard et al., 1996; Micheo et al., 2012). The issue is that the majority of runners train on their strength-related exercises at the gym by performing squats, leg extensions, or arm and shoulder presses. These workouts certainly improve strength and muscle power, but they do it apart from running, concentrating on specific joints and small groups of muscles (Runners world, 2015).

In contrast, hill sessions make athletes' hip, thigh, ankle, and foot muscles engage in unison while bearing their entire body weight, precisely like they must do during regular jogging. Additionally, because your muscles must work harder than usual to lift you up the hill, they contract more forcefully on uphill sections (Runners world, 2015). More power is the consequence, which enables longer, quicker running strides.

Mitchell and Saltin (2003), found that runners who trained on hills had significantly higher concentrations of aerobic enzymes in their quadriceps muscles than those who only ran on flat ground. Aerobic enzymes allow your muscles to work at a high intensity for extended periods of time without becoming fatigued (Bogdanis, 2012). Improved knee lift during running and faster forward motion of each leg while you run are both results of increased aerobic power in your quadriceps (Slater & Hart, 2022). It has also been demonstrated that those who run uphill’s are less likely to lose fitness when they take a break from exercising (Gentilin et al., 2023b). Hill training is also thought by many scientists to increase the flexibility of muscles, tendons, and ligaments, enabling these tissues to perform more work with less effort and exhaustion(Rubio-Peirotén et al., 2025).

In summary, hill training appears to elicit significant physiological and biomechanical adaptations that surpass those obtained through flat-ground running. The elevation in aerobic enzyme concentrations within the quadriceps enhances oxidative capacity, thereby prolonging high-intensity performance. These adaptations contribute to improved running mechanics, such as enhanced knee lift and leg turnover, while also providing protective benefits during periods of detraining. Additionally, evidence indicates that hill running promotes musculoskeletal flexibility and resilience, which may reduce fatigue and risk of overuse injury. Collectively, these findings suggest that hill training is a highly effective modality for improving endurance performance and sustaining long-term fitness.

2.2.2.1 Acute effects of hill running on bio-motor skills, physiological, and biomechanical metrics of running performance

The acute effects of hill running on bio-motor skills, physiological, and biomechanical metrics of running performance are multifaceted, impacting various aspects of athletic capability. Hill running, characterized by increased intensity due to elevation, significantly influences physiological responses, neuromuscular function, and running biomechanics. It places a greater demand on the pulmonary, respiratory, skeletal muscle, and cardiovascular systems to meet the increased oxygen and energy needs during uphill exercise (Lemire, Hureau, et al., 2021; Zouhal et al., 2020). For instance, a study reported that hill running elevates heart rate and oxygen consumption, with studies showing participants reaching 89% of their maximum heart rate and 87% of their VO2max during a timed hill run (Lember et al., 2021). A strong correlation exists between hill running performance and VO2max, indicating that higher aerobic capacity enhances performance on inclines. Chronic hill training leads to lasting adaptations that enhance overall fitness and performance, including improvements in muscular strength and endurance, cardiovascular function, lung capacity, and aerobic capacity (Hellsten & Nyberg, 2015; Hughes et al., 2018; Morici et al., 2016; Vernillo et al., 2016).

The acute effects of uphill running on bio-motor skills are significant, as this form of locomotion imposes unique physiological and biomechanical demands compared to level running. Research indicates that uphill running requires greater muscular activation, particularly in the lower limbs, due to the increased gravitational resistance and the need to elevate the body's center of mass

(COM) against gravity (Okudaira, Willwacher, Kuki, et al., 2021). This results in altered stride mechanics, including shorter stride lengths, increased stride frequency, and reduced ground contact times affecting running performance (Whiting et al., 2020). Electromyographic (EMG) studies have shown that muscles such as the gluteus maximus, vastus medialis, and medial gastrocnemius exhibit heightened activity during uphill running, reflecting the increased mechanical work required for propulsion and stabilization (Okudaira, Willwacher, Kuki, et al., 2021; Whiting et al., 2020). Notably, the soleus muscle shows reduced integrated EMG per stride during steep uphill running compared to lower hill and level running, suggesting a shift in muscular workload distribution.

Biomechanically, uphill running increases the net mechanical work performed by the lower limb muscles, which is crucial for generating the potential energy needed to ascend inclines. This is consistent with findings by Vernillo et al. (2017), who reported that uphill running significantly alters joint kinetics and kinematics, leading to increased energy expenditure and muscle recruitment. These adaptations highlight the importance of uphill running in enhancing specific bio-motor skills such as muscular strength, coordination, and endurance.

Uphill running raises the metabolic cost significantly, with studies showing a 53% increase in metabolic cost at a 7% incline compared to level running (J. Padulo et al., 2013). Net oxygen cost and oxygen kinetics are affected, with elite runners demonstrating a strong correlation between uphill and level running conditions (Willis et al., 2019). Heart rate and blood lactate levels also increase, indicating higher cardiovascular demands during uphill running (Minetti et al., 2002; J. Padulo et al., 2013). The increase in blood lactate on uphill running is caused by the total recruitable muscle mass during running. This means running uphill increases anaerobic demands, resulting in higher lactate production as muscles fight harder to counteract gravity and maintain forward motion. The rise in blood lactate levels reflects the need for anaerobic energy pathways to satisfy the increased metabolic demands of uphill ascents. Despite the majority consensus, some studies didn’t find significant differences among uphill, level, and downhill running groups (Fleckenstein et al., 2021; Held et al., 2023; Lemire et al., 2018; Pringle et al., 2002). There could be several reasons, such as variations in research designs, participant attributes, and contextual variables like individual differences in how they react to different degrees of fitness and exercise intensity.

Cardiovascular response increases as the degree of inclination increases. All the muscles require more energy to function. Uphill running requires greater muscular effort to overcome gravity, leading to increased oxygen consumption and heart rate to supply sufficient oxygenated blood to working muscles. Conversely, some studies found no significant difference in heart rate among uphill, level, and downhill running groups (Held et al., 2023; Lemire, Hureau, et al., 2021; Pringle et al., 2002; Staab et al., 1992). There might be several reasons for this disparity in results, including variations in the research design, participant characteristics, and methodological issues with heart rate monitoring, individual diversity in fitness levels, and adaptability to running circumstances.

Additionally, higher maximal oxygen consumption was reported in uphill running compared to level and downhill running (Fleckenstein et al., 2021; Held et al., 2023; Lemire, Falbriard, et al., 2021; Lemire, Hureau, et al., 2021; Minetti et al., 2002; J. Padulo et al., 2013; Pringle et al., 2002). The reason for higher acute oxygen consumption during uphill running is typically attributed to a potential compromise in the use of elastic energy, which forces the body to generate more mechanical energy in the form of greater concentric muscle activity to lift its center of gravity upward and eventually overcome the slope (Snyder & Farley, 2011). However, two studies failed to show significant differences (Lemire et al., 2018; Staab et al., 1992). This may be due to differences in. This discrepancy suggests variations in training protocols, such as the steepness of the inclination, the length of running sessions, or individual response variability. These subtleties emphasize how difficult it is to research how the body reacts to exercise and how crucial it is to consider a variety of elements that may have an impact on results.

The energy cost of running is expressed by the parameter $C_{r,}$ which is an important measurement in the understanding of metabolic needs in different running circumstances. These studies reported that the energy cost of running (C r) linearly increases with a positive slope (Lemire, Falbriard, et al., 2021; J. Padulo et al., 2013), argued that, every joint in the body, especially the hip, produces more force to meet the higher demands of running up an elevation. This implies that when runners ascend inclines, they use more metabolic energy per unit distance than when they run on flat terrain or downhill. The linear connection shows that energy consumption increases proportionally with climb steepness, reflecting the increased muscular effort necessary to overcome gravitational resistance and sustain forward momentum.

The biomechanical changes that occur during hill sessions can provide information on the short-term effects of this training method, and understanding the acute reactions to hill training is critical for improving session design, clarifying the mechanisms underlying performance improvement, and reducing injury risk (Schubert et al., 2014). Running on an inclined surface is linked to changes in metabolism and running mechanics. Depending on the steepness of the hill and your running abilities, there may be times when power hiking is preferable. This occurs when the cardiovascular effort required becomes very high while having a short stride. Based on previous studies uphill running strategies were associated with increased step frequency (SF) and contact time (CT), and concomitant decreases in step length (SL) and flight time (FT) during both over-ground and treadmill running (J. Padulo et al., 2013; Vernillo et al., 2017) compared to level and downhill running. There is also a notable increase in ground reaction forces, which rise by 12% as the incline increases (J. Padulo et al., 2013). Foot strike pattern shifts towards mid- to fore-foot striking is observed during uphill running, contrasting with rear-foot striking in downhill scenarios (Vernillo et al., 2017).

Some studies like Daniels (2013), recommend athletes to run at 180 steps per minute. This suggestion is predicated on the idea that SF should be constant for all runners, regardless of pace. However, Lieberman et al. (2015) found that faster runners run with greater SFs and that doing so lowers their risk of injury. However, there is conflicting evidence to back up these claims. Numerous studies have demonstrated that both SL and SF have a positive curvilinear relationship with speed, suggesting that the idea that SF is constant throughout running speeds is likely false (Bailey et al., 2017; Mercer et al., 2008). SL increases more rapidly at speeds below ~20 km/h, and SF increases more rapidly at speeds above ~20 km/h. The SL curve at a certain speed may suggest that SL limits a further increase in speed. Stride length and frequency determine running speed. In addition, the running surface, an individual's strength, and physical characteristics all affect stride length and frequency (Van Oeveren et al., 2019).

2.2.2.2 Long-term effects of hill training on bio-motor skills, physiological and biomechanical metrics of running performance

Success in running is said to be the consequence of a complex interaction of factors, including genetics, training, diet, (Rodriguez et al., 2009; Tucker & Collins, 2012), physiological, biomechanical, psychological, and environmental factors (Blagrove et al., 2018). In the development of elite distance runners, uphill running constitutes a commonly recommended and regularly employed type of high-intensity interval training (Ferley et al., 2013). For instance, a survey of teams competing in the Division I national cross-country meet of the National Collegiate Athletic Association in 1996 confirmed its widespread usage as a training technique and found a correlation between uphill training and quicker team times (Kurz et al., 2000). Moreover, its potential efficacy as a high-velocity resistance-to-movement exercise has also been mentioned in academic evaluations (Billat, 2001; Midgley et al., 2007). The effects of uphill training on distance running performance have been compared to those of other high-intensity resistance-to-movement training strategies, including explosive strength training, heavy strength training, and plyometric training.

Recent studies show that these training techniques enhance muscular and neuromuscular properties, which eventually increase movement economy (Kelly et al., 2008; Saunders et al., 2006). This enhances the performance of distance runners. However, compared to other high-intensity resistance-to-movement exercises, uphill running can be seen to represent a much more sport-specific training tactic, and as a result, it may be more successful at enhancing distance running performance (Ferley et al., 2013).

By altering step length and step rate, a variety of training techniques have been employed to increase maximum sprint running performance. High-speed uphill running sessions have been used in training programs designed to enhance sprint performance (Slawinski et al., 2008). Coaches have generally agreed that incline sprint training may enhance level running performance. Training for sprint running frequently involves jogging on slopes. When compared to horizontal sprinting, previous studies that looked at the kinematic changes of sprinting on a 3° slope found that the downhill maximum running speed (MRS) was 8.4% faster and the uphill MRS was 2.9% slower (Paradisis et al., 2009). Similar research, conducted by (Paradisis et al., 2013), found that an 8-week uphill/downhill sprint training program significantly increased the knee flexor muscles' maximum isometric force (7.1%) and rate of force production (25%, P 0.05). The maximal sprinting speed and related kinematic characteristics both improved considerably (5.9%, P0.05) with the combined training.

When expressed as oxygen uptake, the energy cost of running (Cr), which is the amount of energy required to move the subject's body a specific distance, does not change with speed during level running (Di Prampero et al., 1986). Nevertheless, even when normalized for distance travelled, Cr appears to be more responsive to changes in speed when expressed in terms of caloric unit cost (Fletcher et al., 2009; Shaw et al., 2014).

Numerous studies have looked at how Cr is affected by higher gradients. Almost all studies reported a linear increase in Cr with each increase in the slope gradient (Lussiana et al., 2013; Johnny Padulo et al., 2013; Snyder & Farley, 2011), despite some methodological differences in how Cr was expressed (i.e., oxygen cost (ml_kg-1_m-1) or caloric cost (J_kg-1_m-1). In downhill running (DR) compared to level running (LR) and uphill running (UR), total EMG, heart rate, and ventilation have all been consistently reported to decrease when evaluated on a treadmill at various moderate slopes (Abe et al., 2011; Maciejczyk et al., 2013).

The increased net mechanical energy generation needed to offset the potential energy associated with slope increases as Cr in UR increases. In order to increase the center of mass (COM) and compensate for the reduced maximum potential elastic energy storage and return, more muscular activity is thus needed to provide a reasonably large quantity of positive (concentric) effort during the push-off phase (Snyder & Farley, 2011). This finally leads to an increase in Cr.

Energy dissipation is typically more common in DR than energy production. An increase in power production at all joints, particularly the hip, is required to meet the increasing workload as the running slope increases (Arnold et al., 2013). This suggests that UR requires more muscle effort than LR and DR. Energy cost of running (C r) linearly increases with a positive slope, whereas Cr of DR reduces until a minimum slope is reached at −20 %, at which point C r increases once again (Minetti et al., 2002).

According to (Staab et al., 1992), despite the fact that speed on hilly courses varied inversely with percentage grade, participants were unable to sustain constant energy expenditure throughout the race. In fact, the increase in DR pace was insufficient to maintain a constant VO2, as evidenced by the fact that, while switching from LR to UR and from LR to DR, respectively, VO2 increased by 40% and decreased by 27%. According to (Gregor, 1970), this shows that the reduced metabolic needs of DR do not make up for the higher metabolic demands of UR. Last but not least, the impact of slope on biomechanics, muscular contraction patterns, and physiological responses has significant ramifications for the performance of athletes competing in graded running events as well as the avoidance of injuries.

Slightly sloping surfaces are frequently present in endurance races, even though training on slanted surfaces is frequently employed by coaches as targeted strength training (Padulo, Annino, Migliaccio, et al., 2012). Therefore, it is important to investigate the adaptations needed for uphill running. According to some theories, when running on flat ground, athletes adopt technique that is optimized for little metabolic expenditure; nevertheless, as the incline of the surface changes, athletes adjust mechanical factors to obtain maximum metabolic efficiency.

According to Vernillo et al. (2017), several studies investigated the impact of uphill running (UR) on kinematic variables and discovered variations when compared to level running (LR). Compared to LR, UR exhibits higher step frequencies (Lussiana et al., 2013; Telhan et al., 2010), increased internal mechanical work (Minetti et al., 1994a), shorter swing/aerial phase durations, and greater stance times (duty factors), whereas DR exhibits longer aerial times, lower step frequencies, and longer duty factors (Vernillo et al., 2017).

A studies by Mastroianni et al. (2000) and Townshend et al. (2010), also indicated that running speed was observed to drop by 0.1 to 0.3 km/h for every 1% change in gradient, resulting in significant biomechanical, neuromuscular, and physiological adaptations. Understanding these adaptations is crucial for training and competitive purposes since ultra-trail running is likely to push human tolerance to its limits (Millet & Millet, 2012). Uphill running is related to greater metabolic cost, as indicated by Minetti et al. (1994b) and Di Prampero (1986). When metabolic expenditure increases, decreases in step length with accompanying increases in step frequency are used to maintain a constant pace during uphill running (Padulo, Annino, Migliaccio, et al., 2012).

A previous study has shown that running uphill increases energy expenditure (Minetti et al., 2002), increases step frequency, and lowers ground reaction forces (GRF) (Gottschall & Kram, 2005). Step frequency, step length, ground reaction force, and metabolic cost all interact to influence metabolic cost, especially while running uphill.

The correlations between these factors may also be mediated by a differential commitment of the neurological system (J Padulo et al., 2013). Excessive step frequency with shorter step length may increase metabolic expenditure via higher mechanical kinematic internal effort (Johnny Padulo et al., 2013). Excessively low step frequency mixed with prolonged step length may result in higher ground reaction forces and, as a result, increased metabolic expenditure. It is possible that the selected technique aims to optimize step frequency, step length, and ground response force to allow for successful uphill running. Foot striking patterns are similarly modified by hill grade, with a gradual adoption of a mid-to fore-foot strike pattern during UR and a rear-foot strike pattern during DR (Lussiana et al., 2013). Lower limb muscles in UR produce more net mechanical effort than LR and DR to raise the body's potential energy (Vernillo et al., 2017).

2.3 Anaerobic running Performances and the energy system

Muscle fiber recruitment advances from type I to type IIa to type IIx as exercise intensity rises. This indicates that anaerobic metabolism will increasingly be required to provide the ATP required for tension buildup (Reid, 2001). In this sense, weariness is unique to the work that is being performed. The performance-limiting criteria for jobs requiring type IIx fibers will be considerably different from those for tasks needing simply type I fiber recruitment.

2.3.1 Ultra Short-Term Anaerobic Performances (10 Seconds or Less)

The shot throw, high jump, long jump, and the 50- and 100-meter sprints are events that fall within this category (Powers et al., 2007). These events need the recruitment of type II muscle fibers and the production of enormous quantities of energy in a brief amount of time (high-power events). The distribution of muscle fibers (type I vs. type II) and the quantity of muscle fibers recruited, both of which are regulated by the degree of arousal and motivation, are what determine maximum performance (Helge et al., 2007). Optimal performance is also influenced by ability and technique, both of which require practice (Hellström, 2009; Wulf & Lewthwaite, 2016). It should come as no surprise that the energy is supplied by anaerobic ATP sources such as the ATP-PC system and glycolysis. However, in these ultra-short episodes, the energy release required for performance is governed largely by the demand created by neuromuscular drive and is not restricted by intramuscular energy supply (Bundle & Weyand, 2012).

Recruiting the proper type II fibers to provide the necessary greater forces output is essential for optimal performance in events lasting ten seconds or fewer (Fry, 2004; Kraemer & Newton, 2000). Arousal and motivation are necessary, as is the ability to control the force, and anaerobic energy is the main source, with phosphocreatine (ATP-PC) as the main component.

2.3.2 Short-Term Anaerobic Performances (10–180 Seconds)

Maximum performances in the 10 to 60-second range are still largely (>70%) anaerobic, employing the high force, fast-twitch fiber, but when maximum performance is prolonged to three minutes, roughly 60% of the energy comes from the slower aerobic, ATP-producing processes (Powers et al., 2007). As the race time extends from 10 to 180 seconds, the maximal running speed falls, and the switch from anaerobic to aerobic energy generation occurs. Given that the ATP-PC system can only supply ATP for a few seconds, anaerobic glycolysis will provide the vast majority of ATP. H+ will build up as a result in the blood and muscles. By impairing troponin's capacity to bind to Ca++, the increased H+ concentration may hinder the continuing synthesis of ATP via glycolysis or the contractile mechanism itself. After exhaustive activity, muscular tension recovers before the H+ concentration does (Powers & Jackson, 2008; Tipton & Charles M., 2006). This highlights the complexity of the fatigue process. Some athletes have tried taking buffers before a race to reduce H+ accumulation.

2.4 Aerobic running Performances and the energy system

As the length of time of an all-out performance increase, energy demand is placed more on the aerobic sources of energy. Furthermore, environmental factors such as heat and humidity, as well as dietary factors such as water and carbohydrate ingestion, contribute to fatigue (Burke, 2001; Maughan et al., 2007).

2.4.1 Moderate aerobic Performances (3–20 Minutes)

Although aerobic processes account for 60% of ATP production in a 3-minute maximal effort, this figure rises to 90% in a 20-minute all-out effort (Powers et al., 2007). Given this reliance on oxidative energy generation, performance is limited by both the circulatory system, which distributes oxygen-rich blood to the muscles, and the mitochondrial composition of the muscles participating in the exercise (Bassett & Howley, 2000; Strasser & Burtscher, 2018). Speed is a need for races lasting less than 20 minutes, therefore in addition to the type I fibers that have previously been recruited, type IIa fibers, which are rich in mitochondria, are also engaged in providing ATP aerobically. The athlete with the greatest VO2max has a clear advantage since races lasting fewer than 20 minutes are run at 90%–100% of peak aerobic power (Powers et al., 2007).

Although type IIx fibers are also recruited, lactate and H+ production are elevated, and H+ accumulation would affect tension development as previously mentioned (Powers & Jackson, 2008; Tipton & Charles M., 2006). According to Lepretre et al. (2005), training and genetics both have an impact on the maximum stroke volume, which is essential for having a high cardiac output. According to Hasan (2013), Astorino and Robergs (2003), the arterial oxygen content (CaO2) is affected by arterial hemoglobin content [Hb], fraction of inspired oxygen (FIO2), and PO2 of the inspired air.

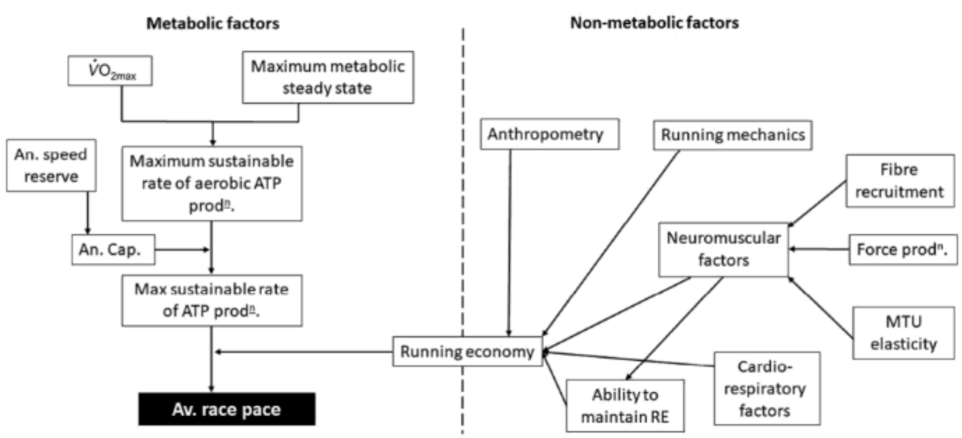


Figure 2 Deterministic model of middle and long-distance running performance. Adopted from (Blagrove & Hayes, 2021), An. = anaerobic, ATP= adenosine triphosphate, Av. = average, Cap. = capacity. MTV= muscle tendon unit, prodn. = production, RE = running economy, VO2max = maximal oxygen uptake. The figure demonstrated how both metabolic and non-metabolic factors interact to determine average race pace.

In summary, running performance is determined by a wide range of interacting factors rather than a single physiological measure. As illustrated in Figure 2, performance outcomes such as average race pace are shaped by both metabolic factors (e.g., VO_2max, lactate threshold, anaerobic capacity) and non-metabolic factors (e.g., running mechanics, neuromuscular efficiency, anthropometry, and cardiorespiratory function).

Theoretical frameworks of the study

This study is grounded in the General Adaptation Syndrome (GAS) theory which explains how the human body responds and adapts to stress (McGuigan, 2017). Training load acts as a physiological stressor that stimulates adaptation in body systems responsible for performance improvement. According to GAS, the body reacts to training stress in three distinct stages: alarm, resistance, and exhaustion (Cunanan et al., 2018). When applied to uphill training, these stages explain the adaptations in physiological, neuromuscular, sychological and biomechanical parameters of running performance. Building on this, Figure 3 provides a broader perspective by showing how training influenced by nutrition and genetics to collectively act to shape multiple domains including physiological capacity, biomechanical efficiency, psychological attributes, and neuromuscular adaptations.

Figure 3 The theoretical framework illustrates training as a stimulus that initiates physiological stress in the body. Through the GAS stages (alarm, resistance, and exhaustion), adaptations occur in, physiological, neuromuscular, biomechanical and psychological components, which ultimately influence running performance improvement or decline.

Building on the theoretical foundations of the general adaptation syndrome (GAS) theory, this study proposes a conceptual framework that illustrates how hill training influences running performance. A well-structured training program particularly one incorporating varied uphill gradients serves as a potent stimulus for enhancing key physical, physiological, and biomechanical variables. These adaptations are not isolated; rather, they interact synergistically to improve overall running efficiency and endurance. The framework visually maps this progression, showing how different slopes of uphill training feed into training load, which in turn drives improvements across bio-motor skills, physiological capacity, and biomechanical function culminating in enhanced running performance.

Figure 4 a conceptual framework for the study how uphill training influence bio-motor skills, physiological and biomechanical metrics of middle-distance running performance. The figure illustrates how varying gradients of uphill training; shallow, intermediate, and steep serve as targeted stimuli to enhance running performance through adaptations in bio-motor skills, physiological capacity, and biomechanical efficiency.

CHAPTER 3: RESEARCH METHODOLOGY

3.1 Research design

A quantitative research approach specifically true experimental study design or randomized control trial (RCT) was employed to examine the effect of steeper, intermediate and shallow hill training on bio-motor skills, physiological and biomechanical metrics of moderately trained middle-distance runners. The researcher employed pre-test post-test measurements, and the three groups received the treatment in parallel, with a fourth group serving as a control. Within-group and between-group comparisons were performed both pre- and post-intervention. The pretest results were necessary for the researcher to determine the degree of group equity or to preserve internal validity among four groups of the study at the beginning of the study, and the post-test results were used to evaluate the rate of change after the intervention and to identify the highest change observed from the group over time as a result of the intervention.

3.2 Study Area

The study was conducted in Bahir University, Bahir Dar town, Amhara Regional state, Ethiopia. Bahir Dar is located at the south shore of Lake Tana at an altitude of 1,820 meters (5,970 ft) above sea level. The city is located approximately 578 km north-northwest of Addis Ababa and 175km to Gondar to its North with about 455,901 inhabitants per 213.4km^2 area (Ethiopian statistics agency 2022); it is the third largest city of Ethiopia, after capital of Addis Ababa, and Dire Dawa. Bahir Dar has a borderline tropical savanna climate very close to a subtropical highland climate. Afternoon temperatures are very warm to hot year-round, and morning temperatures cool; however, the diurnal range is much larger in the largely cloudless dry season. Bahir Dar is one of the leading tourist destinations in Ethiopia, with a variety of attractions in the nearby Lake Tana and Blue Nile River. The city

3.3 Variables in the study

3.3.1 Dependent Variable

The dependent variables of the study were bio-motor skills, including maximal velocity (V_{max}), strength endurance, and time trial performance, physiological metrics including VO_2max, vVO_2max, RHR, and recovery heart rate (HRR) as well as biomechanical measures (spatiotemporal variables) including cadence, step length, ground contact time, and flight time.

3.3.2 Independent Variables

The three uphill gradients were shallow (SHG ~2.5%), intermediate (IHG ~5.1%), and steeper (STHG ~7.6%) were used as an independent variable for the study.

3.4 Participants of the Study

The study targeted moderately trained middle-distance runners. To maintain internal validity and due to limited resources, participants were recruited from Bahir Dar University athletics project. A total of 40 athletes (24 males and 16 females) participated in the study. The mean age was 18.54 ± 1.02 years for males and 17.44 ± 1.09 years for females. The entire population of middle-distance runners within the project was selected using cencus sampling. Athletes who met the inclusion criteria were randomly assigned to one of the four groups: (1) a steep hill gradient training group, (2) an intermediate hill gradient training group, (3) a shallow hill gradient training group, and (4) a control group. Each group consisted of 10 participants.

3.5 Sampe size determination

The main objective of this study was to determine the effects of three uphill training gradients on bio-motor skills, physiological, and biomechanical metrics of middle-distance runners. The sample size estimation was derived from the general rule of thumb for two-way mixed (time [pre-post] X group) repeated measure analysis of variance (Two-way RM-ANOVA). The ideal sample size for our investigation was determined by using G*Power -statistical power analysis software version 3.1.9.4 (Faul et al., 2007). Based on the results of the previous study, all the responses within each subject group are assumed to be normally distributed within group standard deviation for each measurable variable (Bissas et al., 2022), and to detect a 0.62 effect size between the pre and post experimental group with a power of 80% at a significant level of 0.05, the estimated sample size we need was 36 participants. By providing an additional allowance of 10% sample recruitment, due to possible dropout, the required sample size had been increased to 40.

is known for its wide avenues lined with palm trees and a variety of colorful flowers. In 2002, it was awarded the UNESCO Cities for Peace Prize for addressing the challenges of rapid urbanization and Lake Tana region is a UNESCO Biosphere Reserve since 2015. Bahir Dar is known in sport by its football clubs such as Bahir Dar Kenema and Amhara Wuha Sira plays in the Ethiopian Premier League.

3.6 Ethical considerations

The study was conducted in accordance with principles of the Declaration of Helsinki in the use of human subjects, and within the laws and regulations of the country in which the research was conducted. Informed consent was used as a main ethical clearance for the study, so participants were fully informed of: who the researcher are, what the intent of the research is, what data will be collected from participants, how the data will be collected from participants, what level of commitment is required from participants, how this data would be used and reported, and what are the potential risks of taking part in the research.

After that, both parents/legal guardians of minors and minors/participants themselves provided written informed consent to take part in the study, including understanding their rights to access to their information and the right to withdraw at any time. The dignity and well-being of students would be protected at all times, always protected, and the data remained confidential throughout the study, which means participant anonymity or participant's identity was unknown to the researcher.

3.7 Inclusion and exclusion criteria

The inclusion criteria were as follows: all healthy youth middle-distance runners in Bahir Dar University Sport Academy with no muscular, neurological, or tendon injuries and willing to participate in the study. The exclusion criteria were: athletes with less than 6 months of training experience, athletes having recently recorded a musculoskeletal injury in the previous 3 months, and those taking any medications.

3.8 Instruments of Data Collection

The study was conducted using a true experimental study design; therefore, data were collected from pre-test and post-test scores of the experiment. The scores from the pre-test were used to see the degree of group equity before conducting the treatment or to preserve internal validity among the four groups. On the other hand, the scores from post-test were used to measure whether the implemented training influenced the experimental group or not. Therefore, after reviewing the available scientific literature, feasibility, availability of instruments, equipment, and the relevance of the variables to the study, the following variables and instruments were used to collect pre-test and post-test scores of the groups selected for the present study.

Table 1 Bio-motor skills, physiological, and biomechanical variables with type of test used

No.	Variables to be measured	Type of test
	Bio-motor skills	
1.	Maximal velocity (Vmax)	V_{30m} run test
2.	Time trial performance (TT)	800m run test
3.	Strength endurance	Burpee (Squat Thrust & Jump)
	Physiological variables	
1.	Maximal aerobic capacity (VO_2max)	Astrand treadmill protocol
2.	Minimum velocity for VO_2max (vVO2max)	6min run test
3.	Resting heart rate (RHR)	Radial pulse count per min
4.	Recovery heart rate (HRR)	Radial pulse count per min after 1min
	Biomechanical variables	
1.	Cadence (step rate)	Direct count using video-cam on 30m (no of steps per min)
2.	Step length	Using a formula, SL=distance / No of steps
3.	Ground contact time (GCT)	Using Kinovea 0.9.5 motion analysis
4.	Flight time	Using Kinovea 0.9.5 motion analysis

3.9 Data collection procedure

Baseline data collection was carried out during the last two weeks of June (20–30) in four structured sessions. Prior to testing, participants were fully briefed on the nature of the assessments and the devices to be used, and a two-week familiarization period with treadmill running was provided to reduce learning effects and ensure reliable measurements. Informed consent was obtained from participants and, in the case of minors, from their parents or guardians. To protect privacy, each athlete was assigned a unique code, and all data were stored securely in sealed envelope.

At baseline, anthropometric and demographic characteristics (age, height, body weight, and sex) were recorded. A food frequency questionnaire was also administered weekly to monitor habitual dietary intake, thereby controlling for potential nutritional confounders.

Testing sessions were conducted at BDU running track and BDU fitness center in standardised conditions. Prior to each session, participants completed a warm-up consisting of 10 minutes of easy running (5–10 $km \cdot h^{-1}$), dynamic stretching of the lower limbs, and practice accelerations to ensure readiness. More than 12 hours of rest were enforced between sessions to minimize fatigue carryover.

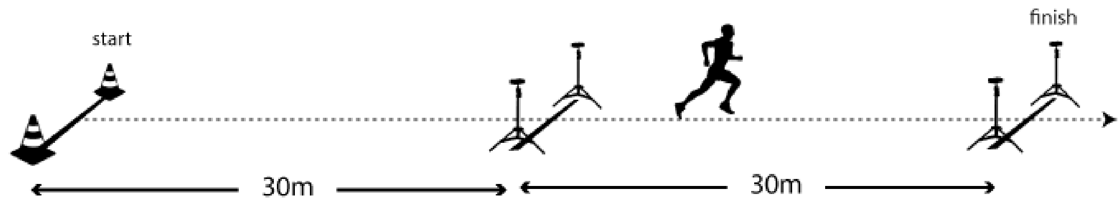
To align with the study objectives, the following sequence of tests was administered: day – 1; maximal sprint speed (Vmax), recovery heart rate (HRR), strength endurance (SE, via burpee test), day – 2; resting heart rate (RHR), time trial performance (800m), day – 3; minimal velocity at VO_2max (vVO_2max), and finally, day – 4; maximal aerobic capacity (VO_2max). This order was selected to move from less fatiguing to more exhaustive tests, while still capturing both bio-motor and physiological performance indicators relevant to middle-distance running. Biomechanical variables (cadence, stride length, contact time, and flight time) were concurrently derived from the Vmax test using high-speed video analysis.

After baseline measurements were collected, the intervention program was implemented at the Bahir Dar University Sport Academy Fitness Center using motorized treadmills. Performance tests were administered both indoors at the fitness center (using the treadmills) and outdoors on the running track at the Bahir Dar University Stadium. Following the intervention period, the same testing protocol as the baseline was repeated to assess training-induced changes in performance variables. Together, the chosen assessments provided a comprehensive evaluation of aerobic capacity, anaerobic endurance, neuromuscular performance, and running biomechanics each of which directly addresses the research aim of understanding the effects of uphill training in youth middle-distance athletes.

3.9.1 Administration Procedure for bio-motor skills

Bio-motor skills were assessed through measures of maximal sprint speed, time-trial performance, and strength endurance. Maximal sprint speed (Vmax) was evaluated using a flying 30 m sprint protocol, which provides valid indicators of peak running velocity in middle-distance athletes. Time-trial performance was assessed through an 800 m run, chosen because it closely resembles the athletes' competitive event demands, thereby offering a sport-specific measure of anaerobic and aerobic endurance. In addition, a burpee test was administered to quantify strength endurance, as it engages both upper and lower body musculature and provides a practical field-based indicator of muscular endurance. Together, these assessments captured the athletes' speed, endurance, and overall functional fitness.

For general warm-up, low-intensity aerobic running for 10 minutes, followed by dynamic stretching movements for 5 minutes to stretch the lower extremity muscles (Moran et al., 2017) were used. Measuring tape or marked track, stopwatch, high-speed camera, cone markers, and a flat and clear surface of at least 100 meters were used to make tests. Cones were set up at 0, 30m, and 60m along a straight line. Measurements were performed by placing a high-speed camera at the start and end points of the 30-meter track. The test involved a 30m acceleration area to enable the runner to get up to their maximum speed, then maximal sprinting over 30 meters. The researcher gave hints to the tester, who was provided hints for maximizing speed (such as keeping low, driving hard with the arms and legs), and encouraged them to continue running with maximum effort past the finish line. Three trials with 6–8 min recovery times between repetitions were allowed, and the best time was recorded to the nearest two decimal places. The timing starts when the athlete's torso passes through the start of the 30 m cone and finishes at the 60 m cone marker (Çelik et al., 2021; Lesinski et al., 2014). With these results, the athlete has a recorded time of their sprinting speed over 30 meters.



To test time trial running performance, speed endurance (anaerobic capacity) or to measure the client's anaerobic endurance, which is important for activities that require high intensity activity to be sustained for longer periods of time, 800m run test can be considered an anaerobic capacity test that is a bit long (Selvan & Sundar, 2018). 400m oval or running track, stopwatch, recording sheets and marker cones were used to take the test. The aim was to complete the 800-meter course in the quickest possible time. To start the test, the client stands behind the starting line, and on the command 'go,' the clock will start, and they will begin running at their own pace. Cheering or calling out the elapsed time was also permitted to encourage the participants. The total time taken to run 800m was recorded.

To measure the strength endurance of a runner, the burpee test was taken as a good option for this study. While some tests concentrate on a specific area of the body or set of muscles, burpee tests are a total body workout in which the participant attempts to perform the maximum number of burpees in the allotted time (Wood, 2017). Stopwatch, and a non-slip surface were equipment needed to test strength endurance using burpee.

To start the test, standing straight with the arms by the side is the usual starting posture for a burpee. Squat down from the standing posture and place your hands in front of your feet. The legs are pushed back into a push-up stance with a straight line from the shoulders to the heels while the body weight is transferred to the hands. Returning to a squatting position after pulling the legs back will allow you to stand up straight again. From standing back to the standing position is one full burpee. The aim is to perform as many burpees as possible within the given time.

3.9.2 Administration Procedure for physiological variables

Physiological performance was examined using standardized assessments of aerobic capacity and cardiovascular function. Maximal aerobic capacity (VO_2max) was measured using the Astrand Treadmill Test, a widely validated protocol that progressively increases incline until exhaustion. This test was selected because it is both reliable and feasible in young athletes. To complement this, the minimum velocity required to elicit VO_2max (vVO_2max) was determined using the six-minute run test, which has been shown to provide a valid field estimate of maximal aerobic speed. Cardiovascular function at rest and during recovery was assessed through radial pulse measurements of resting heart rate (RHR) and recovery heart rate (HRR), providing insight into autonomic regulation and fitness adaptations.

The Astrand Treadmill Test was used to get a quick and accurate measurement of VO_{2max} (Topend sports, 2019). The Astrand protocol maintains a constant running speed with a 2.5% increase in gradient every two minutes, until exhaustion (GRANT et al., 1999; Peric & Nikolovski, 2017). A treadmill on which we can adjust the gradient, and a stopwatch, were the materials needed for this test.

To start a test the treadmill speed was set to 5 miles/hr (8 km/hr). Subjects run at this speed for three minutes, at 0% grade. The gradient was then increased to 2.5% while maintaining the same speed. After every two minutes thereafter, the gradient was increased by 2.5% (keeping the same speed), until the athlete reached exhaustion. When the athlete is unable to continue, the assistant stops the stopwatch and records the time. The total time (expressed in minutes and fractions of a minute) that the subject lasted was recorded, and we use it in the following formula to calculate VO_{2max}. $VO_{2max} = (time \times 1.444) + 14.99$

The maximal aerobic speed (vVO_2max) is the slowest speed at which you reach VO_{2max}. Maximal aerobic speed (vVO2max) can be sustained for approximately 6minutes (Billat, Blondel, et al., 1999; Machenzie, 2000). The six-minute run test has been developed as a shorter alternative to the 12-minute Cooper run test. Participants must run for six minutes, attempting to cover the maximum distance possible at that time. It should be noted that some runners can sustain this pace for longer than six minutes. An oval 400m running track, marking cones, recording sheets, and a stopwatch are equipment needed for the test. To begin the test, we placed markers at set intervals around the track to aid in measuring the completed distance. Participants run for 6 minutes, and the total distance covered is recorded. The first few laps were run at a perceived 90% of maximum possible speed and increased to perceived 100% on the last minute. The maximal aerobic speed (vVO_2max) is the average speed for the run. We divided the run distance in meters by the total time in minutes to get a running speed in meters per minute. This is the maximal aerobic speed (vVO_2max).

Radial Pulse count per minute was used as a good option for us to measure resting heart rate. To measure the heart rate at the radial artery, only a stopwatch and a recording sheet were needed. To start the test, the data collector placed his first two fingers on the lower hand at the radial artery until he could feel the beats, and then counted the number of beats for a minute. The data collector was instructed to be careful not to press too hard.

Recovery heart rate (HRR) is a measurement of our heart's ability to return to its normal, resting pace after we finish a workout. It's the difference between our peak heart rate during exercise and our heart rate 1 minute after we stop. HRR is measured in beats per minute (bpm). We used a running track and stop watch to test recovery heart rate. It was measured using radial pulse count by placing the index and middle fingers together on the opposite wrist, about 1/2 inch on the inside of the joint, in line with the index finger. Once we find a pulse, we counted the number of beats we feel within a one-minute period. To calculate HRR, we counted the heart rate immediately after 1 minute the client stopped exercising. Then we counted it again a minute later and noted the difference. Heart rate recovery is normally measured at 1, 2 or 3-minute intervals, with 1-minute HRR being the one that is most used.

3.9.3 Administration Procedure for Biomechanical Variables

Biomechanical parameters were derived from high-speed video analysis of the maximal sprint test. Step frequency (cadence) and step length were calculated from stride patterns over a defined distance, while temporal parameters such as ground contact time and flight time were obtained using motion analysis software (Kinovea). These measures were selected because they provide detailed insight into running mechanics, enabling the identification of potential efficiency gains resulting from uphill training.

Looking at gait from a spatial perspective allows us to measure gait asymmetries related to the distance between steps (step length) and step rates (Gómez-Molina et al., 2017) and from temporal gait parameters, ground contact time and flight time (Nielson et al., 2011) will be measured as follows. We filmed a clear video of the athlete running the race, and we watched the video in slow motion (or scrolled through it slowly by hand) and counted the steps, then we noted the number of steps it took the athlete to cross the finish line. Therefore, stride length was calculated as = race distance / no of steps, while step frequency was calculated as = no steps per distance / (time taken for distance).

To measure an athlete's cadence or step rate, we used a running track, marking cones, a video camera, recording sheets, and a stopwatch. To measure cadence, we set a distance of 30m for athletes to run and recorded the time in seconds. Then we counted the number of times the athlete's left foot (or right foot) hits the ground. We can double that number to account for a full 60 seconds, then double it again to account for both feet. For example: If we counted 40 left foot strikes in 30 seconds, we doubled that to get 80, then doubled that for a total of 160. Therefore, your cadence is 160steps per minute or in step frequency, divide it by 60, which is 2.67steps per second. The number of strides or steps moved per minute is the athlete's cadence, or the number of strides (steps) moved per second is the stride frequency (step frequency).

The most accurate method of measuring step length is to count how many steps you take in 100 meters while running at a comfortable pace (Kai Ng, 2023). Running tracks, marking cones, video camera, recording sheets, and a stopwatch was the equipment we needed to measure step length. To do this, we located a designated 30-meter distance on a 100m track, and we allowed participants to run it three times while recording the run using a video camera. We determine their step length from their best time of the three trials in a recorded video by dividing the distance by the number of steps taken to complete the distance. For example, if we jogged a total of 100 meters in 112 steps, your step length is 0.89 meters.

To measure athletes' temporal variables (contact time and flight time), a video analysis using Kinovea 0.9.5 motion analysis software was used. Video data was collected of the subjects running 30m using a high-speed camera. In accordance with other studies (Hermens et al., 2000; Padulo, Annino, Smith, et al., 2012), the camera was positioned on a 1.5 m high platform to follow and capture them while they run. The film sequences were analyzed offline using Kinovea 0.9.5 motion analysis software. The contact time (CT) and flight time (FT) were calculated by counting the frames in contact and flight on the video data, then dividing by the sampling rate (J Padulo et al., 2013), (1 frame = 240 Hz ≈ 0.0042 s). The CT and FT were calculated for both the left and right foot. The CT was defined and calculated as the time between initial contact with the ground and the last frame of contact before toe-off. The FT was defined and calculated as the time between toe off and subsequent initial contact of the contralateral foot. Initial contact and toe-off will be visually detected. The initial contact was identified based upon visual detection of the kinematic data and identified as the first frame data in which the foot is in contact with the ground. Toe-off is similarly detected based on visual detection of the kinematic data and identified as the first frame in which the toe has visibly lost contact with the ground.

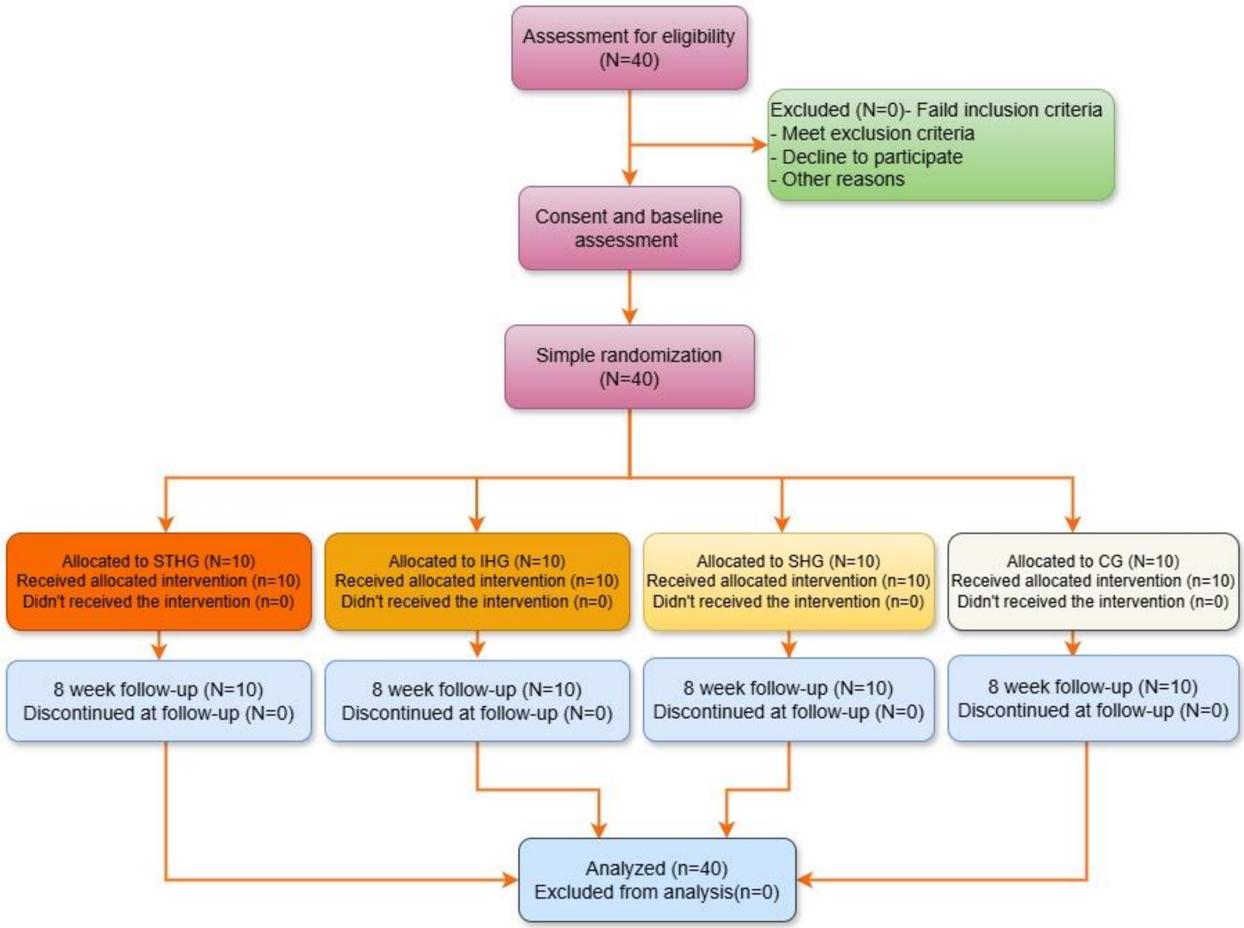


Figure 5 Study flow for steep, intermediate, and shallow hill training modality in bio-motor skills, physiological, and biomechanical variables of the athlete. Adapted from Dowman et al. (2021).

3.10 Method of data analysis

After collecting the data, pre-test and post-test from the experimental group and control group, the researcher measured the score differences from pre-test and post-test of the experimental group and control group using statistical methods to determine the effect size. Since participants are randomly assigned to groups (intervention), the major research question is usually the extent to which statistically significant mean differences exist on dependent variables associated with group membership (within group) and or across the groups. Once significant differences are found, the extent of the mean difference among groups (intervention and control) in terms of dependent variables was assessed.

Statistical analysis was conducted using IBM SPSS Statistics 27 (IBM Corporation). The results for the outcome variables are presented as mean ± standard deviation (SD). A two-way mixed (time [pre-post] X group) repeated-measures analysis of variance (two-way RM-ANOVA) was employed to determine if there were significant differences between pre-training and post-training tests within group and between groups, and any interaction effects for each variable. If significant main effects or interactions were found, post hoc Tukey's HSD test with Bonferroni correction was applied for all pairwise comparisons. The normality of the data was assessed using the Shapiro-Wilk W test, and homogeneity of variance was evaluated with Levene's test. All dependent variables for physiological, biomechanical, and bio-motor skills were analyzed at a significance level of $p < 0.05$. The interpretation of data included the magnitude of the mean ± SD of the mean difference (MΔ), 95% confidence interval (95% CI), and p-values (Batterham & Hopkins, 2006).

CHAPTER 4: RESULTS

4.1 Demographic characteristics of participants of the study

A total of 40 youth middle distance runners (24 males and 16 females) were taking part in the study. The detail demographic characteristics of the participants were presented in Table 2. The participants were randomly assigned to one of the three training groups or the control group. Each group included 10 participants (steep hill group, 7.6%; intermediate hill group, 5.1%; shallow hill group, 2.5%; and control group). The average ages of the athletes in the four groups were 18.50 ± .97, 18.60 ± 1.07, 18.20 ± .63, and 17.10 ± 1.37 years, and the average height was 1.71 ± .04, 1.69 ± .05, 1.71 ± .04, and 1.69 ± .05 for the STHG, IHG, SHG, and CGs, respectively. Additionally, the average weight of the four groups was 54.70 ± 3.83, 54.10 ± 4.01, 54.70 ± 3.83, and 54.10 ± 4.01. Moreover, the average BMI was 18.66 ± 1.04, 18.99 ± 1.50, 18.72 ± .98, and 18.99 ± 1.50, while, the average VO2max was 42.79 ± 4.19, 43.09 ± 3.62, 41.45 ± 4.96, and 42.12 ± 5.08. Finally, a statistical analysis from a weekly food frequency questionnaire showed no significant differences between groups in dietary intake at baseline ($p > 0.05$). Therefore, participants were instructed to replicate their usual diet throughout the intervention period to minimize dietary confounding.

Table 2 Demographic & anthropometric characteristics of the athletes.

Variables	Groups	N	Mean ± SD	Std. error	*95% CI*	
					Lower bound	***Upper bound***
Age (year)	STHG	10	18.50 ± .97	0.31	17.80	19.19
	IHG	10	18.60 ± 1.07	0.34	17.83	19.37
	SHG	10	18.20 ± .63	0.20	17.75	18.65
	CG	10	17.10 ± 1.37	0.43	16.12	18.08
Height (cm)	STHG	10	1.71 ± .04	0.01	1.68	1.74
	IHG	10	1.69 ± .05	0.02	1.65	1.73
	SHG	10	1.71 ± .04	0.01	1.68	1.74
	CG	10	1.69 ± .05	0.02	1.65	1.73
Weight (kg)	STHG	10	54.70 ± 3.83	1.21	51.96	57.44
	IHG	10	54.10 ± 4.01	1.27	51.23	56.97
	SHG	10	54.70 ± 3.83	1.21	51.96	57.44
	CG	10	54.10 ± 4.01	1.27	51.23	56.97
BMI (kg/m^2)	STHG	10	18.66 ± 1.04	0.33	17.92	19.40
	IHG	10	18.99 ± 1.50	0.47	17.91	20.07
	SHG	10	18.72 ± .98	0.31	18.02	19.42
	CG	10	18.99 ± 1.50	0.47	17.91	20.07
VO2max (ml/kg/min)	STHG	10	42.79 ± 4.19	1.32	39.79	45.79
	IHG	10	43.09 ± 3.62	1.14	40.49	45.68
	SHG	10	41.45 ± 4.96	1.57	37.89	45.00
	CG	10	42.12 ± 5.08	1.61	38.49	45.76

Values are expressed as means ± standard deviations (SD). STHG = steeper hill group training group, IHG = intermediate hill group, SHG = shallow hill group, CG = control group, CI = confidence interval, BMI = body mass index, VO2max = maximal oxygen consumption.

4.2 Effects of uphill training on Bio-motor skills

Table 3 summarizes the within-group, between-group as well as interaction effects of the intervention on Vmax, TT, and SE performance. The statistical analysis of all of the pre-training assessments revealed no statistically significant differences among groups in all variables. This demonstrates that groups that were similar at baseline were created by the randomization process, which provides a solid foundation for comparing the three uphill groups to the control group.

Table 3 Changes in the bio-motor skills of middle-distance runners before and after the follow-up.

Variables	STHG (n = 10)		p-Value	IHG (n = 10)		p-Value	SHG (n = 10)		p-value	CG (n = 10)		p-value	p-Value (η_p^2)		
	Pre	Post		Pre	Post		Pre	Post		Pre	Post		Group	Time	Interaction
Vmax (m s^{-1})	7.46 ± 0.75	8.74 ± 0.55	0.001	7.34 ± 1.06	7.93 ± 0.79	0.001	7.31 ± 0.50	7.65 ± 0.55	0.001	7.17 ± 0.76	7.17 ± 0.76	0.933	0.049 (0.20)	0.001 (0.82)	0.001 (0.78)
TT (min)	2.11 ± 0.08	1.53 ± 0.18	0.001	2.07 ± 0.19	1.64 ± 0.25	0.001	2.07 ± 0.18	2.01 ± 0.24	0.152	2.11 ± 0.06	2.12 ± 0.06	0.872	0.001 (0.39)	0.001 (0.81)	0.001 (0.78)
SE (burpee)	20.30 ± 2.40	25.80 ± 2.65	0.001	20.60 ± 2.63	23.40 ± 3.40	0.001	19.70 ± 2.49	20.40 ± 2.54	0.097	19.40 ± 2.36	18.90 ± 1.59	0.231	0.004 (0.30)	0.001 (0.75)	0.001 (0.77)

Values are expressed as means ± standard deviations. STHG = steeper hill group, IHG = intermediate hill group, SHG = shallow hill group, Vmax = maximal velocity, TT = time trial performance, SE = strength endurance

A two-way repeated measure ANOVA revealed a significant time effect on Vmax (F (1, 36) = 173.68, $p < 0.001$, $\eta_p^2 = 0.82$), indicating that Vmax significantly changed over the training period, as indicated in Table 3. Average Vmax were significantly higher on post-test result (M = 7.87 ± 0.86 $m \cdot s^{-1}$) than pre-test result (M = 7.32 ± 0.77 $m \cdot s^{-1}$). Additionally, there is a significant main effect of hill gradient level on Vmax (F (3, 36) = 2.87, p = 0.049, $\eta_p^2 = 0.20$), suggesting differences in Vmax between the different hill gradients as indicated in Tables 3 and 4. Vmax were significantly higher on STHG (M = 8.74 ± 0.55 $m \cdot s^{-1}$), than IHG (M = 7.93 ± 0.79 $m \cdot s^{-1}$), SHG (M = 7.64 ± 0.54 $m \cdot s^{-1}$), and CG (M = 7.16 ± 0.76). There was also a significant interaction effect between time and hill gradient level (F (3, 36) = 42.67, $p < 0.001$, $\eta_p^2 = 0.78$), indicating that the effect of training time on Vmax varied depending on the hill gradient. The post hoc Tukey's Honestly Significant Difference (HSD) indicated that Vmax was significantly higher in the STHG compared to the CG (MΔ = 0.93, 95% CI [0.06 - 1.81], p = 0.032). No statistically significant differences were detected in all other possible pairs of comparisons ($p > 0.05$). The overall findings are presented in Table 4.

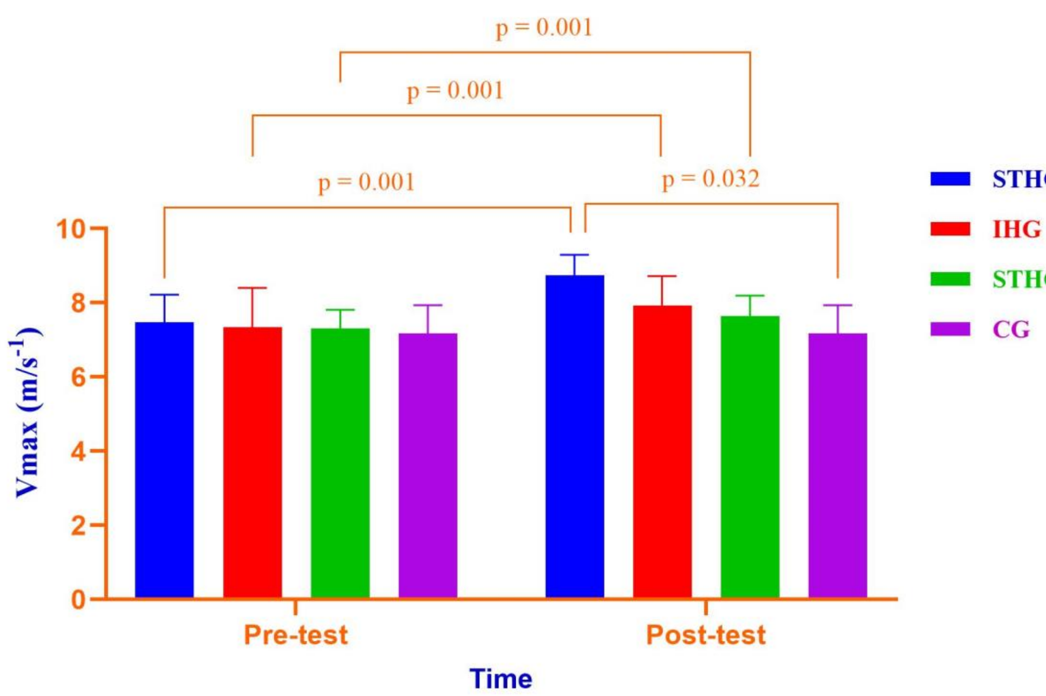


Figure 6 Within and between-group effect of hill training on maximal velocity across various gradients

The analysis for time trial performance revealed a statistically significant time effect of ($F(1, 36) = 155.02$, $p < 0.001$, $\eta_p^2 = 0.81$), indicating that TT performance significantly changed over the training period. Average time trial performance was significantly lower in the post-test result (M = 1.82 ± 0.31 min) than in the pre-test result (M = 2.09 ± 0.14 min). Additionally, there is a significant main effect of hill gradient level in TT ($F(3, 36) = 7.60$, $p < 0.001$, $\eta_p^2 = 0.39$), suggesting differences in TT between the different hill gradients. TT was significantly lower in STHG (M = 1.53 ± 0.18 min) than in IHG (M = 1.64 ± 0.25 min[1]), SHG (M = 2.0 ± 0.24 min), and CG (M = 2.11 ± 0.66 min). There was also a significant interaction effect between time and hill gradient level ($F(3, 36) = 44.01$, $p < 0.001$, $\eta_p^2 = 0.78$), indicating that the effect of training time on TT varied depending on the hill gradient. The post hoc Tukey's HSD indicated that TT was significantly lower in the STHG compared to the SHG and the CG (MΔ = - 0.22, 95% CI [- 0.41 - 0.02], p = 0.023), and (MΔ = - 0.29, 95% CI [- 0.48 – 1.00], p = 0.001) respectively. It was also observed a lower TT in IHG compared to the CG (MΔ = - 0.25, 95% CI [- 0.45 – (- 0.06)], p = 0.006). No statistically significant differences were observed in all other possible pairs of comparisons (p > .05) (Table 4).

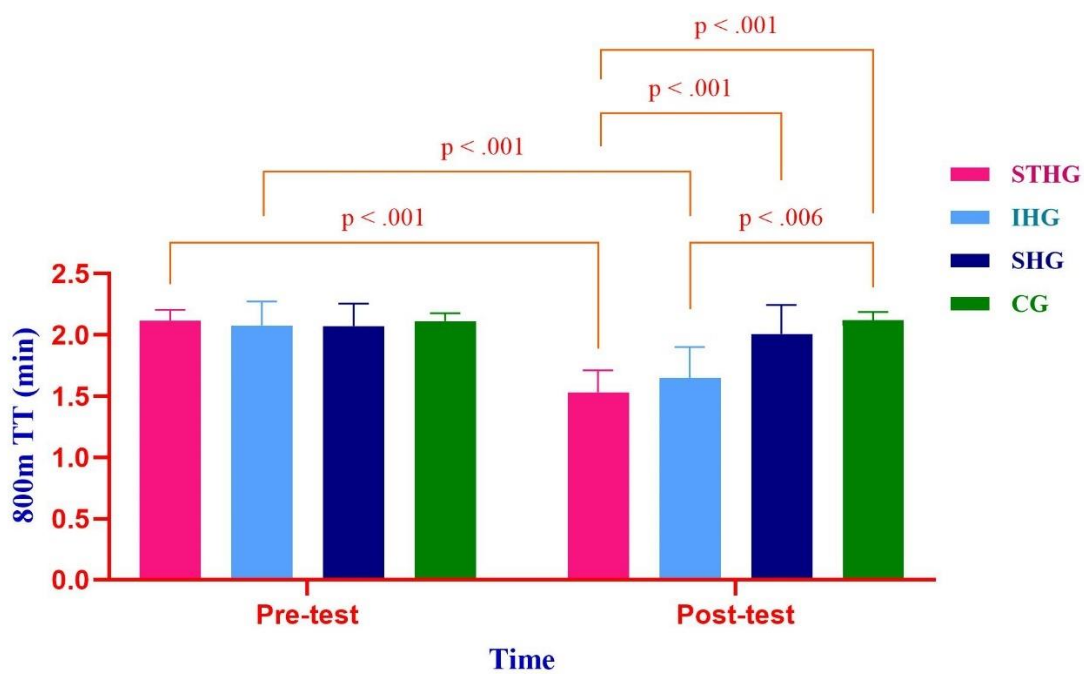


Figure 7 Within and between group effect of hill training on 800m TT performance across various gradients

In addition, the analysis for SE showed a significant time effect of (F (1, 36) = 107.12, p < 0.001, η_p^2= 0.75), indicating that SE significantly changed over the training period. The average SE was significantly higher on the post-test result (M = 22.12 ± 3.70 burpee) than the pre-test result (M = 20.0 ± 2.43 burpee). Additionally, there is a significant main effect of hill gradient level on SE (F (3, 36) = 5.19, p = 0.004, η_p^2= 0.30), suggesting differences in SE between the different hill gradients. SE were significantly higher on STHG (M = 25.80 ± 2.66 burpee) than IHG (M = 23.40 ± 3.40 burpee), SHG (M = 20.40 ± 2.55 burpee), and CG (M = 18.9 ± 1.60 burpee). There was also a significant interaction effect between time and hill gradient level (F (3, 36) = 41.05, p < 0.001, η_p^2= 0.77), indicating that the effect of training time on SE varied depending on the hill gradient. The post hoc Tukey's Honestly Significant Difference (HSD) indicated that SE was significantly higher in the STHG compared to the SHG and the CG (MΔ = 3.0, 95% CI [0.02 – 5.97], p = 0.048), and (MΔ = 3.9, 95% CI [0.92 – 6.87], p = 0.006) respectively. No statistically significant differences were detected in all other possible pairs of comparisons (p > .05), (Table 4).

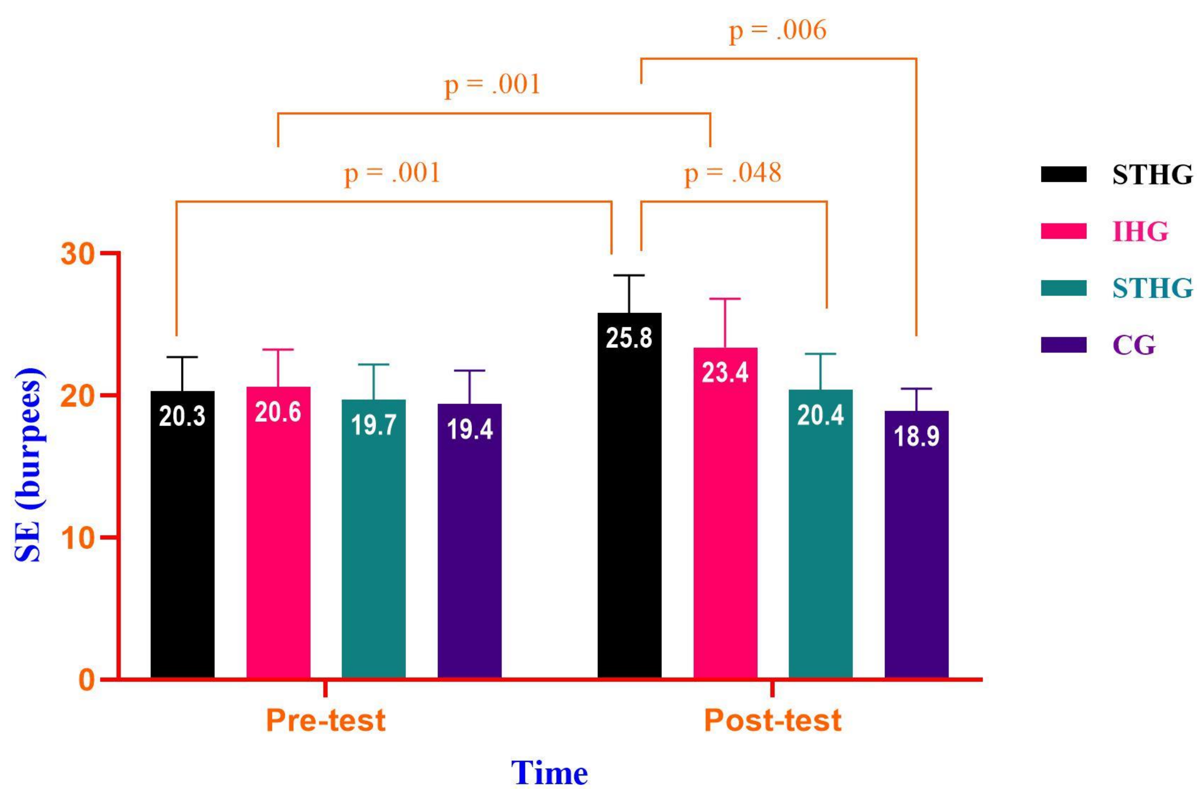


Figure 8 Within and between group effect of hill training on SE across various gradients

Table 4 Between-group effects of intervention on bio-motor skills

Variables	Pairwise Comparison					
	Treatment groups	Mean difference	St. error	Sig.[b]	95% CI	
					Lower bound	Upper bound
Vmax (m/s^{-1})	STHG – IHG	0.47	0.32	0.489	- 0.41	1.34
	STHG – SHG	0.62	0.32	0.236	- 0.25	1.50
	STHG – CG	0.93*	0.32	0.032	0.06	1.81
	IHG – SHG	0.15	0.32	0.963	- 0.72	1.03
	IHG – CG	0.46	0.32	0.487	- 0.41	1.34
	SHG - CG	0.31	0.32	0.776	- 0.56	1.18
TT (min)	STHG – IHG	- 0.04	.072	0.948	- 0.23	0.15
	STHG – SHG	- 0.22*	.072	0.023	- 0.41	- 0.02
	STHG – CG	- 0.29*	.072	0.001	- 0.48	- 1.00
	IHG – SHG	- 0.18	.072	0.083	- 0.37	0.02
	IHG – CG	- 0.25*	.072	0.006	- 0.45	- 0.06
	SHG - CG	- 0.08	.072	0.716	- 0.27	0.12
SE (burpee/min)	STHG – IHG	1.05	1.10	0.778	-1.92	4.02
	STHG – SHG	3.00*	1.10	0.048	0.02	5.97
	STHG – CG	3.90*	1.10	0.006	0.92	6.87
	IHG – SHG	1.95	1.10	0.307	- 1.03	4.93
	IHG – CG	2.85	1.10	0.065	- 0.13	5.83
	SHG - CG	0.90	1.10	0.847	- 2.08	3.88

* Significantly different at ($P<0.05$) as determined by two-way repeated measure ANOVA, and post-hoc Tukey's HSD test, Vmax: maximal running velocity, TT: time trial performance, SE: strength endurance, CI: confidence interval, STHG: steeper hill group, IHG: intermediate hill group, SHG: shallow hill group, and CG: control group.

4.3 Effects of uphill training on Physiological parameters

Table 5 summarizes the within-group, between-group and the interaction effects of the intervention on VO2max, vVO2max, HR, and RHR. The statistical analysis of all of the pre-training assessments revealed no statistically significant differences between groups in all variables. This also demonstrates that groups that were similar at baseline were created by the randomization process, which provides a solid foundation for comparing the three uphill groups to the control group on physiological parameters of running performance.

Table 5 Changes in the physiological parameters of middle-distance runners before and after the follow-up.

Variables	**STHG (n = 10)**		***p*-Value**	**IHG (n = 10)**		***p*-Value**	***SHG (n = 10)***		**p-value**	***CG (n = 10)***		**p-value**	***p*-Value (η_p^2)**		
	Pre	**Post**		**Pre**	**Post**		**Pre**	**Post**		**Pre**	**Post**		**Group**	**Time**	**Interaction**
VO2max (ml/kg/min)	41.67 ± 1.28	48.04 ± 3.04	0.001	41.23 ± 1.40	46.16 ± 2.31	0.001	41.99 ± 1.25	43.04 ± 1.85	0.007	42.12 ± 1.39	42.15 ± 1.42	0.92	0.003 (0.31)	0.001 (0.89)	0.001 (0.85)
vVO2max (km/h)	14.41 ± 0.39	15.41 ± 0.61	0.001	14.51 ± 0.43	15.22 ± 0.55	0.001	14.46 ± 0.39	14.75 ± 0.47	0.12	14.36 ± 0.38	14.48 ± 0.39	0.50	0.012 (0.26)	0.001 (0.48)	0.007 (0.28)
HR (bpm)	66.8 ± 1.62	65.2 ± 0.92	0.001	67.1 ± 1.20	66.0 ± 1.56	0.006	67.0 ± 1.33	66.8 ± 1.81	0.60	66.9 ± 1.20	67.0 ± 1.25	0.79	0.31 (0.09)	0.001 (0.27)	0.01 (0.26)
RHR (bpm)	137.3 ± 4.90	133.7 ± 4.74	0.001	137.9 ± 4.46	136.0 ± 3.74	0.014	138.5 ± 4.43	138.1 ± 3.84	0.59	136.1 ± 5.38	136.8 ± 5.92	0.35	0.59 (0.05)	0.001 (0.26)	0.001 (0.35)

Values are expressed as means ± standard deviations. STHG = steeper hill group, IHG = intermediate hill group, SHG = shallow hill group, VO2max = maximal oxygen consumption, vVO2max = velocity at maximal oxygen consumption, HR = resting heart rate, RHR = recovery heart rate.

A two-way mixed RM-ANOVA revealed a significant time effect on VO2max ($F(1, 36) = 291.63$, $p < .001$, $\eta_p^2 = 0.89$), indicating that VO2max significantly changed over the training period, as indicated in Table 5. Average VO2max was significantly higher on post-test result (M = 44.85 ± 3.13 ml/kg/min) than pre-test result (M = 41.75 ± 1.33 ml/kg/min). Additionally, there is a significant main effect of hill gradient level on VO2max ($F(3, 36) = 5.50$, $p = 0.003$, $\eta_p^2 = 0.31$), suggesting differences in VO2max between the different hill gradients. VO2max were significantly higher on STHG (M = 48.04 ± 2.60 ml/kg/min) than IHG (M = 46.16 ± 2.31 ml/kg/min), SHG (M = 43.04 ± 1.85 ml/kg/min), and CG (M = 42.15 ± 1.42 ml/kg/min). There was also a significant interaction effect between time and hill gradient level ($F(3, 36) = 70.25$, $p < .001$, $\eta_p^2 = 0.85$), indicating that the effect of training time on VO2max varied depending on the hill gradient. The post hoc Tukey's Honestly Significant Difference (HSD) comparisons showed pre-post training differences at $p < .05$ for the STHG (MΔ = 6.37, 95% CI [5.64 – 7.11], p = .001), IHG (MΔ = 4.94, 95% CI [4.20 – 5.67], p = .001), and the SHG (MΔ = 1.04, 95% CI [0.31 – 1.78], p = .007). However, no change was observed in the CG, p = 0.92 (Table 5). Additionally, a significant difference was observed between STHG and SHG (MΔ = 2.34, 95% CI [0.34 – 4.34], p = .016), STHG and CG (MΔ = 2.72, 95% CI [0.72 – 4.72], p = .004), IHG and CG (MΔ = 1.56, 95% CI [0.05 – 3.07], p = .043). No statistically significant differences were detected in all other pairs of comparisons $p > 0.05$ (Table 6).

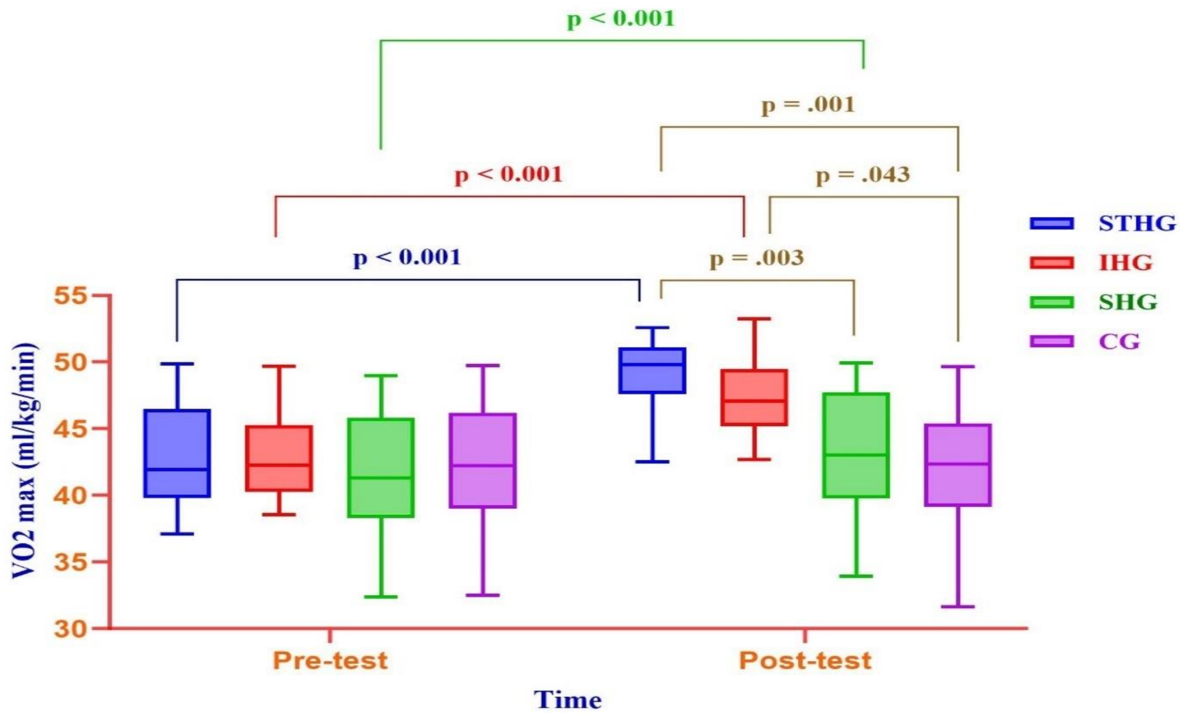


Figure 9 Within and between groups effect of hill training onVO2max across various hill gradients

The analysis for vVO2max revealed a statistically significant time effect of (F (1, 36) = 33.47, p < .001, η_p^2= 0.48), indicating that vVO2max significantly changed over the training period. The average vVO2max was significantly higher in the post-test result (M = 14.97 ± 0.62 km/h) than in the pre-test result (M = 14.44 ± 0.39 km/h). Additionally, there is a significant main effect of hill gradient level on vVO2max (F (3, 36) = 4.20, p = 0.012, η_p^2= 0.26), suggesting differences in vVO2max between the different hill gradients. vVO2max were significantly higher on STHG (M = 15.41 ± 0.61 ml/kg/min) than IHG (M = 15.22 ± 0.55 ml/kg/min), SHG (M = 14.76 ± 0.47 ml/kg/min), and CG (M = 14.48 ± 0.39 ml/kg/min). there was also a significant interaction effect between time and hill gradient level (F (3, 36) = 4.67, p < .007, η_p^2= 0.28), indicating that the effect of training time on vVO2max varied depending on the hill gradient.

The post hoc Tukey's Honestly Significant Difference (HSD) comparisons showed a pre-post training difference at p < 0.05 for the STHG (MΔ = 1.01, 95% CI [0.63 – 1.38], p < .001), and IHG (MΔ = 0.70, 95% CI [0.33 – 1.08], p < .001). However, no significant change was observed in the SHG, p = 0.12 and CG, p = 0.50 (Table 5), Additionally, a significant difference was observed between STHG and CG (MΔ = 0.49, 95% CI [0.06 – 0.92], p = .019), IHG and CG (MΔ = 0.44, 95% CI [0.02 – 0.87], p = .038). However, no statistically significant differences were detected in all other pairs of comparisons p > 0.05 (Table 6).

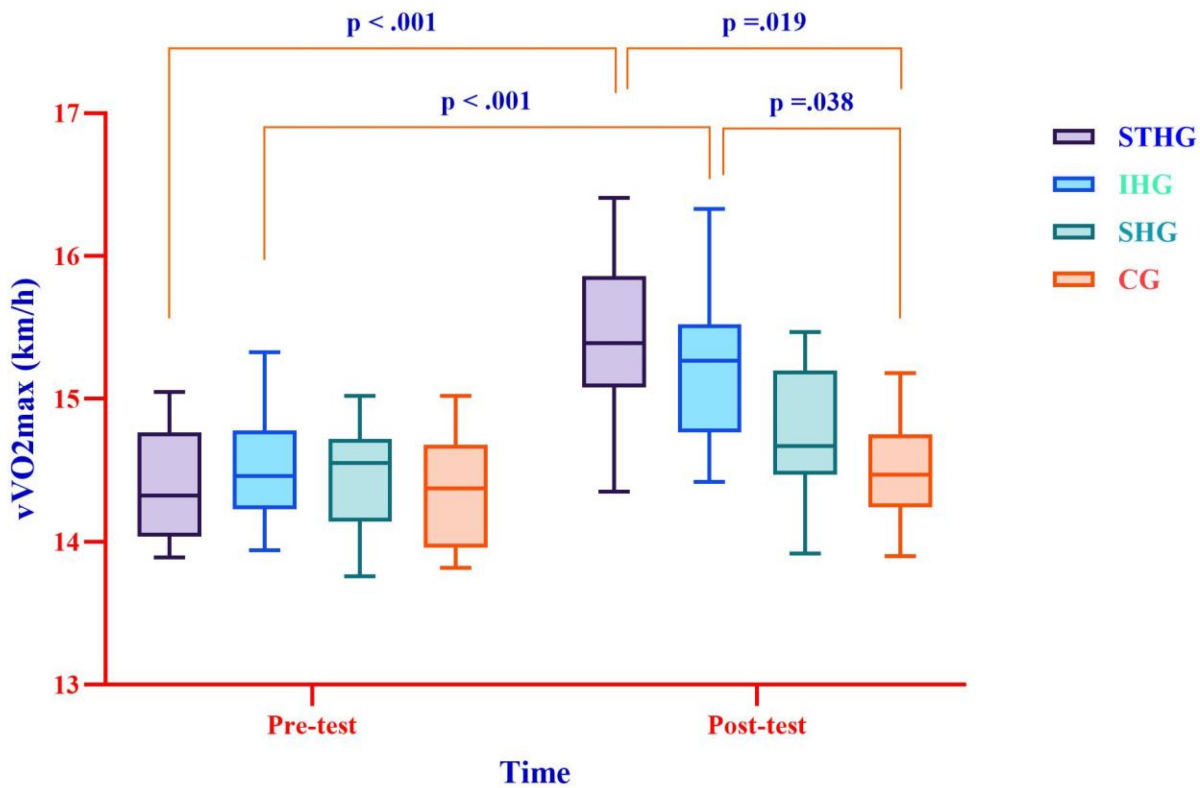


Figure 10: Within-between groups effect of hill training on vVO2max in two time points

Concerning HR, the result showed a significant time effect (F (1, 36) = 13.62, p < .001, η_p^2= 0.27), indicating that HR significantly changed over the training period. The average HR was significantly lower on the post-test result (M = 66.25 ± 4.55 bpm) than the pre-test result (M = 66.95 ± 4.56 bpm). In addition, there was also a significant interaction effect between time and hill gradient level (F (3, 36) = 4.31, p = .011, η_p^2= 0.26), indicating that the effect of training time on HR varied depending on the hill gradient. The post hoc Tukey's Honestly Significant Difference (HSD) comparisons showed a pre-post training differences at the 0.05 level for the STHG and the IHG (MΔ = - 1.60, 95% CI [- 2.37 – (- 0.83)], p < .001), (MΔ = - 1.10, 95% CI [- 1.87 – (- 0.33)], p = .006) respectively. All other pairwise comparisons showed no differences (Table 6).

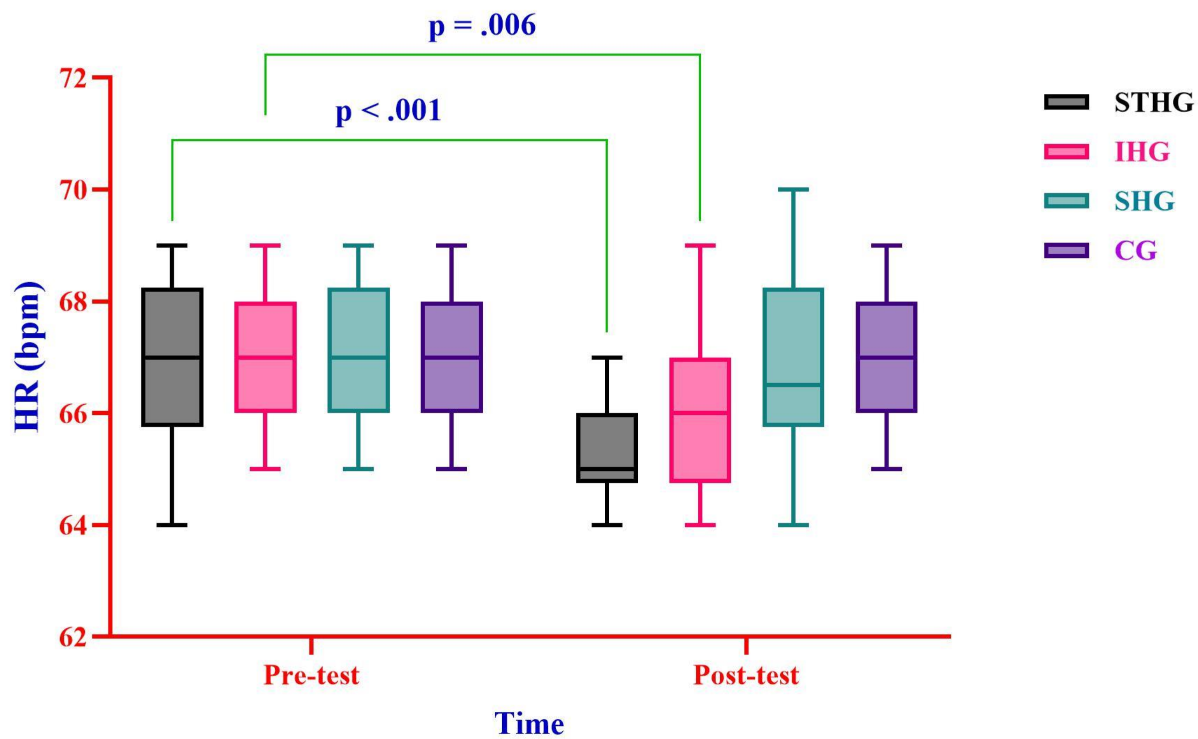


Figure 11: Within-between groups effect of hill training on HR in two time points

Lastly, the analysis for RHR also showed a significant time effect (F (1, 36) = 12.43, p = .001, η_p^2= 0.26), indicating that RHR significantly changed over the training period. The average RHR was significantly increased on the post-test result (M = 136.15 ± 4.75 bpm) than the pre-test result (M = 137.45 ± 4.71 bpm). In addition, there was also a significant interaction effect between time and hill gradient level (F (3, 36) = 6.41, p = .001, η_p^2= 0.35), indicating that the effect of training time on HR varied depending on the hill gradient. The post hoc Tukey's Honestly Significant Difference (HSD) comparisons showed a pre-post training differences at p < .05 for the STHG and the IHG (MΔ = - 3.60, 95% CI [-5.11 – (-2.10)], p < .001), (MΔ = -1.90, 95% CI [-3.41 – (-0.40)], p < .001) respectively. All other pairwise comparisons showed no difference (Table 6).

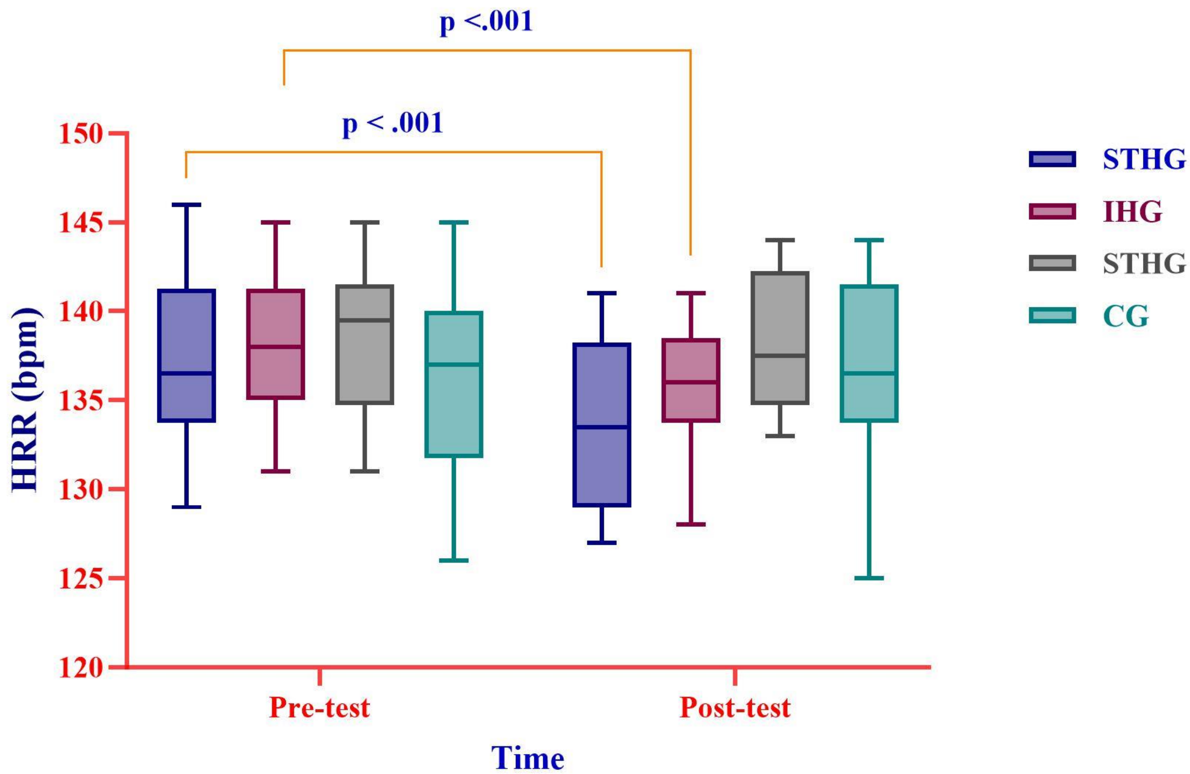


Figure 12: Within-between groups effect of hill training on RHR in two time points

Table 6 Between-group effects of intervention on physiological parameters

Variables	Pairwise Comparison					
	Treatment groups	Mean difference	St. error	Sig.^{b}	95% CI	
					Lower bound	Upper bound
VO2max (ml/kg/min)	STHG – IHG	1.16	0.74	0.41	- 0.84	3.16
	STHG – SHG	2.34*	0.74	0.02	0.34	4.34
	STHG – CG	2.72*	0.74	0.004	0.72	4.72
	IHG – SHG	1.18	0.74	0.39	- 0.82	3.18
	IHG – CG	1.56*	0.74	0.04	- 0.054	3.07
	SHG - CG	0.38	0.74	0.95	- 1.62	2.38
vVO2max (km/h)	STHG – IHG	0.04	.158	0.99	- 0.38	0.47
	STHG – SHG	0.30	.158	0.24	- 0.12	0.73
	STHG – CG	0.49*	.158	0.02	0.06	0.92
	IHG – SHG	0.26	.158	0.37	- 0.17	0.68
	IHG – CG	0.44*	.158	0.038	0.02	0.87
	SHG - CG	0.18	.158	0.65	- 0.24	0.61
HR (beat/min)	STHG – IHG	- 0.55	0.56	0.33	-1.68	0.58
	STHG – SHG	- 0.90	0.56	0.12	- 2.03	0.23
	STHG – CG	- 0.95	0.56	0.09	- 2.08	0.18
	IHG – SHG	- 0.35	0.56	0.54	- 1.48	0.78
	IHG – CG	- 0.40	0.56	0.48	- 1.53	0.73
	SHG – CG	- 0.05	0.56	0.93	- 1.18	1.08
HRR (beat/min)	STHG – IHG	- 1.45	2.05	0.48	- 5.60	2.70
	STHG – SHG	- 2.80	2.05	0.18	- 6.95	1.35
	STHG – CG	- 0.95	2.05	0.65	- 5.10	3.20
	IHG – SHG	- 1.35	2.05	0.51	- 5.50	2.80
	IHG – CG	0.50	2.05	0.81	- 3.65	4.65
	SHG – CG	1.85	2.05	0.65	- 2.30	6.00

* Significantly different at ($P<0.05$) as determined by two-way repeated measure ANOVA, and post-hoc Tukey's HSD test, VO2max: maximal oxygen consumption, HR: heart rate, HRR: recovery heart rate, CI: confidence interval, STHG: steeper hill group, IHG: intermediate hill group, SHG: shallow hill group, and CG: control group.

4.4 Effects of uphill training on biomechanical parameters

Table 7 presents a summary of the within group, between group and interaction effects of the intervention on kinematic characteristics of participants throughout the study. The statistical analysis of the pre-training assessments revealed no statistically significant differences between groups across all variables. This also demonstrates that groups that were similar at baseline were created by the randomization process, which provides a solid foundation for comparing the three uphill groups to the control group.

Table 7 Changes in the biomechanical parameters of middle-distance runners before and after the follow-up.

Variables	STHG (*n* = 10)		*p*-Value	IHG (*n* = 10)		*p*-Value	*SHG (n = 10)*		p-value	*CG (n = 10)*		p-value	*p*-Value (η_p^2)		
	Pre	Post		Pre	Post		Pre	Post		Pre	Post		Group	Time	Interaction
SR (Hz)	4.13 ± 0.41	5.08 ± 0.51	0.001	4.09 ± 0.53	4.70 ± 0.39	0.001	4.11 ± 0.36	4.21 ± 0.38	0.104	4.09 ± 0.36	4.07 ± 0.45	0.723	0.035 (0.21)	0.001 (0.84)	0.001 (0.83)
SL(m)	1.77 ± 0.10	1.80 ± 0.08	0.001	1.75 ± 0.08	1.78 ± 0.08	0.001	1.69 ± 0.09	1.70 ± 0.09	0.147	1.70 ± 0.08	1.70 ± 0.07	0.196	0.066 (0.18)	0.001 (0.52)	0.001 (0.52)
CT (ms)	122 ± 3.33	122 ± 3.23	0.186	122 ± 4.33	121 ± 4.17	0.287	121 ± 4.42	120 ± 4.09	0.067	122 ± 4.20	123 ± 3.52	0.287	0.80 (0.03)	0.114 (0.07)	0.184 (0.12)
FT (ms)	119 ± 4.45	120 ± 3.20	0.618	118 ± 3.30	119 ± 2.83	0.321	117 ± 2.99	118 ± 2.10	0.321	118 ± 2.71	118 ± 3.21	0.321	0.45 (0.07)	0.087 (0.08)	0.98 (0.005)

Values are expressed as means ± standard deviations. STHG = steeper hill group, IHG = intermediate hill group, SHG = shallow hill group, Vmax = maximal velocity, TT = time trial performance, SE = strength endurance.

A two-way mixed repeated measure ANOVA revealed a significant time effect of SR (F (1, 36) = 194.24, p < 0.001, η_p^2= 0.84), indicating that SR significantly changed over the training period. The average SR was significantly higher in the post-test result (M = 4.52 ± 0.59 Hz) than in the pre-test result (M = 4.11 ± 0.41 Hz). Additionally, there is a significant main effect of hill gradient level in SR (F (3, 36) = 2.87, p = 0.049, η_p^2= 0.20), suggesting differences in SR between the different hill gradients. SR was significantly higher in STHG (M = 5.08 ± 0.51 Hz) than in IHG (M = 4.70 ± 0.39 Hz), SHG (M = 4.21 ± 0.38 Hz), and CG (M = 4.07 ± 0.45 Hz). There was also a significant interaction effect between time and hill gradient level (F (3, 36) = 59.37, p < 0.001, η_p^2= 0.83), indicating that the effect of training time on SR varied depending on the hill gradient. The post hoc Tukey's Honestly Significant Difference (HSD) comparisons showed pre-post training differences at p < 0.05 for the STHG (MΔ = 0.95, 95% CI [0.83 – 1.07], p = 0.001), and IHG (MΔ = 0.61, 95% CI [0.50 – 0.73], p = 0.001). However, no significant change was observed in the SHG and CG (Table 3). In addition, SR was significantly higher in the STHG compared to the CG (MΔ = 0.52, 95% CI [0.02 - 1.03], p = 0.04), while no statistically significant differences were detected in all other possible pairs of comparisons p > 0.05 (Table 8).

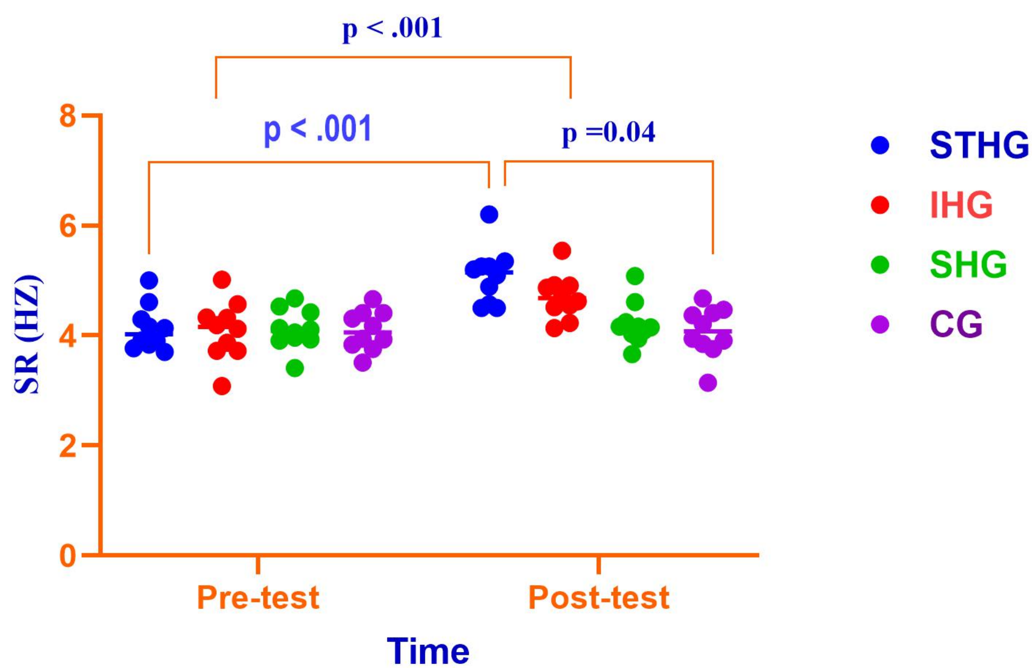


Figure 13 Within groups effect of hill training on SR in two time points

The analysis for SL also showed a significant time effect of (F (1, 36) = 39.09, p < 0.001, η_p^2= 0.52), indicating that SL significantly changed over the training period. The average SL was significantly higher on the post-test result (M = 1.74 ± 0.09 m) than the pre-test result (M = 1.73 ± 0.09 m). In addition, there was also a significant interaction effect between time and hill gradient level (F (3, 36) = 4.02, p < 0.001, η_p^2= 0.52), indicating that the effect of training time on SL varied depending on the hill gradient. The post hoc Tukey's Honestly Significant Difference (HSD) comparisons showed pre-post training differences at the 0.05 level for the STHG and the IHG (MΔ = 0.031, 95% CI [0.019 – 0.043], p < 0.001), (MΔ = 0.028, 95% CI [0.016 – 0.040], p < 0.001) respectively. All other comparisons showed no differences. Lastly, contact time and flight time didn't show significant changes (Table 7).

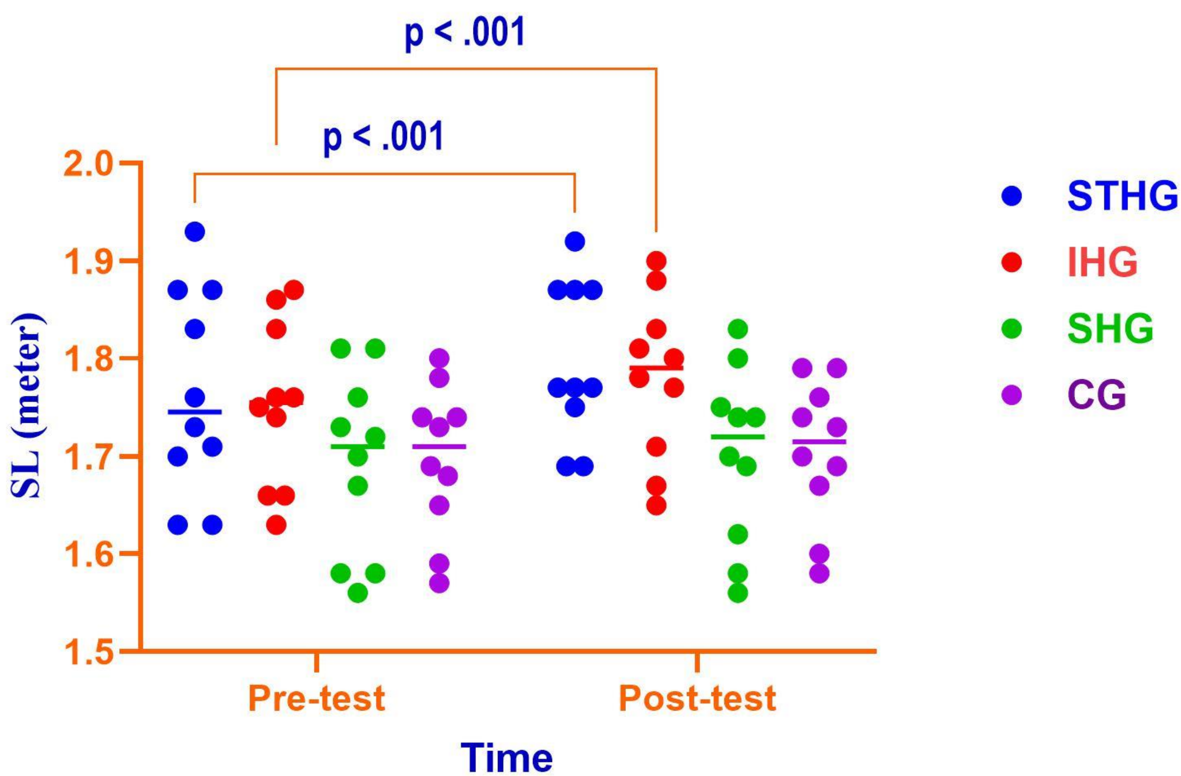


Figure 14 Within groups effect of hill training on SL in two time points

Table 8 Between-subject effects of intervention on biomechanical parameters

Variables	Pairwise Comparison					
	Treatment groups	Mean difference	St. error	Sig.[b]	95% CI	
					Lower bound	Upper bound
SR (HZ)	STHG – IHG	0.21	0.19	.68	- 0.29	0.71
	STHG – SHG	0.44	0.19	.10	- 0.06	0.95
	STHG – CG	0.52†	0.19	.04	0.02	1.03
	IHG – SHG	0.23	0.19	.59	- 0.27	0.74
	IHG – CG	0.31	0.19	.35	- 0.19	0.82
	SHG - CG	0.08	0.19	.97	- 0.42	0.58
SL (m)	STHG – IHG	0.01	0.04	.98	- 0.09	0.12
	STHG – SHG	0.08	0.04	.14	- 0.02	0.19
	STHG – CG	0.08	0.04	.17	- 0.02	0.18
	IHG – SHG	0.07	0.04	.28	- 0.03	0.17
	IHG – CG	0.06	0.04	.34	- 0.04	0.17
	SHG - CG	0.00	0.04	.99	- 0.12	0.10
CT (ms)	STHG – IHG	0.25	1.74	.99	- 4.44	4.94
	STHG – SHG	1.10	1.74	.92	- 3.59	5.79
	STHG – CG	- 0.65	1.74	.98	-5.34	4.04
	IHG – SHG	0.85	1.74	.96	- 3.84	5.54
	IHG – CG	- 0.90	1.74	.95	- 5.59	3.79
	SHG – CG	- 1.75	1.74	.75	- 6.44	2.94
FT (ms)	STHG – IHG	1.00	1.38	.89	- 2.73	4.73
	STHG – SHG	1.90	1.38	.52	- 1.83	5.63
	STHG – CG	1.60	1.38	.66	- 2.13	5.33
	IHG – SHG	0.90	1.38	.91	- 2.83	4.63
	IHG – CG	0.60	1.38	.97	- 3.13	4.33
	SHG - CG	- 0.30	1.38	.99	- 4.03	3.43

† Significantly different at ($P < 0.05$) as determined by two-way repeated measure ANOVA, and post-hoc Tukey's HSD test, Vmax: maximal running velocity, TT: time trial performance, SE: strength endurance, CI: confidence interval, STHG: steeper hill group, IHG: intermediate hill group, SHG: shallow hill group, and CG: control group.

CHAPTER 5: DISCUSSION AND IMPLICATIONS

The main aim of this study was to investigate the effects of training at different uphill gradients on bio-motor skills, physiological and biomechanical metrics running performance among young middle-distance runners. It was hypothesised that, steep, intermediate and shallow hill training will have significant positive effect on bio-motor skills, physiological and biomechanical metrics of running performance among young middle distance runners. Additionally it was predicted that there were no significant difference between the steep, intermediate, and shallow hill group results of the dependent variables.

5.1 Effects of uphill training on Bio-motor skills

The first objective of this study was to examine the chronic effects of uphill training on Vmax, TT performance and SE performance. Additionally, the study aimed to determine the most effective uphill gradient for enhancing these performance measures on moderately trained middle-distance runners. The major findings of the present investigation suggest that 8 weeks of high intensity uphill training can significantly improve the maximal velocity, 800m time trial performance and strength endurance performance (Table 3). To the authors' knowledge, this is among the few studies covering the relative effectiveness of different uphill gradients on Vmax, TT performance, and SE performance. Therefore, the present study demonstrated that steep uphill training ≥7.6% can only significantly improve Vmax compared to the intermediate and the shallow hill groups.

Although studies on the chronic effects of uphill training at steep slopes on the maximal velocity and performances of runners are scarce, research on intermediate combined uphill and downhill sprint training has shown a significant effect on running performance. Combined uphill-downhill training on an intermediate slope of 3° improved maximal velocity by 4.8% in experienced sprinters (Paradisis et al., 2015) and 3.5% in physical education students (Paradisis & Cooke, 2006). Bissas et al. (2022) also reported a 3.7% improvement from a similar design after 6 weeks of training on sport science and physical education students. This is contradictory to the present study, which doesn't show a significant change. This may be due to the combined effect of uphill with downhill training because training on both uphill and downhill gradients may ensure a balanced development of both concentric and eccentric muscle action and development. The resistance encountered during uphill running demands greater force production from the lower limb muscles, particularly the quadriceps, hamstrings, and calves (Okudaira, Willwacher, Kawama, et al., 2021). This heightened muscular effort promotes hypertrophy and neuromuscular adaptations, enhancing the athlete's capacity to generate force rapidly (Paradisis et al., 2013). In contrast, downhill training enhances stride frequency and neuromuscular coordination, both of which are essential components of maximal running speed (Paradisis et al., 2015).

Additionally, uphill running alters stride length and frequency, thereby refining sprinting mechanics and contributing to more effective acceleration and overall speed performance (Lata & Dubey, 2016; Swanson & Caldwell, 2000). However, the reason why the shallow hill might not produce significant change is due to insufficient resistance to significantly overloading the muscles required for sprinting.

This study also showed that steep and intermediate uphill training can improve 800m time trial performance, while the shallow hill training has shown no statistically significant change. The result is supported by previous studies (Barnes et al., 2013; Ferley et al., 2013), while no specific studies support the intermediate hill training result. Barnes et al. (2013) demonstrated that uphill training on a 10 –15% gradient with 100 –110% vVO2max improved 5km time trial performance by 2%. Similarly, Ferley et al. (2013) also reported that a six-week interval uphill training performed on a 10% gradient improved running performance significantly by 2%. This demonstrated that uphill training on intermediate to steeper uphill gradients with some type of high-intensity training can improve 800m time-trial performance by enhancing both anaerobic and aerobic capacities. The anaerobic glycolytic system is highly engaged during uphill running, improving the athlete's ability to tolerate and clear lactate (Mastalerz et al., 2024). This increased lactate threshold allows athletes to maintain higher intensities for longer periods. Additionally, the aerobic benefits of uphill running, such as improved VO2 max and cardiovascular efficiency, contribute to better overall endurance (Held et al., 2023; Lember et al., 2021). Consequently, athletes experience faster 800m times, as they can sustain higher speeds and resist fatigue more effectively. Uphill running can be a more sport-specific training strategy than other high-intensity resistance-to-movement workouts, such as plyometric and weightlifting. Research indicated that enhancing the amount of time spent at or near $\dot{V}$O2max, or the amount of work done at a high intensity, through training such as uphill training is essential because the ability to sustain near maximal efforts in running is highly correlated with running performance in races ranging from 800 m to 10 km (Billat et al., 1998; Held et al., 2023).

The performance in terms of strength endurance also improved across intermediate and steep hill gradients in the present study, but no statistically significant change was found in the shallow hill group. A previous study confirmed that treadmill running at a 10% gradient with 90% maximal aerobic speed can significantly improve muscle endurance by 21.2% (Theofilidis et al., 2021). In addition, uphill training performed at 3^{o} has been shown to increase maximal isometric force and rate of force production in leg muscles, with improvements of 7.1% and approximately 25%, respectively (Paradisis et al., 2013). This indicates that uphill running necessitates greater net mechanical work compared to level or downhill running, leading to enhanced muscular endurance (Vernillo et al., 2017). The continuous effort required to overcome gravity during uphill runs promotes muscular endurance, allowing athletes to perform at a high intensity for extended durations. This type of training also improves running economy, as athletes learn to optimize their stride mechanics and energy expenditure (Praz et al., 2016). As a result, they can maintain a faster pace with less effort over long distances.

The classification of hill gradients into steep, intermediate, and shallow categories is critical for customizing training programs. The effect sizes resulting from time, hill gradient level, and their interaction are presented in Tables 4 and 5. Relative to intermediate hill training, steeper uphill training significantly enhances performance metrics by optimizing biomechanical efficiency, energy expenditure, and kinematic adaptations. This is because a steeper incline leads to distinct kinematic features, such as increased joint angles and higher ranges of motion during sprinting, which are crucial for acceleration (Okudaira, Willwacher, Kawama, et al., 2021), and steep gradients exhibit faster stride frequencies and shorter foot-ground contact times compared to lower hills, indicating a more efficient running gait (Whiting et al., 2020). Although steep and intermediate hill gradients resulted in notable performance benefits, training on shallow inclines does not elicit significant improvements across key performance parameters. This discrepancy may be attributed to differences in muscle recruitment patterns, metabolic demands, and perceptual responses. Steep and intermediate gradients are known to enhance activation of major lower-limb muscles particularly, the gluteus maximus, hamstrings, and quadriceps more effectively than shallow gradients, which may not sufficiently challenge these muscle groups to induce meaningful adaptations (Franz & Kram, 2011; Roussos et al., 2019).

Additionally, compared to intermediate inclines, shallow hill gradients may not sufficiently challenge the body's physiological systems to trigger meaningful adaptations, as they place lower demands on both aerobic and anaerobic energy systems (Lussiana et al., 2013). From a biomechanical standpoint, intermediate gradients can promote more effective force application and stride mechanics, than shallow gradients in improving running economy. Furthermore, the perceived exertion at intermediate gradients may strike an optimal balance challenging enough to drive adaptation, but not so intense as to impair training quality or recovery. In contrast, shallow gradients may not provide sufficient training stimulus, resulting in insignificant performance improvements.

Although treadmill running can replicate certain physiological responses and shows strong correlations with outdoor performance (Brocherie et al., 2014; Mugele et al., 2018; Stevens et al., 2015), its ecological validity remains a subject of debate. For instance, a study confirmed that treadmill running results in longer completion times and higher perceived exertion, along with elevated blood lactate levels compared to outdoor running, suggesting discrepancies in effort and physiological responses (Stevens et al., 2015). Additionally, treadmill conditions may restrict natural running mechanics, particularly affecting acceleration and deceleration patterns that are crucial in outdoor races (Morin & Sève, 2011). Similarly, a study highlighted that treadmill running may not fully replicate outdoor race conditions due to differences in pacing strategy, heart rate responses, and environmental factors, suggesting that performance on a treadmill is generally slower and less motivating than on a track (Peserico & Machado, 2014). This finding suggests that treadmill running offers a controlled setting ideal for monitoring physiological responses and training adaptations enhances experimental reliability and repeatability, it may not fully capture the complexities and demands of outdoor race conditions, including environmental variability such as terrain variability, wind resistance, humidity, temperature, visual cues and physiological conditions experienced during outdoor races limit their ecological validity. These differences can influence running biomechanics, energy expenditure, and psychological responses.

5.2 Effects of uphill training on physiological parameters of running performance

The second objective of this study was to examine the long-term effects of uphill training on physiological parameters of middle-distance runners, and to identify the hill gradient that can best modify those physiological measures. The main findings of the study suggest that 8 weeks of high-intensity uphill training can positively impact key physiological parameters of middle-distance runners. The cross-group results emphasize the efficacy and superiority of the steeper uphill gradients training over intermediate and shallow hill training across all physiological variables (VO2max, vVO2max, RHR, and HRR), while no specific study existed comparing different uphill gradients on these parameters. Research indicated that uphill running could lead to significant improvements in VO2max, with experimental groups showing increases up to 15.69% compared to control groups (Ali, 2024). Another research reported a similar result in VO2max when performed at 11% uphill training for 6 weeks compared to the downhill and control groups (Gentilin et al., 2023a). Moreover, a study also reported that a 7% incline on a lower body positive pressure treadmill led to a notable increase in VO2max and HR compared to level running (Fleckenstein et al., 2021). Uphill training performed at 10% slope improved VO2max and vVO2max in well-trained athletes (Ferley et al., 2013; Sá Filho et al., 2024; Theofilidis et al., 2021).

Barnes et al. (2013), identified an optimal uphill running protocol with elevations of 7-10%, suggesting that this range offers the best balance of intensity and effectiveness for improving aerobic capacity. These results highlight the increased physiological demands of running uphill, which probably lead to increased muscular and cardiovascular adaptations and an increase in VO2 max. However, one study didn’t observe any significant difference between level and uphill running groups (Ferley et al., 2013). This inconsistency illustrates the complexity of training responses and suggests that various factors could influence the effectiveness of uphill training, including training protocols (differences in duration, frequency, and intensity of the training programs), participant characteristics (variations in baseline fitness levels, experience, and individual adaptation capacities), and measurement methods (differences in how VO2max is assessed and interpreted).

The superiority of uphill training in raising physiological parameters can be explained by several factors. Athletes must overcome the increased gravitational resistance when running uphill, which calls for a stronger activation of the lower body muscles. Because of the increased oxygen demand and utilization caused by this increased muscular activation, there may be more adaptations made to the respiratory and cardiovascular systems (Sloniger et al., 1997). Running uphill probably increases mitochondrial density and function, capillary development, and overall cardiovascular efficiency because of its increased intensity. Although level running offers a steady and moderate intensity, these running styles cannot compare to the physiological demands of uphill running (Cai et al., 2010). The higher level of effort needed for uphill running probably results in stronger muscle and cardiovascular adaptations, which boost VO2 max. However, no significant changes were observed in the vVO2max, RHR, and HRR among the shallow hill groups. This may be due to several reasons, such as Shallow hills might not have provided enough intensity or resistance to stimulate cardiovascular adaptations (Midgley et al., 2006). If the incline gradient was too mild, the aerobic and anaerobic systems might not have been challenged adequately.

A study by Du et al. (2005), reported that athletes exhibited faster HR recovery after endurance training performed on a treadmill. This is also true in uphill training, particularly in the form of high-intensity interval exercise, which has been shown to influence recovery heart rate (RHR) by affecting the cardiovascular and autonomic nervous systems. The effects of such training on recovery HR can be attributed to the physiological demands and adaptations induced by the uphill gradient, which can enhance aerobic capacity and heart rate variability (HRV), leading to faster HR recovery post-exercise (Fares et al., 2021; Ibba et al., 2014).

Steep uphill training is increasingly recognized for its superior impact on physiological parameters related to running performance compared to intermediate and shallow hill training. Uphill training raises the ventilatory threshold, indicating better lactate clearance and utilization during high-intensity efforts (Kavaliauskas et al., 2018). Research indicates that steeper inclines significantly enhance oxygen uptake and metabolic demands, which are crucial for improving overall running efficiency and performance. Steeper inclines (e.g., 8%) lead to higher mean and peak oxygen uptake ($\dot{V}$O2mean and $\dot{V}$O2peak) compared to moderate inclines (e.g., 2%) (Held et al., 2023). Uphill running at steep gradients result in greater lactate accumulation, indicating increased anaerobic effort (Doyenart et al., 2022). steeper hills elicit a more significant heart rate response, which is essential for cardiovascular conditioning (Fleckenstein et al., 2021), and it enhances maximal cardiac output through cardiac enlargement and improved contractility, allowing for greater stroke volume and oxygen delivery to muscles (Hellsten & Nyberg, 2015). Finally, Steeper uphill intervals have been shown to enhance running economy, allowing runners to maintain higher speeds with less energy expenditure (Barnes et al., 2013).

5.3 Effects of uphill training on biomechanical parameters of running performance

The third objective of this study was to examine the chronic effects of uphill training on kinematic characteristics of middle-distance runners, with specific attention to identify the hill gradient that can best modify kinematic characteristics of middle-distance runners. The major findings of the present investigation suggest that 8 weeks of high intensity uphill training can positively impact key kinematic characteristics of middle-distance runners. In particular, Vmax was improved across all hill gradients, with substantial improvement observed at the steeper and intermediate hill gradients. While studies directly comparing the long-term effects of different uphill gradients on Vmax are limited, our findings align with earlier research. For instance, Tziortzis (1991) showed a 3.3% improvement after 12 weeks of training on an uphill training slope of 8° on maximal running speed. This supports the notion that steeper gradients may elicit greater neuromuscular and biomechanical adaptations conducive to speed development. The key difference between the present study and the earlier work by Tziortzis is the shorter intervention duration eight weeks compared to twelve and the lower the gradient level (7.6%) compared to (14%). Interestingly, this reduced timeframe and hill gradient was still sufficient to elicit meaningful performance adaptations, suggesting that significant improvements can occur within a relatively brief training period and less steep gradients. Similar studies have reported improvements in maximal running velocity (Vmax) of 3.7% and 3.5% using a 5.24% hill gradient compared to flat-surface training (Bissas et al., 2022; Paradisis & Cooke, 2006). A key distinction between the present study and these previous investigations lies in the training design: while earlier studies employed a combined uphill-downhill training approach, the current study focused on the isolated effects of different uphill gradients. This distinction allows for a more precise understanding of how specific incline levels independently influence performance adaptations.

As the uphill training increases resistance, which helps in building strength and power (Antono & Nugroho, 2022), which are crucial for maximal running speed. The resistance provided by running uphill requires greater force production from the lower limb muscles, particularly the quadriceps, hamstrings, and calves. The rationale for the superiority of the steeper hill gradient against intermediate and shallow hill gradients is due to the increased muscular demand leading to hypertrophy and neuromuscular adaptations, improving the athlete's ability to generate force quickly (Paradisis et al., 2013). Uphill running necessitates more force application, which can increase muscle strength and power, contributing to improved acceleration and maximal velocity (Pajić et al., 2008).

The efficiency of uphill training is further demonstrated by the improvements observed in step rate (SR) and step length (SL), particularly at steeper and intermediate hill gradients. These enhancements were most pronounced at the steeper inclines. Similar findings were reported by (Paradisis et al., 2009; Paradisis et al., 2013), who observed improvements in SR but no significant changes in SL. However, a key difference lies in the study design: the previous studies utilized a combined uphill and downhill training protocol on a 3° gradient, with comparisons made against horizontal and control groups. In contrast, the present study isolated the effects of different uphill gradients, allowing for a more targeted analysis of their specific impact on running kinematics. Notably, there is a lack of experimental data in existing literature examining long-term changes in SR, SL, CT, and FT across varying uphill gradients. This highlights the novelty and contribution of the present study in addressing this gap and providing new insights into the gradient-specific adaptations in running mechanics.

It is well known that incline running modifies the length and frequency of strides, improving sprinting mechanics and allowing athletes to accelerate more effectively (Lata & Dubey, 2016; Swanson & Caldwell, 2000). Sprinting performance requires the legs to traverse through the stride cycle at quicker rates and the muscles to shorten and lengthen more quickly, which is dependent on stride rate (Miller et al., 2012). Acute uphill running leads to increased stride rate and a shorter stride length as runners adjust to the incline by lifting their knees more and keeping their center of gravity over their lead foot (Lata & Rakesh, 2016; Vermand et al., 2022). This, in the long run, improves stride rate and stride length in horizontal running performance. Compared to intermediate and shallow hill training, steep hill training increases the body's potential energy by having lower limb muscles execute a higher net mechanical work. All joints, but especially the hip, produce more power to meet the increased needs of work as the running inclination rises. This suggests that compared to intermediate and shallow hill training, steep hill training necessitates higher levels of muscle activation.

Therefore, adaptations to uphill training directly impact neuromuscular activation, which ensures the overall efficiency of movement, including step rate and step length (Vernillo et al., 2017). The study also demonstrated a significant difference among training groups in Vmax and SR, while no significant difference was observed in the rest of the variables (SL, CT, and FT). Vmax and SR were significantly different in STHG compared to the control group. This suggests that uphill training at these gradients is particularly effective in enhancing maximal sprinting speed, likely due to increased neuromuscular demand and biomechanical adaptations. While the absence of significant changes in step rate (SR) and step length (SL) in the shallow hill gradient (SHG) group, as well as in contact time (CT) and flight time (FT) across all training groups, may initially seem unexpected, several plausible explanations can be considered. One key factor is the relatively short duration of the intervention, eight weeks, which, although sufficient to elicit improvements in certain performance variables such as Vmax and SR, may not provide enough time for more subtle neuromuscular and biomechanical adaptations to manifest in all kinematic parameters. Previous research suggests that longer training periods are often required to elicit measurable changes in variables such as CT and FT, especially when the training stimulus is moderate (Hardin et al., 2004).

Additionally, the specificity of the training stimulus plays a crucial role. The training protocols may have been more effective in targeting velocity-related adaptations rather than those influencing temporal gait characteristics like CT and FT. For instance, improvements in Vmax and SR may result more directly from enhanced force production and stride mechanics, whereas changes in CT and FT might require more focused interventions, such as plyometric or technique-specific drills. Studies have shown that resisted sprint training (e.g., sleds, uphill running) tends to produce moderate effects on acceleration and step frequency, but not always on CT or FT when compared to traditional sprinting (Myrvang & van den Tillaar, 2024).

Individual variability in response to training is another important consideration. Although baseline characteristics of the participant were not significantly different, individual athletes may differ in their baseline kinematic profiles, neuromuscular efficiency, and adaptability, which can influence how they respond to a given training stimulus. This variability can dilute group-level statistical significance, even when individual improvements are present. Finally, it is also possible that certain kinematic parameters, particularly CT and FT, are more resistant to change and may require either a longer training duration or a higher training volume and intensity to produce measurable effects (Myrvang & van den Tillaar, 2024). Future studies with extended intervention periods, larger sample sizes, and more targeted training modalities may help clarify these relationships and further elucidate the mechanisms underlying kinematic adaptations to uphill training.

CHAPTER 6: CONCLUSION AND FUTURE DIRECTIONS

6.1 Conclusion

The present study investigated the effects of three different uphill training gradients on bio-motor skills, physiological, and biomechanical parameters of running performance among young middle-distance runners. The study revealed that steeper uphill training at 7.6% can improve all bio-motor skills (Vmax, TT, and SE). Additionally, the intermediate uphill training at 5.1% can also improve 800m time trial performance, while no significant change was observed from the shallow hill training on each performance parameters. The steep hill gradient is the most effective gradient across all biomechanical measurements.

The findings of this study also demonstrate clearly the beneficial effects of uphill training on physiological parameters that are linked with middle-distance running performance. An uphill training program of 8 weeks with 2 times per week can make a difference in physiological parameters in a range of sports. The result demonstrated that as little as 2.5% to 7.6% uphill training can improve VO2max, while intermediate to steep uphill training can significantly improve the vVO2max, recovery heart rate, and resting heart rate. It was also concluded that steeper uphill training was most effective hill gradient in improving the selected physiological parameters of performance. As a result, the study offers original and pragmatic guidance to coaches and athletes to use hill training as an instrument in the development and maintenance of performance among various athletic disciplines requiring greater aerobic capacity, providing the ability to generate a high-power output through ground reaction forces for high velocities over moderate distances. In addition, intermediate hills could be applied to longer distances, requiring relatively less power output and efficient use of energy through improved running mechanics and running economy.

Furthermore, the results of this study demonstrated the positive effects of uphill training on key kinematic characteristics of middle-distance runners that are related to maximal running speed. The gains in Vmax were supported by improvements in SR and SL in favor of steeper uphill gradients. Different uphill training gradients appear to elicit specific training adaptations, implying that uphill training should be carefully tailored to the athlete's strengths and limitations. Until further evidence is available, runners can presume that changes in a range of kinematic characteristics induced by modifying the uphill-running loadings will result in improvements in key kinematic characteristics. This could be applicable in middle-distance runners, requiring large anaerobic capacity, providing the ability to generate a high power output through ground reaction forces for high velocities over moderate distances (Thompson, 2017). In addition, intermediate hills could be applied to longer distances, requiring relatively less power output and efficient use of energy through improved running mechanics and running economy (Weston et al., 2000). Moreover, coaches and athletes need to consider and apply uphill training as an efficient alternative training strategy for improving the kinematic characteristics of middle-distance runners.

6.2 Limitations

While this study constitutes a first in the literature, comparing the chronic effects of three different uphill gradients on bio-motor skills, physiological and biomechanical parameters of running performance among young middle-distance runners, it has methodological limitations that need to be acknowledged and addressed in the future. Due to the small number of participants available in the field, the study included a range of training experiences (6 months to 4 years), and a mixed gender group was part of the study. These may affect the result of the study, as athletes at different stages of their training journey, and due to gender, may respond differently to the same training regimen. This diversity of the study population may be considered as a limitation. However, the intervention study on athletes having some training experience while using a well-established controlled training protocol can be viewed as an advantage in the current study and for the future development of an efficacious training program.

6.3 Future directions and recommendations

The current study provides novel insights into the effects of uphill training gradients on bio-motor, physiological, and biomechanical parameters among young middle-distance runners. Despite its contributions, the findings also highlight the need for further investigation to refine and expand the application of uphill training in athletic development. The following future directions and recommendations are proposed based on the study's outcomes and acknowledged limitations:

Future research should aim to include a larger and more homogeneous sample to improve statistical power and generalizability. Stratifying participants by training experience, age, and gender will help to better understand specific responses to uphill training interventions and reduce variability due to heterogeneous baseline characteristics. While this study employed an 8-week training period, further investigations should assess the long-term effects of uphill training protocols spanning 12 to 24 weeks or across an entire competitive season. Additionally, exploring how uphill training can be incorporated into different phases of periodized training (e.g., preparatory, pre-competitive, and competitive phases) could offer greater practical relevance to coaches and athletes.

Future studies could benefit from comparing uphill running with other resistance-based training modalities such as resisted sprints (e.g., Tier or sled drag, sand running, or weight-vest training. This comparative analysis could help identify the most effective methods for enhancing specific performance parameters in middle-distance athletes. The result also suggests that steeper gradients (7.6%) are more effective for improving maximal running speed, stride rate, and power-related mechanics, which are critical in shorter middle-distance events like the 800m. Intermediate gradients (5.1%) showed promising results for enhancing the velocity at VO2max and aerobic efficiency (VO2max), which may be more beneficial for events such as the 1500m. Therefore, it is recommended that coaches tailor the selection of hill gradients to the specific physiological and biomechanical demands of different distance events.

To better understand the underlying mechanisms of performance improvements, future studies should incorporate assessments of neuromuscular activity (e.g., electromyography), muscle-tendon properties (e.g., tendon stiffness), and musculoskeletal adaptations (e.g., muscle architecture via ultrasound). Such evaluations would provide deeper insight into how different gradients influence mechanical efficiency and injury prevention. The improvements observed in VO_2 max, vVO_2 max, and other performance indicators suggest that uphill training may be beneficial across various sports beyond middle-distance running, particularly those that require both aerobic endurance and explosive power. Further studies could evaluate the effects of hill training in team sports, endurance sports, and youth athletic development programs.

Based on the current findings, the following practical recommendations are suggested for coaches and practitioners to incorporate uphill training 1–2 times per week in a structured manner, progressively increasing intensity and gradient. Coaches and athletes should utilize relatively steeper gradients (6–8%) for short, high-intensity repetitions (e.g., 60–150 m) to improve sprint mechanics and anaerobic power. Coaches and athletes should employ intermediate gradients (4–6%) for longer intervals (e.g., 200–400 m) aimed at enhancing running economy and aerobic efficiency. Finally, coaches should regularly monitor individual responses to training load and training gradients should be selected based on the athlete's event specialization, training experience, and physiological profile.

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Appendix-I

Table 1: 8-week uphill training protocols for intervention groups (STHG, IHG, and SHG)

1. Steeper Hill Training (7.6%)						
Month	**Week**	**Day**	**Training load**			
			Volume	**Intensity (%Vmax)**	**Recovery b/n rep.**	**Recovery b/n set**
Month-1	Week-1	Day-1	Warm up -15min			
			4x6x30 sec	Comfortable	4min	6min
			Cool down - 10min			
		Day-2	Warm up -15min			
			4x6x30 sec	Comfortable	4min	6min
			Cool down - 10min			
	Week-2	Day-1	Warm up -15min			
			4x8x30 sec	80-85%	4min	6min
			Cool down - 10min			
		Day-2	Warm up -15min			
			4x8x30 sec	80-85%	4min	6min
			Cool down - 10min			
	Week-3	Day-1	Warm up -15min			
			4x10x30 sec	80-85%	4min	6min
			Cool down - 10min			
		Day-2	Warm up -15min			
			4x10x30 sec	80-85%	4min	6min
			Cool down - 10min			
	Week-4	Day-1	Warm up -15min			
			4x6x45 sec	80-85%	4min	6min
			Cool down - 10min			
		Day-2	Warm up -15min			
			4x6x45 sec	80-85%	4min	6min
			Cool down - 10min			
Month-2	Week-1	Day-1	Warm up -15min			
			4x8x45 sec	85-90%	3min	5min
			Cool down - 10min			
		Day-2	Warm up -15min			
			4x8x45 sec	85-90%	3min	5min
			Cool down - 10min			
	Week-2	Day-1	Warm up -15min			
			3x10x60sec	85-90%	3min	5min
			Cool down - 10min			
		Day-2	Warm up -15min			
			3x10x60sec	85-90%	3min	5min
			Cool down - 10min			
	Week-3	Day-1	Warm up -15min			
			3x5x90 sec	90-100%	2min	4min
			Cool down - 10min			
		Day-2	Warm up -15min			
			3x5x90 sec	90-100%	2min	4min
			Cool down - 10min			
	Week-4	Day-1	Warm up -15min			
			3x7x90 sec	90-100%	2min	4min

			Cool down - 10min			
		Day-2	Warm up -15min			
			3x7x90 sec	90-100%	2min	4min
			Cool down - 10min			

2. Intermediate Hill Training (5.1%)						
Month	**Week**	**Day**	**Training load**			
			Volume	**Intensity (%Vmax)**	**Recovery b/n rep.**	**Recovery b/n set**
Month-1	Week-1	Day-1	Warm up -15min			
			2x6x60sec	Comfortable	4min	6min
			Cool down - 10min			
		Day-2	Warm up -15min			
			2x6x60sec	Comfortable	4min	6min
			Cool down - 10min			
	Week-2	Day-1	Warm up -15min			
			2x8x60 sec	80-85%	4min	6min
			Cool down - 10min			
		Day-2	Warm up -15min			
			2x8x60 sec	80-85%	4min	6min
			Cool down - 10min			
	Week-3	Day-1	Warm up -15min			
			2x10x60 sec	80-85%	4min	6min
			Cool down - 10min			
		Day-2	Warm up -15min			
			2x10x60 sec	80-85%	4min	6min
			Cool down - 10min			
	Week-4	Day-1	Warm up -15min			
			2x6x90 sec	80-85%	4min	6min
			Cool down - 10min			
		Day-2	Warm up -15min			
			2x6x90 sec	80-85%	4min	6min
			Cool down - 10min			
Month-2	Week-1	Day-1	Warm up -15min			
			2x8x90 sec	85-90%	3min	5min
			Cool down - 10min			
		Day-2	Warm up -15min			
			2x8x90 sec	85-90%	3min	5min
			Cool down - 10min			
	Week-2	Day-1	Warm up -15min			
			2x10x90sec	85-90%	3min	5min
			Cool down - 10min			
		Day-2	Warm up -15min			
			2x10x90sec	85-90%	3min	5min
			Cool down - 10min			
	Week-3	Day-1	Warm up -15min			
			2x6x2min	90-100%	2min	4min
			Cool down - 10min			
		Day-2	Warm up -15min			
			2x6x2min	90-100%	2min	4min
			Cool down - 10min			
	Week-4	Day-1	Warm up -15min			
			2x8x2 min	90-100%	2min	4min

			Cool down - 10min			
		Day-2	Warm up -15min			
			2x8x2 min	90-100%	2min	4min
			Cool down - 10min			

3. Shallow Hill Training (2.5%)					
Month	**Week**	**Day**	**Training load**		
			Volume	**Intensity (%Vmax)**	**Recovery b/n rep.**
Month-1	Week-1	Day-1	Warm up -15min		
			6x2 min	Comfortable	4min
			Cool down - 10min		
		Day-2	Warm up -15min		
			6x2 min	Comfortable	4min
			Cool down - 10min		
	Week-2	Day-1	Warm up -15min		
			8x2 min	80-85%	4min
			Cool down - 10min		
		Day-2	Warm up -15min		
			8x2 min	80-85%	4min
			Cool down - 10min		
	Week-3	Day-1	Warm up -15min		
			10x2 min	80-85%	4min
			Cool down - 10min		
		Day-2	Warm up -15min		
			10x2 min	80-85%	4min
			Cool down - 10min		
	Week-4	Day-1	Warm up -15min		
			6x3 min	80-85%	4min
			Cool down - 10min		
		Day-2	Warm up -15min		
			6x3 min	80-85%	4min
			Cool down - 10min		
Month-2	Week-1	Day-1	Warm up -15min		
			8x3 min	85-90%	3min
			Cool down - 10min		
		Day-2	Warm up -15min		
			8x3 min	85-90%	3min
			Cool down - 10min		
	Week-2	Day-1	Warm up -15min		
			10x3min	85-90%	3min
			Cool down - 10min		
		Day-2	Warm up -15min		
			10x3min	85-90%	3min
			Cool down - 10min		
	Week-3	Day-1	Warm up -15min		
			6x4 min	90-100%	2min
			Cool down - 10min		
		Day-2	Warm up -15min		
			6x4 min	90-100%	2min
			Cool down - 10min		
	Week-4	Day-1	Warm up -15min		
			8x4 min	90-100%	2min

			Cool down - 10min		
		Day-2	Warm up -15min		
			8x4 min	90-100%	2min
			Cool down - 10min		

Appendix-II

Informed Consent Form - (Parental/legal guardian)

TITLE OF THE STUDY: ***Effects of Uphill Training on Bio-motor skills, Physiological, and Biomechanical Metrics of Middle-Distance Runners***

PRINCIPAL INVESTIGATOR

Name: Yehualaw Alemu

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PURPOSE OF STUDY: The purpose of this study is to determine the effects of hill training modalities on bio-motor skills, physiological, and biomechanical metrics of middle-distance runners, so, dear participants, before you decide to participate in this study, it is important that you have to understand why the research is being done and what it will involve. Please read the following information carefully and ask the researcher if there is anything that is not clear or if you need more information.

STUDY PROCEDURES

To determine the effect of hill training modalities on bio-motor skills, physiological, and biomechanical metrics of middle-distance runners in Ethiopia, the participants will be assigned in to four groups: The experimental group (steeper hill training, intermediate hill training and reduced hill training groups) and the control group. Before treatment is given, an explanation of the intention, goal, and procedure of research followed by the informed consent will be provided as the research feedback. Then, the pre-test will be taken to measure bio-motor skills (Vmax, speed endurance, & strength endurance), physiological metrics (VO2max, vVO2max, RHR, & HRR) and biomechanical measures (stride length, stride frequency, FT & GCT). The test will be given in four different days for each principal component. After the research feedback the treatment (three hill training variations) will be given in high intensity, 2 times a week for 12 weeks in addition to

their normal training program. Finally, the post-test measurement will be given after 48 hours of last training day to provide recovery time from their training load.
The test will be given in three consecutive days for each principal component of the performance metrics by following the test procedures described in the plan for both pre-test and post-test.

RISKS: Risks associated with participation in this study are minimal include potential discomfort or fatigue during the running sessions. Running on a motorized treadmill without holding the support and attaching the safety clip may result falling down hence injury for inexperienced athletes. But efforts will be made to minimize these risks, and you will be closely monitored throughout the study.

BENEFITS: There may be no direct benefits to you for participating in this study. However, athletes participating in this study will get a minimum benefit of training experience on a motorized treadmill which is common in developed world. Athletes may learn the alternative training modality and equipment for hill training to improve and develop their fitness and running performance. Further, the knowledge gained from this research may contribute to the understanding of hill training effects on running performance, which could benefit athletes, coaches, and fitness enthusiasts.

CONFIDENTIALITY

Dear parents, participant data will kept confidential except in cases where the researcher is legally obligate to report specific incidents include abuse and risk the benefit of athletes.

CONTACT INFORMATION

If you have questions at any time about this study, or adverse effects as a result of participating in this study, you may contact the researcher whose contact information is provided on the first page. If you have questions regarding rights of a research participant, or if problems arise, you can discuss with the primary investigator, please contact the Institutional Review Board at Bahir Dar University.

VOLUNTARY PARTICIPATION

Your son/daughter participation in this study is voluntary. It is up to you to decide whether or not to take part in this study. If you decide your son/daughter to take part in this study, you will be asked to sign a consent form. After you sign the consent form, you are still free to withdraw your son/daughter at any time and with or without a reason.

Withdrawing your son/daughter from this study will not affect the relationship you have, if any, with the researcher. If you withdraw your son/daughter from the study before data collection is completed, your son's/daughter's data will be returned to you or destroyed.

CONSENT

I have read and I understand the provided information and have had the opportunity to ask questions. I understand that my son/daughter's participation in the study is voluntary and that I am free to withdraw my son/daughter at any time, with or without a reason and without cost. I understand that I will be given a copy of this consent form. I voluntarily agree that my son/daughter to take part in this study.

Parent's/Legal guardian's signature ________________Date ______________________________

Investigator's signature _________________________Date ______________________________

Appendix - III

በመረጃ የተደገፈ የስምምነት ቅጽ - (የወላጅ/ሕጋዊ አሳዳጊ)

የጥናቱ ርዕስ፡- *የዳገት ላይ ስልጠና ዘዴዎች በመካከለኛ ርዝመት የሩጫ አትሌቶች ላይ በባዮሞተር ክህሎቶች፣ ፊዚዮሎጂካል፣ እና ባዮሜካኒካል መለኪያዎች ላይ የሚያሳዩትን ተፅእኖ*

ዋና ተመራማሪ

ስም፡ የኋላው አለሙ
ክፍል፡ ስፖርት ሳይንስ
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የጥናቱ ዓላማ፡- የዚህ ጥናት ዓላማ ከተራ ስልጠና ዘዴዎች በመካከለኛ ርዝመት የሩጫ አትሌቶች ላይ በባዮሞተር ክህሎቶች፣ ፊዚዮሎጂካል፣ እና ባዮሜካኒካል መለኪያዎች ላይ የሚሳዩትን ተፅእኖ መመርመር ነው። ስለዚህ ውሳኔ ከማድረግዎ በፊት ይህ ጥናት ለምን እንደሚካሄድ እና ምን እንደሚያካትት መረዳትዎ አስፈላጊ ነው። እባክዎ የሚከተለውን መረጃ በጥንቃቄ ያንብቡ እና ግልጽ ያልሆነ ነገር ካለ ወይም ተጨማሪ መረጃ ከፈለጉ ተመራማሪውን ይጠይቁ።

የጥናቱ ሂደት፡- የዳገት የስልጠና ዘዴዎች በኢትዮጵያ የመካከለኛ ርቀት ሯጮች በባዮ ሞተር ክህሎት፣ ፊዚዮሎጂ እና ባዮሜካኒካል መለኪያዎች ላይ ያለውን ተጽእኖ ለመወሰን ተሳታፊዎቹ በአራት ቡድን ይመደባሉ፡ የሙከራ ቡድን (የከፍተኛ ዳገታማ ኮረብታ ስልጠና፣ መካከለኛ ኮረብታ ስልጠና እና የተቀነሰ የኮረብታ ስልጠና ቡድኖች) እና የቁጥጥር ቡድን። ስልጠናው ከመሰጠቱ በፊት፣ በመረጃ የተደገፈ ፈቃድ ተከትሎ ስለ ምርምር ዓላማ፣ ግብ እና ሂደት ማብራሪያ እንደ የምርምር ግብረ መልስ ይሰጣል። ከዚያም የቅድመ-ሙከራው የባዮ-ሞተር ክህሎቶችን (ከፍተኛ ፍጥነት, የሩጫ ሰአት ፈተና እና ጥንካሬን መቋቋም), የፊዚዮሎጂ መለኪያዎችን (ከፍተኛ አየር አጠቃቀም፣ ዝቅተኛ ፍጥነት በከፍተኛ አየር አጠቃቀም ጊዜ፣ የረፍት ጊዜ የልብ ምት እና ጊዜ ከእንቅስቃሴ መልስ የማገገም የልብ ምት) እና ባዮሜካኒካል መለኪያዎችን (የእርምጃ ርዝመት, የእርምጃ ድግግሞሽ, የአየር ላይ ሰአት እና በመሬት ላይ የመቆየት ጊዜ) ለመለካት ይወሰዳል. ፈተናው ለእያንዳንዱ ዋና አካል በአራት የተለያዩ ቀናት ውስጥ ይሰጣል። ከምርምር ግብረመልስ በኋላ ስልጠናው (የሦስት ኮረብታ ስልጠና ልዩነቶች) ከመደበኛ የሥልጠና መርሃ ግብራቸው በተጨማሪ በሳምንት 2 ቀን ለ8 ሳምንታት በከፍተኛ ጥንካሬ ይሰጣሉ ። በመጨረሻም የድህረ-ፈተና ልኬት የሚሰጠው ከ48 ሰአታት የመጨረሻ የስልጠና ቀን በኋላ ከስልጠና ሸክማቸው የማገገሚያ ጊዜን ለመስጠት ነው።

ስጋቶች፡- በዚህ ጥናት ውስጥ ከመሳተፍ ጋር ተያይዘው የሚመጡ አደጋዎች በትንሹ ናቸው በሩጫ ክፍለ-ጊዜዎች ሊፈጠሩ የሚችሉ ምቾት ማጣት ወይም ድካም። ድጋፉን ሳይዙ በሞተር ትሬድሚል ላይ መሮጥ እና የሴፍቲ ክሊፕን በማያያዝ ልምድ

በሌላቸው አትሌቶች ላይ ጉዳት ሊያስከትል ይችላል። ነገር ግን እነዚህን አደጋዎች ለመቀነስ ጥረቶች ይደረጋሉ, እና በጥናቱ ጊዜ ውስጥ በቅርብ ክትትል ይደረግልዎታል.

ጥቅማ ጥቅሞች፡ በዚህ ጥናት ውስጥ ለመሳተፍ ምንም አይነት ቀጥተኛ ጥቅሞች ላይኖርዎት ይችላል። ይሁን እንጂ በዚህ ጥናት ውስጥ የሚሳተፉ አትሌቶች ባደጉት አገሮች የተለመደ በሆነው በሞተር ትሬድሚል ላይ ቢያንስ የስልጠና ልምድ ያገኛሉ። አትሌቶች የአካል ብቃት እና የሩጫ አፈፃፀማቸውን ለማሻሻል እና ለማዳበር አማራጭ የስልጠና ዘዴን እና የሂል ስልጠና መሳሪያዎችን ሊማሩ ይችላሉ። በተጨማሪም ከዚህ ጥናት የተገኘው እውቀት በሩጫ አፈጻጸም ላይ ያለውን የሂል ማሰልጠኛ ተፅእኖ ለመገንዘብ አስተዋፅዖ ያደርጋል፣ ይህም አትሌቶችን፣ አሰልጣኞችን እና የአካል ብቃት አድናቂዎችን ሊጠቅም ይችላል።

ሚስጥራዊነት:- ውድ ወላጆች፣ ተመራማሪው በህጋዊ መንገድ የተወሰኑ ክስተቶችን ሪፖርት የማድረግ ግዴታ ካለባቸው በስተቀር የተሳታፊዎች መረጃ በሚስጥር ይጠበቃል።

የግንኙነት መረጃ:- ስለዚህ ጥናት በማንኛውም ጊዜ ጥያቄዎች ካሉዎት ወይም በዚህ ጥናት ውስጥ በመሳተፍዎ ምክንያት አሉታዊ ተፅእኖዎች ካሉዎት በመጀመሪያ ገጽ ላይ የመገኛ መረጃው የቀረበውን ተመራማሪ ማነጋገር ይችላሉ። የጥናት ተሳታፊ መብቶችን በሚመለከት ጥያቄዎች ካሉዎት ወይም ችግሮች ካጋጠሙ ከዋናው መርማሪ ጋር መወያየት ይችላሉ፣ እባክዎ በባህር ዳር ዩኒቨርሲቲ የሚገኘውን የተቋማዊ ግምገማ ቦርድ ያነጋግሩ።

በፈቃደኝነት ላይ የተመሰረተ ተሳትፎ:- በዚህ ጥናት ውስጥ የእርስዎ ልጅ/ሴት ልጅ ተሳትፎ በፈቃደኝነት ነው። በዚህ ጥናት ውስጥ ለመሳተፍ ወይም ላለመሳተፍ መወሰን የእርስዎ ውሳኔ ነው። ልጅዎ/ሴት ልጅዎ በዚህ ጥናት እንዲሳተፍ ከወሰኑ፣ የስምምነት ፎርም እንዲፈርሙ ይጠየቃሉ። የስምምነት ቅጹን ከፈረሙ በኋላ፣ በማንኛውም ጊዜ እና ያለምክንያት ልጅዎን/ሴት ልጅዎን ለማውጣት ነፃ ነዎት።

ልጅዎን/ሴት ልጅዎን ከዚህ ጥናት ማውጣት ከተመራማሪው ጋር ያለዎትን ግንኙነት አይጎዳውም:: መረጃ መሰብሰብ ከመጠናቀቁ በፊት ልጅዎን / ሴት ልጅዎን ከጥናቱ ካነሱት, የልጅዎ / የልጅዎ መረጃ ወደ እርስዎ ይመለሳል ወይም ይጠፋል.

ስምምነት፡¨አንብቤ የቀረበውን መረጃ ተረድቻለሁ እና ጥያቄዎችን ለመጠየቅ እድሉን አግኝቻለሁ። የልጄ/የልጄ ተሳትፎ በጥናቱ በፈቃደኝነት እንደሆነ እና ልጄ/ሴት ልጄን በማንኛውም ጊዜ ያለምክንያትም ሆነ ያለ ምንም ወጪ ለማውጣት ነፃ መሆኔን ተረድቻለሁ። የዚህ የስምምነት ቅጽ ቅጂ እንደሚሰጠኝ ተረድቻለሁ። ልጄ/ሴት ልጄ በዚህ ጥናት እንዲሳተፉ በፈቃዴ እስማማለሁ።

የወላጅ/ህጋዊ ሞግዚት ፊርማ ____________________ ቀን ____________________________________

የተመራማሪው ፊርማ ______________________________ ቀን _____________________________________

Appendix – IV

Informed consent form – (minor's)

TITLE OF THE STUDY: ***Effects of Hill Training Modalities on Bio-motor skills, Physiological, and Biomechanical Metrics of Middle-Distance Runners in Ethiopia***

PRINCIPAL INVESTIGATOR

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PURPOSE OF STUDY: The purpose of this study is to determine the effects of hill training modalities on bio-motor skills, physiological, and biomechanical metrics of middle-distance runners in Ethiopia, so, dear participants, before you decide to participate in this study, it is important that you have to understand why the research is being done and what it will involve. Please read the following information carefully and ask the researcher if there is anything that is not clear or if you need more information.

STUDY PROCEDURES

To determine the effect of hill training modalities on bio-motor skills, physiological, and biomechanical metrics of middle-distance runners in Ethiopia, the participants will be assigned in to four groups: The experimental group (steeper hill training, intermediate hill training and reduced hill training groups) and the control group. Before treatment is given, an explanation of the intention, goal, and procedure of research followed by the informed consent will be provided as the research feedback. Then, the pre-test will be taken to measure bio-motor skills (Vmax, speed endurance, & strength endurance), physiological metrics (VO2max, vVO2max, RHR, & HRR) and biomechanical measures (stride length, stride frequency, FT & GCT). The test will be given in three different consecutive days for each principal component. After the research feedback the treatment (three hill training variations) will be given in moderate to high intensity, 2 times a week

for 12 weeks in addition to their normal training program. Finally the post-test measurement will be given after 48 hours of last training day to provide recovery time from their training load.
The test will be given in three consecutive days for each principal component of the performance metrics by following the test procedures described in the plan for both pre-test and post-test.

RISKS: Risks associated with participation in this study are minimal include potential discomfort or fatigue during the running sessions. Running on a motorized treadmill without holding the support and attaching the safety clip may result falling down hence injury for inexperienced athletes. But efforts will be made to minimize these risks, and you will be closely monitored throughout the study.

BENEFITS: There may be no direct benefits to you for participating in this study. However, athletes participating in this study will get a minimum benefit of training experience on a motorized treadmill which is common in developed world. Athletes may learn the alternative training modality and equipment for hill training to improve and develop their fitness and running performance. Further, the knowledge gained from this research may contribute to the understanding of hill training effects on running performance, which could benefit athletes, coaches, and fitness enthusiasts.

CONFIDENTIALITY

Dear study participants your data will kept confidential except in cases where the researcher is legally obligate to report specific incidents include abuse and risk the benefit of athletes.

CONTACT INFORMATION

If you have questions at any time about this study, or you experience adverse effects as a result of participating in this study, you may contact the researcher whose contact information is provided on the first page. If you have questions regarding your rights as a research participant, or if problems arise that you do not feel you can discuss with the primary investigator, please contact the Institutional Review Board at Bahir Dar University.

VOLUNTARY PARTICIPATION

Your participation in this study is voluntary. It is up to you to decide whether or not to take part in this study. If you decide to take part in this study, you will be asked to sign a consent form. After you sign the consent form, you are still free to withdraw at any time and without giving a reason. Withdrawing from this study will not affect the relationship you have, if any, with the researcher. If you withdraw from the study before data collection is completed, your data will be returned to you or destroyed.

CONSENT

I have read and I understand the provided information and have had the opportunity to ask questions. I understand that my participation is voluntary and that I am free to withdraw at any time, without giving a reason and without cost. I understand that I will be given a copy of this consent form. I voluntarily agree to take part in this study.

Participant's signature ________________Date _____________________________

Investigator's signature ________________Date _____________________________

Appendix - V

በመረጃ የተደገፈ የስምምነት ቅጽ - (ለታዳጊዎች)

የጥናቱ ርዕስ፡ - ***የዳገት ማሰልጠኛ ዘዴዎች በባዮ ሞተር ክህሎት፣ ፊዚዮሎጂ እና ባዮሜካኒካል መለኪያዎች በመካከለኛ ርቀት ሯጮች ላይ ያለው ተፅእኖ***

ዋና መርማሪ

ስም፡ ኢዩአላው አለሙ

ክፍል: ስፖርት ሳይንስ

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የጥናት ሂደቶች

የሂል ማሰልጠኛ ዘዴዎች በኢትዮጵያ የመካከለኛ ርቀት ሯጮች በባዮ ሞተር ክህሎት፣ ፊዚዮሎጂ እና ባዮሜካኒካል መለኪያዎች ላይ ያለውን ተጽእኖ ለመወሰን ተሳታፊዎቹ በአራት ቡድን ይመደባሉ፡ የሙከራ ቡድን (የዳገታማ ኮረብታ ስልጠና፣ መካከለኛ ኮረብታ ስልጠና እና የተቀነሰ የኮረብታ ስልጠና ቡድኖች) እና የቁጥጥር ቡድን። ሕክምና ከመሰጠቱ በፊት፣ በመረጃ የተደገፈ ፈቃድ ተከትሎ ስለ ምርምር ዓላማ፣ ግብ እና ሂደት ማብራሪያ እንደ የምርምር ግብረ መልስ ይሰጣል። ከዚያም የቅድመ-ሙከራው የባዮ-ሞተር ክህሎቶችን (Vmax, የፍጥነት ጽናትን እና ጥንካሬን መቋቋም), የፊዚዮሎጂ መለኪያዎችን (VO2max, vVO2max, RHR, እና HRR) እና ባዮሜካኒካል መለኪያዎችን (የእርምጃ ርዝመት, የእርምጃ ድግግሞሽ, FT እና GCT) ለመለካት ይወሰዳል. ፈተናው ለእያንዳንዱ ዋና አካል በሶስት ተከታታይ ቀናት ውስጥ ይሰጣል። ከምርምር ግብረመልስ በኋላ ሕክምናው (የሦስት ኮረብታ ስልጠና ልዩነቶች) ከመደበኛ የሥልጠና መርሃ ግብራቸው በተጨማሪ በሳምንት 2 ጊዜ ከመካከለኛ እስከ ከፍተኛ ጥንካሬ ይሰጣሉ ። በመጨረሻም የድህረ-ፈተና ልኬት የሚሰጠው ከ48 ሰአታት የመጨረሻ የስልጠና ቀን በኋላ ከስልጠና ሸክማቸው የማገገሚያ ጊዜን ለመስጠት ነው።

ፈተናው በቅድመ-ፈተና እና በድህረ-ፈተና በእቅዱ ላይ የተገለጹትን የፈተና ሂደቶችን በመከተል ለእያንዳንዱ የስራ አፈጻጸም መለኪያ ዋና አካል በሶስት ተከታታይ ቀናት ውስጥ ይሰጣል።

ስጋቶች፡- በዚህ ጥናት ውስጥ ከመሳተፍ ጋር ተያይዘው የሚመጡ አደጋዎች በትንሹ ናቸው በሩጫ ክፍለ-ጊዜዎች ሊፈጠሩ የሚችሉ ምቾት ማጣት ወይም ድካም። ድጋፉን ሳይዙ በሞተር ትሬድሚል ላይ መሮጥ እና የሴፍቲ ክሊፕን በማያያዝ ልምድ በሌላቸው አትሌቶች ላይ ጉዳት ሊያስከትል ይችላል። ነገር ግን እነዚህን አደጋዎች ለመቀነስ ጥረቶች ይደረጋሉ, እና በጥናቱ ጊዜ ውስጥ በቅርብ ክትትል ይደረግልዎታል.

ጥቅማ ጥቅሞች፡ በዚህ ጥናት ውስጥ ለመሳተፍ ምንም አይነት ቀጥተኛ ጥቅሞች ላይኖርዎት ይችላል። ይሁን እንጂ በዚህ ጥናት ውስጥ የሚሳተፉ አትሌቶች ባደጉት አገሮች የተለመደ በሆነው በሞተር ትሬድሚል ላይ ቢያንስ የስልጠና ልምድ ያገኛሉ። አትሌቶች የአካል ብቃት እና የሩጫ አፈፃፀማቸውን ለማሻሻል እና ለማዳበር አማራጭ የስልጠና ዘዴን እና የሂል ስልጠና መሳሪያዎችን ሊማሩ ይችላሉ። በተጨማሪም ከዚህ ጥናት የተገኘው እውቀት በሩጫ አፈጻጸም ላይ ያለውን የሂል ማሰልጠኛ ተፅእኖ ለመገንዘብ አስተዋፅዖ ያደርጋል ይህም አትሌቶችን፣ አሰልጣኞችን እና የአካል ብቃት አድናቂዎችን ሊጠቅም ይችላል።

ሚስጥራዊነት

ውድ የጥናት ተሣታፊዎች ተመራማሪው በህጋዊ መንገድ የተወሰኑ ክስተቶችን ሪፖርት የማድረግ ግዴታ ካለባቸው ጉዳዮች በስተቀር መረጃዎ በሚስጥር ይጠበቃል።

የእውቂያ መረጃ

ስለዚህ ጥናት በማንኛውም ጊዜ ጥያቄዎች ካሉዎት ወይም በዚህ ጥናት ውስጥ በመሳተፍዎ ምክንያት አሉታዊ ተጽእኖዎች ካጋጠሙዎት, የመገኛ መረጃው በመጀመሪያው ገጽ ላይ የቀረበውን ተመራማሪ ማነጋገር ይችላሉ. እንደ ጥናትና ምርምር ተሳታፊ የሙብት ጥያቄ ካሎት ወይም ከዋናው መርማሪ ጋር መወያየት ይችላሉ ብለው የማታስቡ ችግሮች ካጋጠሙ የባህር ዳር ዩኒቨርሲቲ የተቋማዊ ግምገማ ቦርድን ያነጋግሩ።

በፈቃደኝነት ላይ የተመሰረተ ተሳትፎ

በዚህ ጥናት ውስጥ ያለዎት ተሳትፎ በፈቃደኝነት ነው። በዚህ ጥናት ውስጥ ለመሳተፍ ወይም ላለመሳተፍ መወሰን የእርስዎ ውሳኔ ነው። በዚህ ጥናት ለመሳተፍ ከወሰኑ፣ የስምምነት ፎርም እንዲፈርሙ ይጠየቃሉ። የስምምነት ቅጹን ከፈረሙ በኋላ በማንኛውም ጊዜ እና ምክንያት ሳይገልጹ አሁንም ነጻ ነዎት።

ከዚህ ጥናት መውጣት ከተመራማሪው ጋር ያለዎትን ግንኙነት አይጎዳውም:: መረጃ መሰብሰብ ከመጠናቀቁ በፊት ከጥናቱ ከወጡ፣ የእርስዎ ውሂብ ወደ እርስዎ ይመለሳል ወይም ይጠፋል።

ስምምነት

አንብቤ የቀረበውን መረጃ ተረድቻለሁ እና ጥያቄዎችን ለመጠየቅ እድሉን አግኝቻለሁ። የእኔ ተሳትፎ በፈቃደኝነት እንደሆነ ተረድቻለሁ እናም በማንኛውም ጊዜ ምክንያት ሳልገልጽ እና ያለምንም ወጪ ለመልቀቅ ነፃ መሆኔን ተረድቻለሁ። የዚህ የስምምነት ቅጽ ቅጂ እንደሚሰጠኝ ተረድቻለሁ። በዚህ ጥናት ለመሳተፍ በፈቃዴ ተስማምቻለሁ።

የተሳታፊ ፊርማ ____________________ ቀን ____________________________________

የመርማሪው ፊርማ ____________________ ቀን ____________________________________

Appendix-VI

Weekly Food Frequency Questionnaire (WFFQ)

Instructions:

For each day of the past 7 days, record the types of foods consumed during breakfast, lunch, and dinner. Check the food groups consumed during each meal. This is intended to assess consistency in dietary intake across groups and throughout the training.

Day	Meal time	Injera/grains: - Bread - Pasta/ - Macaroni - Rice - Nifro - Kolo	Legume: - Shiro - Misir kik - Ater kik - Bean kik	Meat -egg	Vegetables: - Cabbage - Carrots - Potatoes - Tomatoes	Fruit: - Banana - Mango - Avocado - Orange	Dairy: - milk - yogurt - cheese	Beverage (Drinks): - tea, - milk - soft drinks
Monday	Breakfast							
	Lunch							
	Dinner							
Tuesday	Breakfast							
	Lunch							
	Dinner							
Wednesday	Breakfast							
	Lunch							
	Dinner							
Thursday	Breakfast							
	Lunch							
	Dinner							
Friday	Breakfast							
	Lunch							
	Dinner							
Saturday	Breakfast							
	Lunch							
	Dinner							
Sunday	Breakfast							
	Lunch							
	Dinner							

Appendix - VII

ሳምንታዊ የምግብ ድግግሞሽ መጠይቅ_(WFFQ)

መመሪያዎች፡-

ላለፉት 7 ቀናት ለእያንዳንዱ ቀን በቁርስ፣ በምሳ እና በእራት ወቅት የሚበሉትን ምግቦች ይመዝግቡ። በእያንዳንዱ ምግብ ወቅት የሚበሉትን የምግብ ቡድኖች ይፈትሹ. ይህ በቡድን እና በስልጠናው ጊዜ ሁሉ የአመጋገብ ስርዓትን ወጥነት ለመገምገም የታሰበ ነው።

ቀን	የመመገቢያ ጊዜ	እንጀራ/ ጥራጥሬዎች፡ - ዳቦ - ፓስታ/ ማካሮኒ - ሩዝ - ንፍሮ - ቆሎ	ጥራጥሬዎች: - ሽሮ - ምስር ክክ - አተር ክክ - ባቄላ ክክ	- ስጋ - እንቁላል	አትክልቶች; - ጎመን - ካሮት - ድንች - ቲማቲም	ፍራፍሬ፡ - ሙዝ - ማንጎ - አቮካዶ - ብርቱካን	የወተት ምርት - ወተት - እርጎ - አይብ	መጠጥ - ሻይ, - ወተት - ለስላሳ መጠጦች
ሰኞ	ቁርስ							
	ምሳ							
	እራት							
ማክሰኞ	ቁርስ							
	ምሳ							
	እራት							
እሮብ	ቁርስ							
	ምሳ							
	እራት							
ሐሙስ	ቁርስ							
	ምሳ							
	እራት							
አርብ	ቁርስ							
	ምሳ							
	እራት							
ቅዳሜ	ቁርስ							
	ምሳ							
	እራት							
እሁድ	ቁርስ							
	ምሳ							
	እራት							